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RÉPUBLIQUE FRANÇAISE

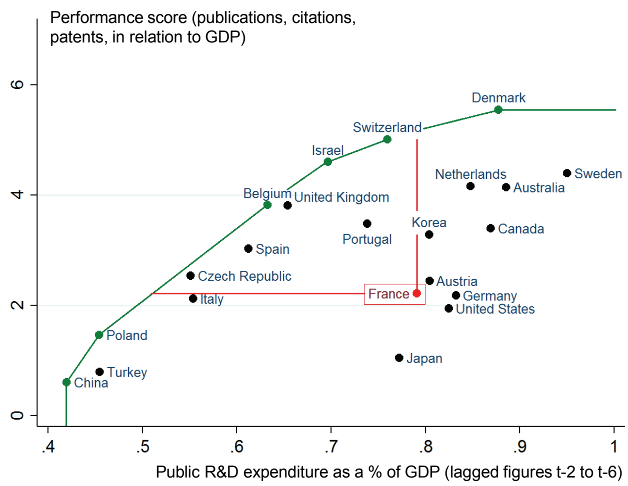
Trésor-economics

No. 219 • April 2018

The efficiency of the French public research system

- In 2015, France was in fifth place amongst major OECD countries for public R&D spending. Including defence-related R&D, this spending accounted for 0.86% of GDP, putting France above the OECD average but leaving it trailing the leading pack (Nordic countries, South Korea and Germany) and below the Lisbon Strategy target of 1% of GDP.
- Specific features characterise the organisational structure and governance of the French research system. The system has been set up around research centres, such as the National Centre for Scientific Research (CNRS), whereas higher education occupies centre stage in other countries. Today, laboratories are often jointly managed- with many having a number of supervisory entities. In addition, resources mainly comprise recurrent (rather than contractual) budgetary appropriations and the amount of project-based funding appears to be the lowest among benchmark countries.
- French scientific output extends to all fields and is resolutely international. Outcome indicators (which have limitations) point to the French scientific production being comparable with the average of other advanced countries. France is in seventh place in terms of publication volumes, the quality of which (gauged by the number of citations) is also within the average. The field profile of these publications is evolving at the same pace as the global average. Lastly, increasing numbers of patent applications are being made on the back of French public research.
- France is below the "efficiency frontier" of public R&D spending, which can be estimated by setting expenditure levels against outcome indicators from a set of benchmark countries. In this respect, it does not differ significantly from the average of second-tier nations which include Germany and Japan. The situation has been improving since 2004, thus demonstrating positive momentum.

Public R&D expenditure efficiency



How to read this chart: The vertical distance between each point and the green frontier shows the increase in performance that could be theoretically achieved with the same spending levels ("output inefficiency"); the horizontal distance shows the spending savings that could be theoretically made with the same performance levels ("input inefficiency").

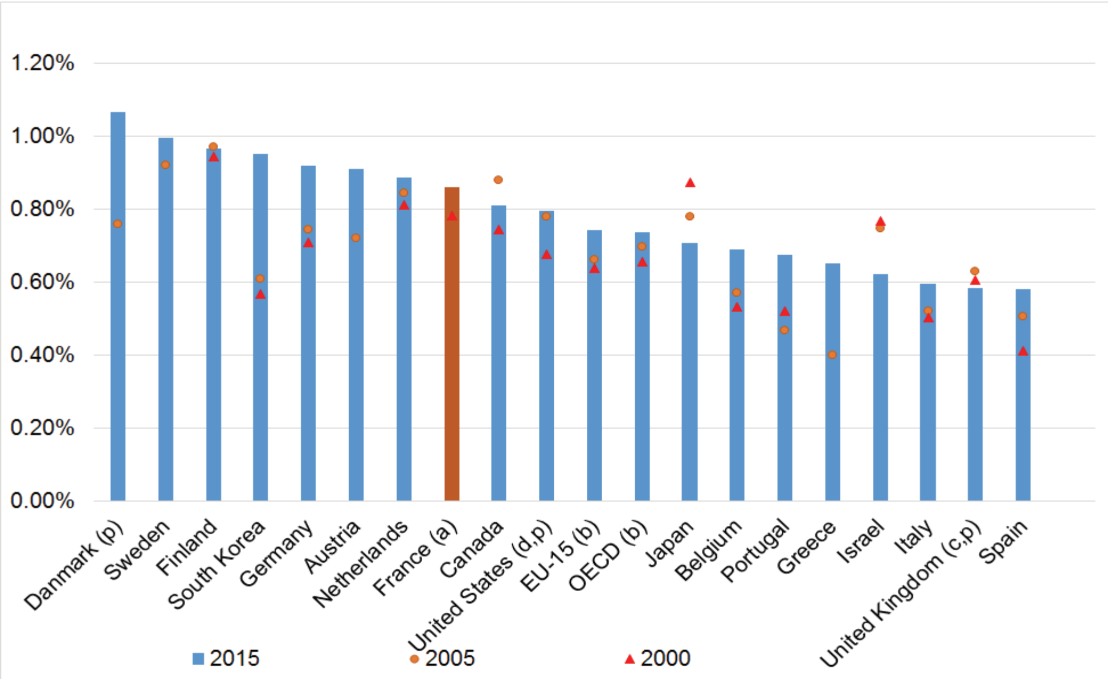
MINISTÈRE DE L'ÉCONOMIE
ET DES FINANCES

1. Amongst advanced countries, French public R&D expenditure is in the high average[1]

1.1 France is in fifth place worldwide for public R&D spending

In 2015, French public domestic expenditure on R&D (PERD) totalled €18.9bn[2], putting France in fifth place worldwide amongst the main OECD countries for public R&D spending, behind the US, China, South Korea and Germany. This expenditure accounted for 0.86% of GDP (see box 1) which was higher than the average for OECD countries (0.74%), but still lower than the leading pack (Nordic countries, South Korea and Germany) and below the Lisbon Strategy target of 1% (see chart 1).[3]

Chart 1: Public expenditure on R&D in relation to GDP



Source: OECD, Information Systems and Statistical Studies Department (SIES), INSEE, DG Trésor chart.
(a) Breaks in the series with the previous year. (b) OECD estimate or forecast based on domestic sources.
(c) Domestic estimate or forecast. (d) All or part of capital expenditure excluded. (p) Provisional.

Since 2000, public R&D spending has experienced low apparent growth of around 1.5% per annum in real terms. This is in stark contrast to the momentum in many OECD countries where it has risen sharply. Examples include Germany (+2.9%) and the US (+2.8%). Nevertheless, if the level of expenditure is re-calculated to factor in methodological breaks (see box 1), then public R&D spending in relation to GDP is seen to be increasing at a pace comparable to the average of other advanced countries.

1.2 French public research is characterised by large numbers of support staff and low wages for researchers

In 2015, the French public research system employed 111,787 researchers (in full-time equivalents), which puts France in fourth place in the OECD. With 3.8 researchers per 1,000 employed persons in 2014, France was slightly below the EU-15 average and on level pegging with Germany. However, France stands out due to the large number of support staff, namely 0.60 per researcher, a figure which is

(1) This paper has been reviewed by the Science and Technology Monitoring Unit of the High Council for Evaluation of Research and Higher Education (HCERES), and by the Information Systems and Statistical Studies Department (SIES) of the Ministry for Higher Education, Research and Innovation. More detailed figures are available in the SIES' authoritative publication, *l'état de l'enseignement supérieur et de la recherche en France*. The authors remain responsible for the messages and any possible errors.

(2) The public intramural expenditure on R&D is the amount earmarked for R&D performed by the Higher Education sector, the Government sector, and the private Non-profit sector. It is obtained by subtracting Business Enterprise Expenditure on R&D (BERD) to the Gross Domestic Expenditure on R&D (GERD). The figures published by the Ministry for Higher Education (semi-definitive results for 2015, taken from the R&D survey carried out by the *SIES*) no longer factor in defence R&D spending: expenditure was therefore €18.1bn in 2015 (see box 1).

(3) Now replaced by the Europe 2020 Strategy. The other objective of the Lisbon Strategy is a split for total public R&D spending of 1/3 performed by the public sector and 2/3 by the private sector. Owing to readjustments carried out over the last decade, France is close to achieving this objective.

higher only in Japan, Italy and South Korea, whereas it is 0.48 in Germany.

The other key feature is the relatively low wages of French tenured researchers compared to other countries. This is borne out by a number of comparative studies[4], although the extent of the gap varies according to the methodology used. For instance, the European Knowledge Transfer Indicators Survey (EKTIS), commissioned by the European Commission, shows that, in 2011, a grade three lecturer (maître de conferences) received a gross annual starting salary of €21,711 (in purchasing power parity, PPP). This figure represented 63% of the average starting salary for researchers in Europe and OECD countries. The maximum salary for a researcher in France was equal to 91% of the maximum average annual European salary and 84% of that for OECD countries.

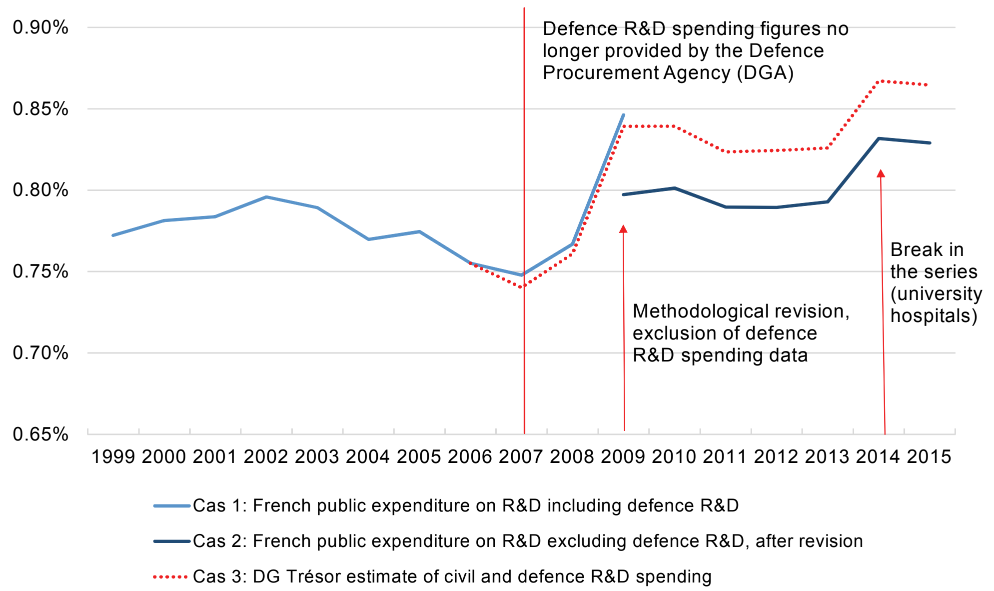
Box 1 : Methodological breaks in R&D spending series; a re-estimate including defence R&D spending

In 2010, defence R&D spending was excluded and this caused a drop of around €0.9bn in research expenditure. To rectify this break and allow for international comparisons, domestic defence R&D spending may be re-calculated and added to the civil domestic expenditure on R&D (PERD), by taking (i) the defence R&D effort (ERDF, available from 2002 to 2015 in the statistical defence directory) and (ii) the domestic R&D spending of the Ministry of Defence, available from 2000 to 2006. Based on these estimates (see chart 2), the extent of public R&D was under-estimated in 2013 and should have been 0.82% of GDP instead of 0.79%.

There were other breaks in the series in 2014 and 2015. A review of expenditure allocated to schools outside the direct supervision of the Ministry for Research, and a research staff review within university hospitals, increased spending by around €1bn (0.056% of GDP). The available data is such that these corrections cannot be applied to expenditure prior to 2014.

If the defence R&D spending adjustment were applied to 2015 figures, the PERD would represent 0.86% of GDP. This would not alter France's position for international comparison purposes as it would still be positioned between Canada (0.81%) and the Netherlands (0.89%).

Chart 2: Effect of changes in the 2010 scope on the development of the GOVERD (% of GDP)



Source: DG Trésor chart, fiscal data and R&D survey by the Ministry for Higher Education

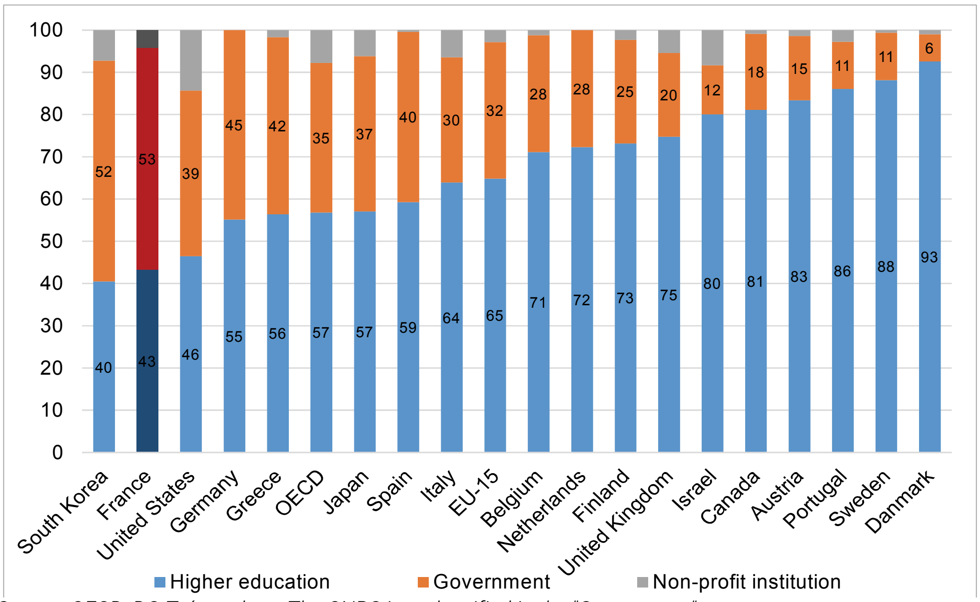
(4) Available comparisons include Altbach *et al.*, 2012, data compiled by the Academic Career Observatory, and OECD benchmarks (Education at a Glance 2016, pp.440-442, concerning higher education).
Altbach P.G., Reisberg L., Yudkevich M., Androushchak G. and Pacheco I.F. (2012), "Paying the professoriate. A global comparison of compensation and contracts", *Routledge Press*, New York,

2. Research centres are central to the French system which is essentially funded by recurrent budgetary appropriations

2.1 The overriding role of research centres

The French public research system is largely based on public research organisations (OPRs) and this dates back to the choices made in the post-war period, with the introduction of major technological programmes managed by dedicated institutions. However, today and in practice, laboratories are mostly managed jointly. They are comprised of researchers who report contractually to research organisations and others who report to universities. This organisational structure is a specific feature of the French system. A comparison of the breakdown of research expenditure by implementing sector[5], including expenditure by the OPRs in the "Government" sector, shows that this accounts for 53% of the total in France. This is the highest share in comparable countries (see chart 3).

Chart 3: Public domestic expenditure on R&D by sector of performance (2015, %)



Source: OECD, DG Trésor chart. The CNRS is reclassified in the "Government" sector.

Besides the monitoring targets considered by the boards of directors and the annual fiscal plans, management of OPRs is based on their multiannual Service Level and Performance Contract (COP, "contrat d'objectifs et de performance") which they take into account when allocating resources in-house according to their priorities and those of their research teams. These contracts are fairly general in nature and OPRs have substantial room for manoeuvre in deploying their human and financial resources as the orientation, funding and implementation of research, and researcher assessment, come under the same authority.[6]

In contrast, universities account for 55% of German public R&D spending (they report to the Land in which they are based), together with four multi-disciplinary research organisations.[7] The central role of universities is even more marked in the UK where there are 166 higher education institutions (universities, university colleges, special higher education establishments and others), 24 of which belong to the Russell Group. The latter alone receive 70% of higher education and research funding, under rationale that is similar to the excellence-based approaches in the French

(5) In the data provided by the Ministry for Higher Education and Research, the R&D implemented by the CNRS is classified in the "Government" sector (as for other research institutes). This also applies to OECD data for other countries such as Italy. In the data provided by France to the OECD, the CNRS is nevertheless included in the higher education sector to reflect the joint management of laboratories. Here, OECD data is restated to reintegrate this expenditure into the "Government" sector. This sector also includes the R&D spending of ministerial departments which was around 1.2% of the total in 2015. Without this restatement, the share of higher education is 61%.

(6) See, in particular, IGAENR report no. 2012-072 "Étude des mécanismes d'allocation des moyens humains et financiers aux unités de recherche par les organismes de recherché". However, the establishments must be assessed by external bodies: either by the HCERES, or by an external committee using a procedure that must have been approved by the HCERES. In 2016-17, this procedure had not yet been rolled out for the CNRS.

(7) This concerns (1) Max Planck (MPG) which focuses on basic research, (2) Fraunhofer (FhG) which concentrates on applied research and technology transfer, (3) The Helmholtz research centre community which houses the main research infrastructure, and (4) The Leibniz community (WGL) which works on applied research in regional Germany.

Invest for the Future Programme or the Exzellenzinitiativ in Germany.

The specific nature of the French organisational structure also helps explain why the proportion of public research spending earmarked for basic research is one of the highest in the world. In France, 58% of expenditure was devoted to basic research in 2014[8], 28% to applied research and 4% to experimental development. Only Israel, Poland and the Czech Republic spend as much on basic research. The UK, Ireland, the Netherlands, Denmark and Spain allocated more than 40% of their resources to applied research. The US and South Korea earmarked more than 25% of spending for R&D work connected with experimental development.

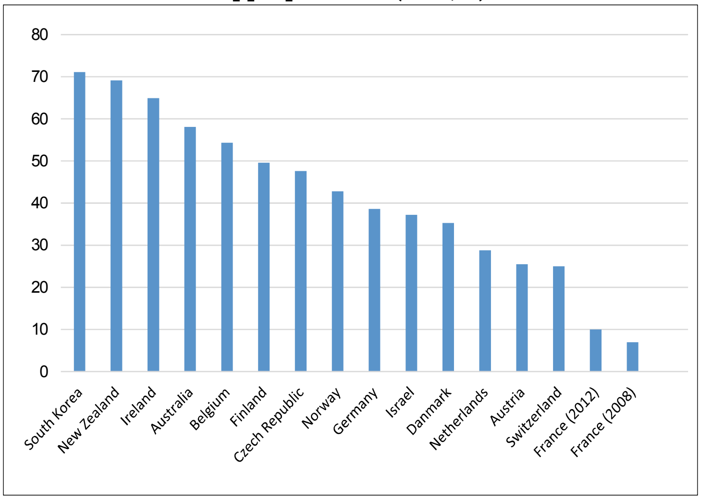
2.2 Funding is mainly from recurrent budgetary appropriations

The majority of resources for public research in France come from recurrent budgetary appropriations (65.4% in 2015). Contractual financing accounts for 22.4% (60% from the public sector and the remainder from businesses and foreign institutions, including the EU), and own resources for 12.2%.

For higher education institutions, between 2009 and 2014, around 3% of budgetary appropriations were conditional upon performance indicators by using an allocation model called "SYMPA" (*SYstème de répartition des Moyens à la Performance et à l'Activité*), but the narrow scope limited its incentive effect. The model was phased out in 2014/2015 and resources are now allocated according to their past value. One exception is engineering schools which have introduced a new performance-based allocation model called "MODAL".

The proportion of project-based funding (obtained by replying to competitive calls for projects[9]) in total resources is hard to assess and compare between countries. According to the French Technological Research Association (ANRT), it stood at around 10% of resources in France in 2012 (compared to approximately 7% in 2008 – see Chart 4). The increase is attributable to the setting up of the French Research Agency (ANR) in 2005 and the launch of the Invest for the Future Programme. Nevertheless, total project-related funding remains low and France is in last place among comparable countries (OECD, 2014[10]). The relative novelty of this form of funding probably partly explains the poor rate of responses to calls for projects for EU research programmes. In France this rate is lower than its potential and is constantly falling.[11]

Chart 4: Proportion of project-related funding in public R&D appropriations (2011, %)



Source: OECD (2014), ANRT for France. Data not available for the other countries. The figures are probably under-estimated for France as the salaries of researchers involved in the funded projects are assumed by the organisations.

Financing on calls for projects is much more widespread in Germany where it is managed by separate agencies.[12] It accounts for around 40% of funding allocated by the Federal Government to support R&D.

(8) Figure prior to the revised data including university hospitals (see box 1), which drags down the share of basic research. 10% of spending is not classified using this typology and information is not available for all OECD countries.
(9) In the figures provided above, project-based funding accounts for part of contractual financing which covers other methods.
(10) OECD Reviews of Innovation Policy: France, OECD (2014).
(11) In mid-2016, France had only received 10.6% of subsidies by calls for projects for the ongoing programme (H2020), compared to 16% for Germany. Given that the national contribution represents 15.9% of the EU budget for the same period, the response rate for H2020 was only 0.67 (for €1 contributed to the EU budget, only €0.67 reverted to France through this channel) - compared to 1.25 for the UK.
(12) DFG, Projektträger, and foundations such as Alexander von Humboldt.

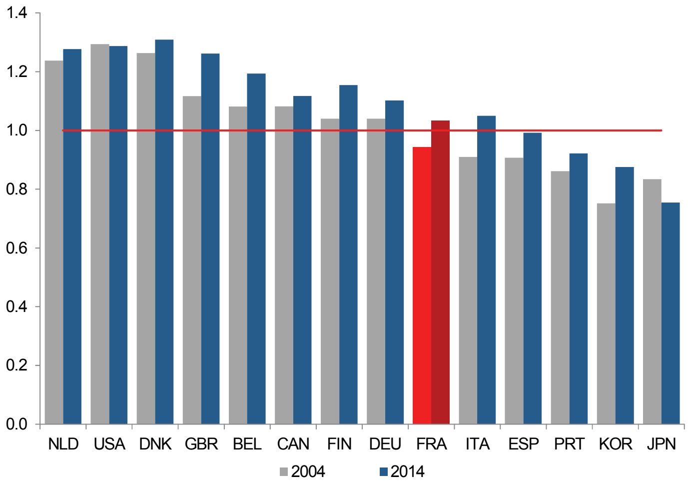
3. French scientific output is within the average of advanced countries

3.1 France is in seventh place worldwide in terms of the number of scientific publications

With 3.3% of global scientific publications, France was in seventh place in 2015, trailing the US (21%) and China (15.3%). In Europe, it is in third place. France and other developed countries have seen their share decline since the turn of the century with the emergence of new stakeholders onto the international scientific stage, China in particular. In relation to the workforce or GDP, the level of this output puts France within the low average of developed countries (1.8 annual publications per 1,000 employed persons in 2014), and it is lagging behind northern European countries which dominate the ranking with 3 to 3.5 publications per 1,000 employed persons.

The quality of publications can be estimated by the number of citations (with a number of major limitations: see box 2). France has a 3.8% share of global citations compared to 29% for the US. An impact index can be established to carry out an international comparison of the number of citations using the ratio of a country's share of total global citations to its share in the volume of global publications for the same type of document, the same year and in the same field. If the standard of French research is assessed in this manner, France is within the average of advanced countries and this standard has been improving over the past decade (see chart 5).

Chart 5: Scientific publication impact index



Source: OST chart, Clarivate Analytics - WoS data, OST-Hcéres processing. Fractional count: a publication co-authored by C contributor countries is counted 1/C for each country.

How to read this chart: An index of more than 1 shows that the country's publications have greater visibility than the average of global publications. The three-year impact index is defined by the proportion of the total number of worldwide citations received over a three-year period by Country C's publications in relation to this country's share of total publications. 2014 data calculated over two years.

Box 2 : Outcome indicators: contributions and limitations

There are three main indicators for quantifying scientific and technological output: publications, citations of these publications and patents.[a] However, the intangible, uncertain and highly specific nature of knowledge-based assets calls for them to be used conservatively when assessing and comparing the performance levels of public research systems.

Criticism is sometimes levelled at the volume of publications as it is thought that it biases international comparisons as the propensity for publishing and citing varies significantly depending on the field, and field specialisations differ according to the country.[b] Furthermore, databases may less systematically record publications that are not in English[c] or that are not in article form (such as books or conference proceedings), which are more commonplace in certain fields. Lastly, the majority, but not all scientific publications, originate from public research.

The number of citations provides a delayed gauge of quality (the most recent publications are the least cited), and a high number of citations is not always a sign of quality (some may be attributable to the authors themselves, and an article may be frequently cited after its results have been disproven).

Lastly, as regards patents, some discoveries with economic interest are not patented and, conversely, certain patents have little economic value.

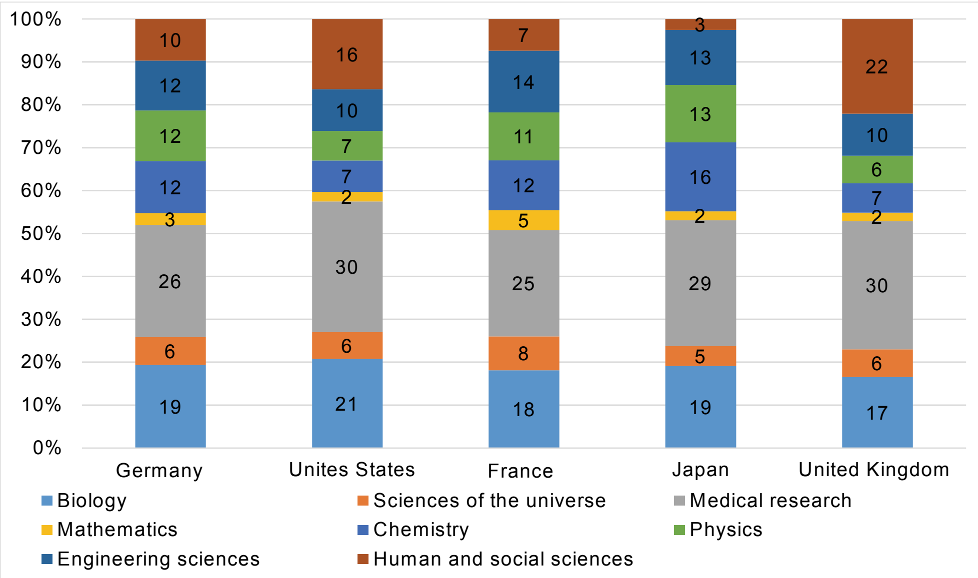
a. The country-based publication counting used here is a "fractional account: a publication labelled with a C for contributor country is counted 1/C for each country (according to the institution to which the researcher reports).
b. In addition to the danger of encouraging sub-standard output if it is used as an individual assessment criterion: see, in particular, Smaldino, P. & McElreath R. (2016), The natural selection of bad science, R. Soc. open sci. 3: 160384. http://dx.doi.org/10.1098/rsos.160384
c. The major databases listing citations have an explicit preference for English: for instance, World of Science (WoS) only references reviews that have at least abstracts in English.

The extent of the internationalisation of publications can also be compared. Among comparable countries, France is in fifth place in terms of the number of articles co-authored with foreign researchers. The internationalisation of French research is lagging behind northern European countries (Denmark, Belgium, Sweden) but is comparable with that of the UK and Germany. In 2015, 54.1% of publications involved at least one foreign laboratory. Country size has a significant effect on this figure. In principle, co-publication with affiliated researchers abroad is less likely for countries with large-scale research systems.

Lastly, countries can be compared on the basis of the field of their scientific output. In this respect, while medical research represents a significant proportion of publications in all countries, the share of human and social sciences ranges from 3% in Japan to 22% in the UK.

In relation to the global breakdown of disciplines, mathematics appears as the main field in which France specialises.[13] Owing to the above-mentioned specificities, this skews comparisons of performance and efficiency using publication volumes to the detriment of French research as the propensity to publish mathematics-related papers is lower in all the countries.

Chart 6: Breakdown of publication fields by country (2014)



Source: Clarivate Analytics - WoS data, OST-Hcéres processing, DG Trésor chart. Fractional count.
How to read this chart: 11% of publications attributed to France belong to the physical sciences field compared to 7% of those for the US.

The momentum of research can also be assessed in light of changes in terms of field specialisation. A total lack of changes over a sufficiently long period could point to relative inertia.[14] However, a number of indicators suggest that the French scientific profile evolved broadly at the same pace as the global average during the 2000s.

3.2 French public research's share of patent filings is on the rise

The proportion of patents originating from public research in the total number of patents (measured by filings with the French Patent Office, INPI) jumped from 7.2% to 12.1% between 1999 and 2011. The main three filing OPRs are the Atomic Energy Commission (CEA), the CNRS and the French Oil and New Energies Institute (IFPEN) which

(13) This point may be confirmed by calculating a relative specialisation index which compares the discipline-related share of country i in field j (number of publications in this field in relation to the total for a country) with the share of global publications in the same field. For mathematics, this index is 1.57 for France compared to 0.75 for the US. Physical and engineering sciences (including IT), for which the index is 1.2, are also relative specialisation fields.
(14) Marked changes in terms of specialisation are not uniformly desirable but a total lack of changes is a negative sign.

respectively filed 40%, 27% and 14% of applications deriving from public research in 2014.

An analysis of patents filed under the Patent Cooperation Treaty (PCT), which provides protection in 148 countries on the basis of stricter criteria than the INPI and at a higher cost, reveals that 1,042 patents were filed by French research bodies in 2013, which represented 21% of the number filed by the US, the leading filer. Among comparable countries, the proportion of public research out of total French patent applications under the PCT (16% in 2011, up from 11% in 2002) is one of the highest. OPRs make a particularly significant contribution to total patents in certain sectors, inter alia semi-conductors (39% of published patent applications in 2013), analysis of biological materials (45%), biotechnologies (46%) and nanotechnologies (59%).

Assessing the value of filed patents is not a straightforward task. Use of the derived income (assignments or licences) may be ambiguous: many outcomes are not intended to generate income or may be valued in other forms (such as shareholdings). Between 2007 and 2014, the share of intellectual property royalties in the resources of OPRs fell. This may point to a relative decline in the rate of return of these patents or be connected with certain leading patents entering the public domain (such as Taxotère, a patent which led to a drug used for intensive chemotherapy and which was one of the mainstays of CNRS royalties).

4. Whilst French public R&D spending is not one of the most efficient, it does not differ substantially from second tier nations

To compare the efficiency of public research systems, outcome indicators need to be set against the resources used. International comparisons have been conducted using a *23-country* sample[15] for which data on both outcomes and resources is available (domestic research spending amounts). The amount used is the public domestic expenditure on R&D (PERD) as compiled by the OECD, expressed in constant dollars and purchasing power parity.[16] The outcome indicators reviewed are restricted to those which are best measured with the limitations explained in box 2. For 2013, this was the total number of scientific publications[17], the number of publications belonging to the 10% most cited, which measures strong impact output, and the total number of patents filed by public research bodies.[18]

There is a strong link between resources deployed and scientific publications, patent applications and the most-cited publications. Countries with the highest public R&D spending are also those with the highest "output" levels. The elasticity of outcomes to resources (calculated by linear adjustment without a constant) is 1.2, 0.6 and 1 for the volume of publications, patents filed by French researchers and the most-cited publications respectively.

(15) All the data and programmes used are available on the GitHub platform. 2013 data available for Australia, Austria, Belgium, Canada, China, Czech Republic, Denmark, France, Germany, Israel, Italy, Japan, South Korea, the Netherlands, Poland, Portugal, Russia, Spain, Sweden, Turkey, the UK and the US.

(16) OECD's Main Science and Technology Indicators database. Research spending has a delayed impact on outcomes. The average extent of this delay was estimated by Crespi & Geuna (2008). As a result, we are using a weighted smoothing of spending from years t-2 to t-6 (methodology used by Auranen & Nieminen, 2010, among others).
Auranen O. & Nieminen M. (2010), "University research funding and publication performance. An international comparison", *Research Policy* 39 (2010) 822-834.
Crespi G. & Geuna A. (2008) "An empirical study of scientific production: A cross-country analysis, 1981-2002", Research Policy 37 (2008) 565-579.

(17) Data from the Science and Technology Observatory (HCERES) which is an enhanced version of Clarivate Analytics' Web of Science database.

(18) Data from version 2 of the World Intellectual Property Organization's database.

Comparing spending efficiency between countries involves estimating the technological frontier, based on the sample studied, to work out each entity's distance from this frontier. The theoretical performance levels are calculated based on the circumstances of the highest-performing countries. To this end, two methods are used: DEA (Data Envelopment Analysis; Charnes *et al.*, 1978) and SFA (Stochastic Frontier Analysis; Aigner *et al.*, 1977).[19] The first[20] is preferred below (see box 3), as stochastic analysis is used as a stress test (see below).

Whether on the basis of absolute values or amounts that are standardised by GDP, France is below the efficiency frontier.

Chart 7 illustrates the first approach. A group of countries, including the US, China, South Korea, Israel, Belgium and the UK, are shown as being efficient or very close to the frontier.[21] Other countries seem to be much less efficient and their spending levels could, in light of other countries' performance levels, be materialised by much higher output (Turkey, Portugal, Japan and Russia – which suffers from the lack of public research patents). France is at a certain distance from the frontier and is in an intermediate position among countries with similar spending levels. The performance level of French public research lags slightly behind that of South Korea, although France spent 60% more during this period.

Box 3 : Principles of an analysis by efficiency frontier (Data Envelopment Analysis)

The idea behind DEA is to calculate the technological frontier for a sample of countries using a linear programming procedure. There are a number of potential assumptions concerning the frontier's form, which is dictated by assumptions as to its convexity and the type of returns to scale (increasing, decreasing, constant or variable). However, assumptions on distribution and relations between parameters are not required. Countries positioned on this frontier, which have the highest level of output for a given level of inputs, will be considered efficient. As for the others, the distance from the frontier represents a measurement of inefficiency which may take two forms: input inefficiency, i.e. the proportion of inputs that it is theoretically possible to save by keeping the same output level (horizontal distance), or output inefficiency, i.e. the potential increase in output with unchanged inputs (vertical distance - see chart on the cover).

DEA merely provides a measurement of efficiency and not explanations. Owing to its nature, the analysis depends on the country sample: excluding efficient countries would alter the form of the frontier and the score of all the other countries. A conservative approach should therefore be adopted when looking at the efficiency scores themselves, but their relative values provide indications of the ranking of countries' efficiency, and the extent of the gaps (with the above-mentioned limitations concerning the output indicators).

(19) Aigner D., Knox Lovell C. & Schmidt P. (1977), "Formulation and estimation of stochastic frontier production function models", *Journal of Econometrics*, 6(1): 21-37.
Charnes A., Cooper W. & Rhodes E. (1978), "Measuring the efficiency of decision making units", *European Journal of Operational Research*. 2: 429-444.

(20) It allows the simultaneous factoring in of the three indicators by building a synthetic performance score, using a Principal Component Analysis. The score corresponds to the coordinates on the first axis which accounts for 95.2% of the total variation. The method can be used if the three outcome indicators allow an unambiguous hierarchy to be established (when a higher value is uniformly desirable). By standardising performance measurements, the method makes the difference between a standard deviation in publications quantity and a standard deviation in patents quantity equivalent. The score is then transformed linearly to be strictly positive. The Principal Component Analysis (PCA) gives an equivalent weight to each performance variable; the standard deviation ratio shows that the increase of one patent will affect the performance score to the same extent as an increase of around 72 publications.

(21) Greece, which has the lowest public spending, was removed from the sample group.

Chart 7a: Efficiency frontier of public research systems (non-standardised expenditure and performance indicators, 2013)

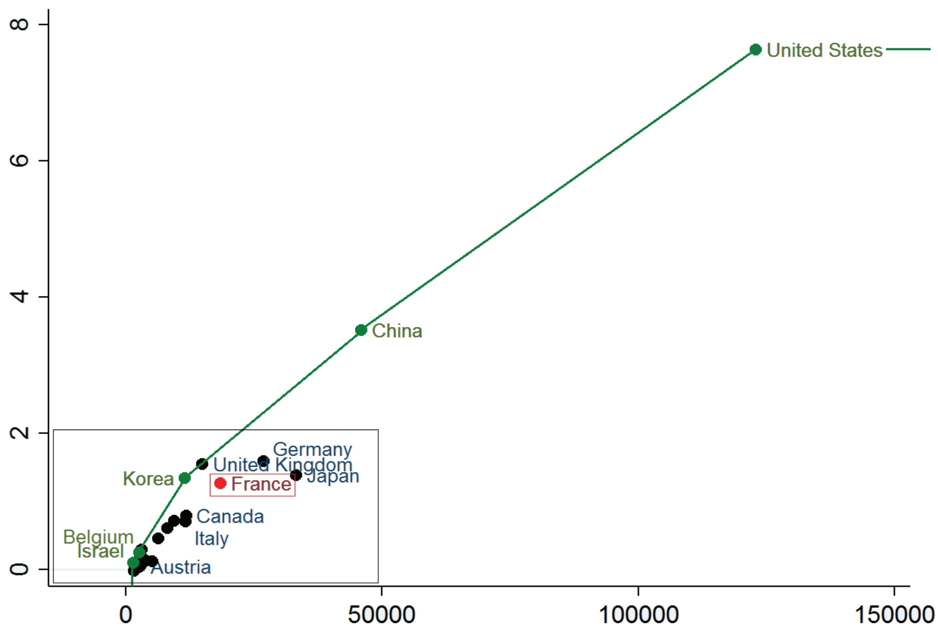
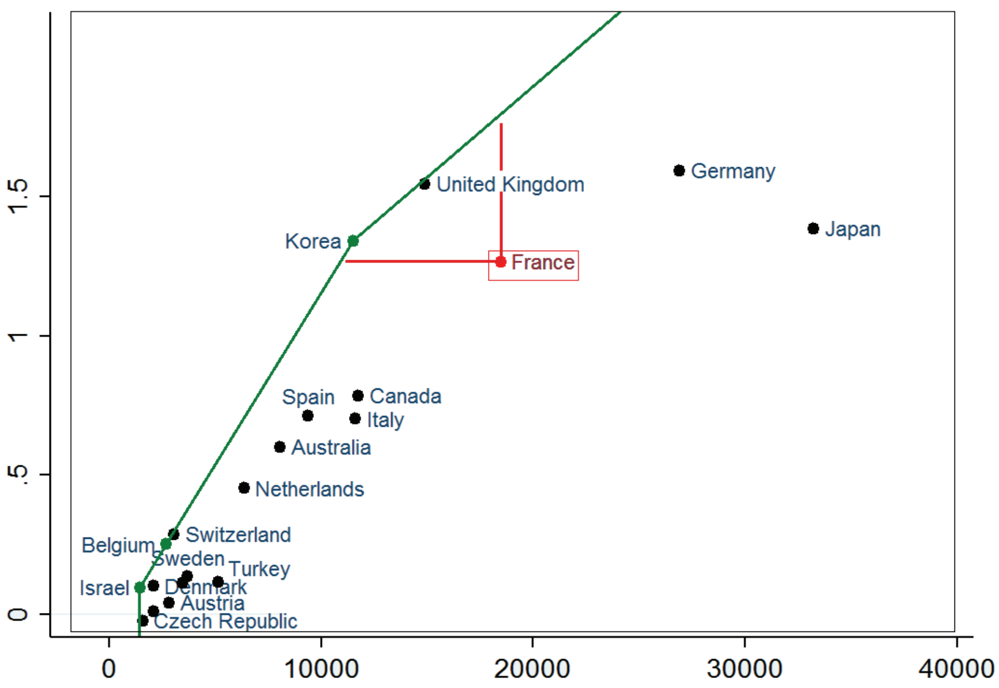


Chart 7b: Blow-up of Chart 7a to show France's position



Source: DG Trésor.

The second approach (illustrated by the chart on page 1) involves standardising spending and outcome indicators according to the size of economies. It supplements the first method as it relates the extent of the research effort to the relative volume of scientific output.[22] This view, which favours smaller countries, demonstrates that the distance between French public research and the efficiency frontier is significant and on a similar scale to that of Germany or Austria. In this case, the US are not positioned on the efficiency frontier, which may point to the existence of fixed costs for very large-scale research systems. As a result, it is thought that the efficiency of expenditure falls beyond a certain threshold.

France's position has been backed up by a number of robustness tests, in particular by changing assumptions on the return to scale[23], the use of an alternative definition for research expenditure that excludes defence R&D spending, application of the Bootstrap (by randomly excluding countries from the sample), and use of an alternative parametric regression method (SFA).

Lastly, this benchmark may be reproduced for a year in the more distant past (2004, taking weighted spending from 1998 to 2002). The country sample for which data is available is the same with the exception of China and Russia, and the addition of Mexico. This approach shows that, in 2004, for non-standardised values for expenditure and outcomes, French public research belonged to third-tier countries, lagging behind in relation to the most efficient countries (UK, Israel) and to the group of intermediate countries. South Korea was not in its current position as its efficiency level put it far behind. The change experienced by France between 2004 and 2013 was due to the combined effect of a moderate increase in the volume and frequency of publications, and a sharp rise in the number of patents originating from public research.

Axel DEMENET

(22) Production indicators are divided by GDP before conducting the PCA, which provides the score, and this removes the country size impact.
(23) The main results assume that there are variable returns to scale. This assumption means imposing a convex form on the frontier and searching for the smallest convex envelope containing the couples (input, output). This method is preferable as it is the least restrictive of the various returns to scale: we assume that an increase in spending does not cause a proportional rise in performance levels.

Publisher:
Ministère de l'Économie
et des Finances
Direction générale du Trésor
139, rue de Bercy
75575 Paris CEDEX 12

Publication manager:
Michel Houdebine

Editor in chief:
Jean-Luc Schneider
(01 44 87 18 51)
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English translation:
Centre de traduction
des ministères économique
et financier

Layout:
Maryse Dos Santos
ISSN 1962-400X
eISSN 2417-9698

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