Chapter 1

Overall Assessment and Recommendations

This chapter sets out the strategic issues facing the French research and innovation system today. It tracks its past history, marked by the central role the State has played via, in particular, the large research organisations, and looks at the effectiveness of this kind of model in the current global and national economic context. It then summarises the main findings of the review in regard to human resources for innovation, the public sector research system, public-private knowledge transfers, corporate innovation policies, innovative entrepreneurship and overall governance of the system. Finally, it looks in more detail at the "Investments for the Future" Programme, a ten-year plan launched in 2010 to develop and transform the French research and innovation system.

Strategic challenges facing the French research and innovation system (SFRI)

France, like other high-income countries, needs to strengthen its capacity for growth and respond to the major challenges facing society, such as climate change and an ageing population. It cannot do so without mobilising research and innovation. This message gradually worked its way to the heart of the governmental discourse and became established there once and for all at the end of the 2000s. It follows that it is fundamental to find ways of mobilising the French research and innovation system effectively so that it can play its part in these efforts.

Mobilisation and effectiveness are certainly two related issues, and the successive plans implemented by France, such as the "Investments for the Future" Programme (PIA) launched in 2010, looked at both aspects, seeking both to mobilise and reform the SFRI. This report is an attempt to take stock of the SFRI in 2010 and note the changes that have occurred since that time. In this context, it seeks to evaluate the capacity of the SFRI to respond to economic and social challenges and to identify factors that might act as stumbling blocks.

France is a country with a longstanding scientific and technical tradition, and today it still plays a significant world role in this area. France was at the heart of the scientific revolution in the 17th century, then of the industrial revolutions in the 18th and 19th centuries in Europe. Since that time, it has never stopped playing an active part on the global scientific and technical stage. The SFRI acquired its present structure gradually over the past century, in particular during the decades following the Second World War, the "reconstruction" period. The SFRI has a number of historical features that set France apart from other countries.

A first feature of the SFRI is that the State plays a crucial role. This is a common feature of society and the economy in France (public spending as a proportion of gross domestic product (GDP) was the second highest in the OECD in 2013) and is also the case in science and innovation. The State funded a total of 37% of research and development (R&D) expenditure in 2010 (actually closer to 50% if one includes the research tax credit (CIR), while for countries of comparable size and wealth (Germany, United Kingdom), the figure is about 30%. This share has tended to diminish in the past few decades (it was 50% in the 1980s, while the OECD average was about 40%). Defence spending, which is higher than in other countries (but has been declining for more than 20 years), helps explain this, but only in part, because the State is also closely involved in financing and executing R&D in the civilian sector.

Another distinctive feature is that universities play little part in public research, which is mostly conducted by public research organisations (PROs), including the National Centre for Scientific Research (CNRS) and the Alternative Energies and Atomic Energy Commission (CEA). To a large extent, the PROs steer and fund research themselves, guided by broad objectives defined by themselves in consultation with the State. These organisations are mainly funded on a recurrent basis and their mandates do not include teaching. For a long time, universities held a marginal position in French public sector research and focused on the task of teaching – except for "elite" teaching, which is carried out in the *grandes écoles*, another specifically French feature.

A third feature (which is not exclusively French, but is particularly pronounced in France) is the proximity of the State and the large enterprises that carry out a major part of R&D, both strategic (the enterprises are involved in public initiatives) and financial (public procurement and State aid). The highest contribution to R&D funding by the State

goes to large enterprises (sizeable sums) and to very small businesses (start-ups), although the funds allocated to the latter are fairly small. Medium-sized enterprises receive virtually nothing.

The establishment of this system coincided with France's economic development after the war, and its structure clearly reflects the growth model of the "golden years", the three post-war decades. The SFRI was structured in the 1950s-70s as a predominantly managed system focusing on the State. Its outlets were the large public enterprises, which generally held a monopoly position (public transport, electricity, telecoms, etc.); the PROs managed the technology aspects, while other large public sector companies were responsible for innovation and production. The State determined the strategic choices and allocation of resources, favouring sectors regarded as most important to the country's development, as well as its security and defence, such as energy (especially nuclear), telecommunications, aeronautics, space, etc. Since France was initially situated at some remove from the cutting edge of global technology, the programmes often consisted in adopting and adapting pre-existing techniques, generally originating in the United States. That is how France succeeded in a dynamic process of technological "catch up". That kind of dynamic is consistent with a fairly centralised institutional model, which ensures stability in regard to technological choices, allocates adequate resources and co-ordinates the various stakeholders. It called for a research and innovation system that was closely structured around these major programmes, and for which centralised research organisations may have appeared particularly effective. Accordingly, a number of major programmes were given their own PRO: the CEA for nuclear energy; the French Space Agency (CNES) for space; the National Institute for Research in Computer Science and Control (INRIA) for information technology; the National Centre for Telecommunications Research (CNET) for telecoms. The failure of attempts to transpose this model to sectors that were more competitive or positioned at the cutting edge of technology, such as IT, demonstrated its limitations. The "Plan Calcul" computer plan of the 1960s is often cited as an example of the limitations of the major-programme model. Yet programmes that succeeded technically, such as the Concorde or Minitel, also show that the model was not adequately geared to the more open and competitive global market that prevailed starting in the 1980s.

The properties of this type of administered model have been analysed elsewhere and may have a positive or adverse impact on its effectiveness, depending on the context; in France, the following positive aspects predominated between the 1950s and 1970s:

- Capacity to effectively adopt and adapt the scientific and technical advances achieved abroad and to make incremental innovations, thanks to a hierarchical system that ensures that decisions are consistent *ex ante*. The downside is a low capacity to achieve radical scientific or technological advances, which require trial and error, a pluralist approach and competition.
- Capacity to conduct very large-scale projects (involving a variety of large stakeholders and major capital injection), with an innovative component and a long-term horizon. The downside of this robustness is low sensitivity to market signals in relation to demand, which is largely captive (telephone, rail, electricity users under a monopolistic national operator, etc.), and no urgent pressure with regard to financial returns, since the funding comes from the State.

- Structural stability, as a result of the administrative nature of the mechanisms in play (budget commitments, status of employees): once a programme has started, it is difficult to stop or re-orient it. This creates a stability horizon that is potentially beneficial to some projects, but makes it difficult to make the sometimes necessary adjustments, with the result that stability may turn into rigidity. Growth is the source of flexibility, producing resources that grow year by year and can be allocated to new priorities without displacing previous-year resources already tied up in earlier objectives. When growth stops, this source of flexibility disappears.

The context has gradually changed, however, and with it the characteristics that ensure the success of a research and innovation system. The adverse effects of the administered model then became more apparent.

First of all, simply as a result of its successful model, France has managed to catch up. Its productivity is now among the highest in the world (productivity per hour of work). French research and French industry are at the forefront of global knowledge in the sectors where they have a presence. This position has a variety of implications for the research and innovation system. At the cutting edge, "the future is not yet written"; one must certainly look at what others are doing, but everyone must make their own way. This means taking a flexible approach, by trial and error, and having the ability to change one's choices and reallocate one's resources rapidly in response to scientific and technical opportunities or demand. It also means that the challenge of productivity, which is always crucial to growth and competitiveness, takes on a new form: there is a need for young, innovative companies as pioneers of innovation, alongside the large groups. The central position of entrepreneurship in the innovation process was reinforced by the role acquired by information and communications technologies (ICTs), in particular software, as the main pathway towards the emergence and distribution of the new products. ICTs have also driven the new innovation processes: open innovation (structured co-operation among enterprises or with public research bodies), innovation by consumers, non-technological innovation often linked to the web. A position at the cutting edge is in fact important not only to science and technology, but also to the organisation and provision of services, the capacity to follow the changing tastes of the consumer, etc. This is especially significant in economies where the service sectors are more important, and the manufacturing sector less important, than in the past. When that happens, innovation in services becomes a priority.

Secondly, the world has become more diverse and interconnected than before. The rapid development of Asia – particularly Korea and then China – and of the other BRIC (Brazil, Russia, India and China) countries over the past decades, has sped up global growth at the very time that growth was perceptibly slowing in the developed countries, including France. France's share of global GDP (in purchasing power parity) fell from nearly 4% in 1970 to a little over 2.5% in 2010, a decline also seen in other countries such as the United Kingdom and Germany. The world has also become more interconnected: flows of goods, services and capital, as well as of information and knowledge, are now far more dense and multidirectional. Production has become increasingly segmented at the global level, in "global value chains" where each country tries to acquire a favourable position and thus depends on multinationals' choices and market dynamics. Furthermore, France joined the European Union (EU), with the effect of not only tightening its economic links with the other member states, but creating a body of rules that are binding within France as well. Within that context, market competition has become stronger and there are few public monopolies left that can impose their technologies of choice on captive consumers; the evolution of telephony is the clearest illustration of this change. Moreover, international treaties and the EU institutions now give member states less margin for manoeuvre; for example, there are

strict ceilings to enterprise subsidies. In the same context, any technological strategy must from the outset obey international rules and be conceived in terms of global demand, which is not captive, instead of national demand, which could be.

Thirdly, the major collective challenges the State is attempting to address, in particular through innovation, have changed. Earlier on, during the Cold War period, defence was the biggest challenge. It mobilised substantial resources, with large amounts channelled towards research and innovation. It was hoped that these investments would have a spillover effect on civilian markets. Yet it appears that these spillovers, however significant, never met the level of spending allocated to other ends. By its very nature, defence research is secret and is not likely to have a trickle-down effect. It is also very national, given that international defence co-operation is limited and regulated. The SFRI was well prepared for operating procedures of this kind, and France was in fact one of the top OECD countries in terms of defence R&D. Over the past two decades, new collective challenges have replaced defence, such as the environment (including energy transition) and the ageing population. Governments are carrying out significant research programmes linked to these challenges, but they differ from the military programmes. First, the approach is more open, since secrecy is no longer a vital requirement; this means a diverse range of stakeholders, such as small businesses and universities, which would have been excluded in the past can now be included. Second, they are drawing on a more diverse range of knowledge from every scientific and technical field; the research therefore needs to be multidisciplinary and laboratories or enterprises in very different fields have to work together. Finally, since these challenges are common to the whole of mankind, international co-operation is the natural operating procedure, even if reality is not always equal to the opportunities.

The new context that has gradually emerged calls for the research and innovation system of countries at the cutting edge of science and technology to show new qualities, against which the SFRI and PIA measures can legitimately be evaluated. The system needs to be:

- *Flexible,* capable of rapidly reallocating resources: this applies to the State, which must therefore develop project funding (whose orientation can be readjusted very rapidly) alongside recurrent funding and draw on universities, which are more flexible than PROs in terms of resource allocation because of their multiple missions; and to industry, which requires a more dynamic demography (renewal of the corporate population, entrepreneurship).
- *Competitive and co-operative,* less compartmentalised: the stakeholders, both public and private, must not adopt a silo mentality and must interact closely; this applies, in particular, to the relationship between public research and businesses.
- *Open to society and the market:* able to respond to the demand of a multitude of consumers, a demand that can change rapidly or shift to other providers. Currently, public demand is directing innovation towards the major economic, environmental and social challenges. That means that the State must manage public research strategically (see below) and encourage interdisciplinary action. This is necessary when research is led by demand, since most of the real issues it is tackling go beyond disciplinary boundaries; it also presupposes flexible and decentralised organisational structures.

- *Entrepreneurial:* new businesses often drive new technologies, especially in the ICT sector, software, the web and biotechnology.
- *Attach more importance to non-technological innovation* and the service sectors: innovation is omnipresent and is no longer confined to a few "high-tech" sectors. Design and marketing form an integral part of innovation activities.
- Internationalised: actively included in global knowledge networks, able to tap and exploit the most recent knowledge.
- Such that *higher education* can offer a solid training to large numbers of young people in order to increase the economy's capacity for innovation and provide future researchers, engineers and entrepreneurs with the capacity for initiative and innovation required by the new dynamic.
- *Managed strategically* but flexible in its implementation. In this diversified and changing environment, the State can no longer apply a command and control model, but must accept a certain amount of flexibility and autonomy on the part of agents; it must also put in place adequate incentives to guide them in their work. This more complex form of governance brings with it a greater need for transparency and evaluation.

The entities responsible for research and innovation in France have certainly realised this and the model has changed significantly over the past two decades, gradually moving away from its initial state – but without, however, fully embracing the new model.

The chosen direction has been to adapt increasingly to the new context described above, with repeated attempts to meet the criteria set out earlier. This led to waves of reforms: the Fillon Act promoting public-private transfers in 1994; the Allègre Act on transfers and Daniel Strauss-Kahn measures to finance entrepreneurship in 1998/99; the "competitiveness cluster" policy in 2004; the creation of the National Research Agency (ANR) for project funding and Evaluation Agency for Research and Higher Education (AERES) in 2006; the Law on Responsibility and Autonomy of Universities (LRU) in 2008; the National Research and Innovation Strategy (SNRI), placing the major social and environmental challenges at the heart of research policy, in 2009; the PIA (about EUR 20 billion spent on research and innovation, excellence, transfers and entrepreneurship, allocated mainly on a competitive basis) in 2010.

The PROs themselves, a legacy of the old model, changed. They forged closer ties with the universities by creating "joint research units" from the 1990s onward and sought to respond, going beyond their supervisory authority, to socio-economic demand (from which they must draw part of their income). Over the same period, public funding of research fell as a share of GDP as a result not only of the decline in military spending, but also of reduced support for businesses; this lasted at least until the reform of the CIR in 2008, which radically reversed the trend by introducing very high State transfers to R&D enterprises. Support for innovative entrepreneurship also became a central concern of many public policy measures.

The SFRI emerged from these successive reforms and policy re-orientations considerably transformed. Yet the changes are only partial, and the current system can be described as mixed – a hybrid between the old administered model and the new open model. This mix is unsatisfactory in many respects, because the friction and segmentation it creates makes the system less effective overall. Looking back to the earlier criteria, the main features of the SFRI can be summarised as follows:

- *Flexibility:* public research funding is allocated in a very rigid manner because of the statutory management of human resources in the PROs and the mechanical allocation of recurrent resources. Hence, public research is not well placed to respond to sudden changes in opportunities and requirements; it is, in fact, the most rigid in the world in thematic terms.
- *Competition and co-operation:* the higher education and research establishments have little strategic, academic, educational or financial autonomy, making them less able to interact and the system less able to generate the few large research universities that France needs. The joint research units have encouraged closer interaction between PRO teams and with the universities; some progress has been made here, but more remains to be done (the joint research units answer to multiple supervisory authorities within their member bodies) and as a result, running costs remain too high. If the host universities moved to a single management system, this evolution could be completed. Higher education is also segmented, because of the split between universities and grandes écoles, which is damaging to both education and research.
- *Openness to society and the market:* public-private transfers are still not measured properly, but appear to have increased slightly in volume since the late 2000s, despite the great variety of reforms and measures put in place; this probably reflects strong systemic obstacles, in particular the lack of incentive for laboratories and researchers to co-operate with enterprises.
- *Entrepreneurship:* public aid chiefly goes towards large firms, while many intermediate-sized enterprises (ISEs) remain untouched by public sector measures. The entrepreneurship policy is certainly generous, but it sometimes resembles patronage rather than venture capital in the sense that it offers almost unconditional protection to a number of young businesses without necessarily giving them either the incentives or the means to achieve growth.
- *Attaches more importance to non-technological innovation* and the service sectors: public sector innovation policies now attach more importance to these new areas of innovation, but there is still room for improvement.
- *Internationalised:* French public research is certainly internationalised, yet France is not attractive enough to foreign R&D and researchers because of the difficult environment (taxation, etc.) overall and a research system that is neither very transparent nor open.
- *Higher education* is finding it hard to produce the large quotas of students needed for an overall more innovative economy; it is, however, increasingly open to entrepreneurial approaches.
- *Managed strategically:* modern public research management means separating the planning and implementing functions (as well as funding and evaluation) in order to align planning more closely with collective needs. In France, however, the PROs are in charge of planning public research, which therefore reflects the direct interests of the teams conducting the research – hence the difficulty in commercialising the research and the thematic rigidity emphasised above. Despite progress in project funding, recurrent funding is still largely predominant (about 90% of public research funding is recurrent), restricting the State's capacity to steer research in some organisations.

The SFRI has embarked on an incomplete process of transformation by trial and error. In the light of the above analyses, the main weaknesses of the SFRI may serve as a guide for political action, which will be described in detail later in this chapter. A similar kind of diagnosis led to the creation of the PIA, which is intended not only as a programme for investment directed at new growth but also as an instrument for transforming the SFRI.

The various plans and strategies published in recent years set out the major objectives of current research and innovation policy in France in a fairly coherent manner. They are consistent with the analysis made earlier and relate to corporate competitiveness on the one hand, and environmental and social challenges on the other.

France has become far less competitive over the past decade. Its share of the export market has fallen, growth has slowed significantly and the number of manufacturing companies with more than ten employees has shrunk by one-quarter. Although this is mainly due to macroeconomic and structural factors (a decline in price and non-price competitiveness), the situation has been exacerbated by the positioning of French industry at the medium rather than the high end of the market and the weakness of its innovative offer. If it wants to restore competitiveness, it will have to speed up its productivity growth. The high-tech sectors where France has made major investments (aeronautics, nuclear, etc.) have not made up for the overall decline.

The first strategic challenge facing the SFRI can be defined as follows: how to help make the French economy more competitive again. That means identifying promising sectors where France has great potential, channelling the necessary human and financial resources towards them and using these resources as efficiently as possible. This has to be done within a new context marked by a globalised, "tertiarised" and competitive economy for which the SFRI is not necessarily prepared. Given the stakes, the identified sectors must have a strong impact on employment, either directly (e.g. (tourism, luxury goods, agri-food) or indirectly through their various ripple effects (high-tech, web, health, etc.).

The second challenge for the SFRI relates to the social and environmental aspect. Energy transition, climate change, greenhouse gas emissions, air and water management, urbanisation, ageing, the development of social inequality: faced with these sometimes radical changes, societies must bring into play all the tools at their disposal, including technological and social innovation. Many countries, like France, have become aware of the issues, which are also economic, since those problems also create opportunities for developing new activities that create value added and employment. The question that arises specifically in France concerns its research and innovation model: how to mobilise and channel the resources needed to respond effectively to the major social and environmental challenges? What adjustments need to be made to the resource allocation mechanisms to facilitate this mobilisation and allow these resources to be used more effectively?

These two challenges are clearly recognised and reflected in the rationale of the PIA (Juppé and Rocard, 2009), which argues that France should aim for stronger and more sustainable knowledge-based growth.

It is also reflected in the "France Europe 2020" strategic agenda published by the Ministry of Higher Education and Research (MESR) in 2013.

It is in the light of these two challenges, and of the conditions necessary to enable France to tackle them, that this survey will assess the SFRI. France will have to answer a number of questions in this context: what is the right balance between efforts to maintain France's position in its "traditional" high-tech sectors (aeronautics, space, nuclear, etc.) and efforts to strengthen the high-tech sectors (ICTs, software, biotechnology) and boost innovation in sectors where France is already competitive (luxury goods, agri-food, tourism, value-added services)? How can France strengthen its position in the global value chain and attract more foreign R&D investment? How can the powerful public research sector be made to rally around these objectives? What political instruments could be used to influence innovation in enterprises that are more heterogeneous and less tied to the State than its partner enterprises during the preceding period? What conditions should be provided to boost the growth of young innovative businesses? If these issues of innovation policy are to be resolved adequately and the solutions implemented, France must pursue the structural changes initiated by the SFRI.

This survey will examine all these challenges. It will endeavour to position France within these different dimensions, both in 2010 (the reference year for the PIA) and in more recent years (the difference between the two is generally negligible): how has France performed? What are its strong points and its weaknesses? How well have past and recent policies worked? What improvements could be made in the light of international experience?

Performance of the SFRI

Overall performance in research and innovation

The performance of the SFRI is shown in detail in the thematic chapters that examine its various dimensions. The salient points of this analysis have not varied since 2010 and are as follows. In regard to human resources, France appears to have a highly skilled elite (e.g. engineers of globally recognised competence), although it is too small (a significant portion of the labour force is not sufficiently skilled to support innovation). France also trains a smaller number of doctoral students than countries that are leaders in the field of research and innovation. In the field of scientific production, France comes behind Germany and the United Kingdom, but ahead of Italy and Spain. It has some internationally respected researchers, but not enough to raise its overall performance to the highest level. In the field of knowledge transfer between the public and corporate sector, France has essentially remained at a modest level for the past ten years, like many other countries in fact. In the field of corporate innovation, France has also posted average performance. France's R&D intensity is distinctly lower than that of Germany, because of the small size of its manufacturing industry. France also has fewer very large research enterprises, because its strength tends to lie more in areas where innovation relies very little on R&D: luxury goods, tourism, agri-food, etc. In innovative entrepreneurship, France scores quite well for business start-ups and venture capital investment, but less well for the growth of these businesses (which remain small in scale). Overall, as reflected in the Innovation Union Scoreboard (see Box 1.1), France occupies a position near the European average, behind the Scandinavian countries, Germany, the Netherlands and the United Kingdom, but ahead of southern Europe and central and eastern Europe.

A SWOT analysis (Table 1.1), showing the strengths and weaknesses of the system and the opportunities and threats facing it, gives a more qualitative picture of the SFRI.

Table 1.1. SWOT of the French research and innovation system

Strengths	Weaknesses
• top-quality, multi-skilled and innovative engineers for industry; • a significant number of researchers internationally recognised for their excellence, although the overall quality of French fundamental research is average; • some top-quality PROs in fields such as health and ICTs; • a growing population of imaginative and skilled entrepreneurs; • easy conditions for business creation and effective policies encouraging the creation of young innovative firms; • various government support schemes for innovation, offering businesses a wide range and allowing them to experiment in order to choose the most effective schemes.	• poor educational performance in major sections of the population; • a low rate of PhDs; • a segmented and rigid labour market which does not encourage labour force mobility; • a segmented public research system, with some rigid components that are not really affected by evaluations and not very reactive to social and economic demand; • PROs that combine the roles of planning, funding, executing and evaluating research while universities remain minimally involved; • a rather ineffective system of public-private knowledge transfers; • an excessively complex system of public aid for businesses; • a tax system that does little to encourage investing in businesses, although conditions have been adjusted for young innovative enterprises; • framework conditions (particularly taxation and social thresholds) that do not support business expansion; • a system of government aid for industry that is not sufficiently selective, keeping businesses with weak growth potential afloat.
Opportunities	**Threats**
• industries where France is strong (agri-foods, luxury goods, tourism, value-added services) are becoming globalised and require a great deal of innovation; • new sectors are emerging (nano, bio, software, etc.) where France could establish a position; • the early phases of project funding and independent evaluation have been a learning curve and now need to be extended and systematised; • the high levels of public procurement could be put to better use by encouraging innovation ("demand-side policies"); • local authorities' strong interest in innovation could lead them to increase their investment in fully autonomous universities to support local development; • the reform package implemented over the past 15 years to open up the system and make it more flexible has led to the creation of mechanisms with a high potential: for instance, university autonomy could foster the establishment of large research universities; • the PIA offers significant funding and a long-term horizon (ten years) and needs to be co-ordinated with the other measures.	• any decline in project funding or independent evaluation could make public research less open to society and the economy; • a proliferation of separate strategies on the part of different public stakeholders would reduce overall co-ordination of efforts and make them less transparent and effective; • a further decline in framework conditions for enterprises (taxation, flexibility of markets) could undermine efforts to foster innovation; • the fragile financial situation of the business sector is reducing its ability to invest.

Box 1.1. France in the Innovation Union Scoreboard

The European Commission's annual "Innovation Union Scoreboard" (EU 2014), a reference for many observers in Europe, places France in the category of "innovation followers", countries that are close to the EU average for the composite indicator of innovation. France ranks 11th out of the 27 EU member states for this indicator, very close to the EU average. The "innovation leaders" in this classification are the northern European countries and Germany. The followers include, along with France, the Netherlands, Belgium and the United Kingdom. France scores better for human resources (7th), scientific performance measured chiefly by publications (8th) and public sector financing and venture capital (8th), but far less well when it comes to corporate investment (14th), entrepreneurship and linkages between enterprises (14th) and innovators, notably small to medium enterprises (SMEs) (14th). The heterogeneous nature of the composite indicators may mask a number of specific realities, which can be analysed only by examining individual indicators. In terms of higher education and research, for instance, France's good ranking is the result of a high degree of internationalisation (as seen in the number of foreign doctoral students), by contrast to its share of most frequently cited scientific publications, which is lower than the EU average. France scores fairly well in terms of venture capital investment (in relation to GDP), but distinctly less so for corporate innovation; it also scores well in terms of applications for European Community trademarks, drawings and models (design), thanks to the SMEs introducing new products or processes, and in knowledge-intensive exports. Over and above the heterogeneous nature of these various indicators, France appears to score somewhat better (without, however, ranking among the leaders) in terms of higher education, research and funding, and innovation indicators.

Human resources

In 2010, France's human resources were marked by duality, as confirmed by the Programme for International Student Assessment and Programme for the International Assessment of Adult Competencies tests and the evidence from enterprises. On the one hand, there was a minority of well-trained specialists or generalists who were able to develop and implement innovations and were internationally recognised, and many of them were employed in large enterprises or PROs (a growing but still tiny number turned to entrepreneurship); on the other hand, a large section of the population had little or poor training and played no part in innovation. That reflects a system of higher education that performs well in terms of training elites (*grandes écoles*, selective advanced training in universities), while general or vocational university training does not produce enough graduates to broaden the human capital base in the French innovation system. This is because vocational training through university institutes of technology (IUTs), advanced technician certificates (BTSs), and specialised master's degrees) was too small-scale, and non-selective general training was often poor, with a high failure rate.

Human resource requirements depend on the characteristics and trend of the innovation system. The dual structure of human resources described above reflects a situation where the SFRI was indeed based on large high-tech businesses and projects, but chiefly with a view to catching up with cutting-edge technology. In a context where France needs to position itself at the cutting edge and on a broader sectoral base, the issue for the educational system is how to produce both pools of excellence to manage the cutting-edge sectors, together with a larger number of highly qualified specialists and generalists to permeate all the sectors and drive a form of innovation that is less radical, but nonetheless necessary to achieve competitiveness in many areas of activity. This can be done first, through pursuing educational excellence policies and strengthening the links with research by promoting a limited number of research universities and other initiatives of excellence (Idex) supported by the PIA and second, by improving the quality and relevance

of general or vocational university training for more students. This means creating the right incentives for universities and teacher-researchers (currently, the quality of the teaching delivered has little impact on the institutions or individuals responsible for delivering it) and reviewing the specific tasks and complementarities of the various players and courses of study that make up higher education in France. While research must be guided by criteria of excellence and, hence, be concentrated in the universities that have the necessary capacities, more emphasis must be placed on teaching in other universities, in response to needs that are felt directly at the regional level in particular; this does not preclude these universities from taking part in innovation activities linked to local needs (particularly those of SMEs) – supported, where possible, by "niches of excellence" in research. The historical separation between *grandes écoles* and universities has now become counterproductive: the *grandes écoles* need research in order to improve their graduates' capacity to innovate, while the universities need to be selective and link up with industry; France needs to pursue the various forms of co-ordination that have been tried out over the past decade. Higher education must also focus more openly on developing student attitudes and competences that are conducive to innovation and entrepreneurship. In the light of international experience, this means, in particular, attaching more importance to individual and group work during training.

Some of these changes must begin as early as the school level, which produces too many (and more and more) poorly educated pupils, as shown by France's mediocre results in the PISA tests. Specifically, school education should emphasise training in skills that are key to innovation and entrepreneurship, such as self-confidence, initiative and group work.

Recommendations:

- Pursue the policy of promoting excellence in teaching linked to research, while also placing more emphasis on teaching in the vast majority of universities, which are not involved in international-level research but may find real comparative advantages in their specific (scientific or economic) assets.
- Support the development of vocational university training and the improvement of the quality and relevance (in relation to social and economic demand) of general university training, including in the humanities and social sciences.
- Place more emphasis in universities on teaching activities likely to make students become more innovative and entrepreneurial (individual or, even more importantly, group work).
- Make the institutions more autonomous at every level (full responsibility for the management of teaching and non-teaching staff, freedom to recruit students, capacity to collect own resources, greater autonomy in the definition and award of diplomas, etc.) and continue to emphasise assessment at all levels.

Public research

According to various quantitative indicators, French scores lower in science than the leading countries and is near the European average. While there is a category of internationally excellent researchers – such as European Research Council (ERC) grant winners – the overall level, as measured by the impact of scientific publications, lies below that of the United Kingdom, Germany and northern Europe, for example, but above that of southern Europe and Asia. French research also seems to be among the most inert in the

world in terms of specialisation; the thematic distribution of publications has changed less than in the other countries since the early 2000s. These two features show how difficult the French public research system finds it to reallocate resources (by subject areas, but more broadly among research units, etc.) and – in direct correlation with that – to focus on excellence.

Public research is centred around the PROs. The largest of these, the CNRS, is mainly responsible for basic research. The others focus more on applied research, in areas where the State plays a major role for either strategic or economic reasons: nuclear (CEA), cutting-edge industrial technologies (CEA), health (Institut national de la santé et de la recherche médicale, French National Institute of Health and Medical Research), information technology (INRIA), agronomy (Institut national de la recherche agronomique, French National Institute for Agricultural Research, INRA), etc. In terms of scientific publications (not the primary objective of all PROs), these organisations generally appear to do well or very well at the European level, except for the CNRS which ranks at the middle or lower end of the European classification system in some fields. This is an average figure; a number of CNRS researchers may well be carrying out internationally recognised research. The French PROs are exceptionally strong compared with those of other countries: they combine the planning, financing, execution and evaluation of research. Most other countries abandoned this model some time ago – if indeed they ever adopted it – because it affects the way the system works, making it very difficult for the political authorities to supervise – meaning they cannot pursue their own priorities, for example in terms of research themes or orienting it research towards transfers to enterprises and society.

A few large research universities (Université Pierre et Marie Curie, Paris-Orsay, etc.) have emerged alongside the PROs, thanks in particular to the 2007 LRU law on the responsibilities and autonomy of universities, but they remain weaker than the PROs or comparable establishments abroad. Moreover, much of their research is conducted by joint research units, some of which are controlled by the CNRS and other PROs, leading to complex working procedures. The "site policy" now promoted by the MESR could eventually simplify this cumbersome system of governance by placing the joint research units under the sole control of the universities.

Project funding was traditionally limited in France, where recurrent funding allocated to the PROs were the norm. The French Parliament allocated the resources among PROs, after which the organisations allocated their resources within themselves, based on their own priorities as discussed with their ministerial authorities. The creation of the ANR in 2006 started a trend that was boosted by the establishment of the PIA in 2010. Project funding now accounts for over 10% of public research budgets (far less than in other countries). This gives the State a potentially powerful lever for promoting excellence and relevance in research. The coexistence of project funding – which is by its very nature limited in time – and the stable status of many public sector researchers proved difficult: some laboratories had to create temporary jobs because they had the funding but not the statutory manpower, while others had to reduce their effective activity because they had the statutory manpower but not the funding. This emphasises the need for a change of status, so as not to hinder gearing human resource allocations to research needs.

Excellent and relevant public research calls for independent, competent and effective evaluation. The AERES was created in 2006 to meet that need. Overall, the Agency has done well in that respect and has, in particular, helped universities manage their research teams. Some PROs also rely on AERES evaluations when they allocate resources among their own research teams. Now that the AERES no longer awards an overall mark to re-

search units, it seems to have become less useful, since it is no longer allows identifying research units that are having difficulties and are therefore candidates for restructuring.

Recommendations:

- The MESR site policy, which puts universities of excellence at the core of research, must be pursued and deepened. In particular, the joint research units need to be fully integrated in the sites concerned and the universities given sole management responsibility (a decision that was taken in the early 2000s and virtually not applied). Following the example of the PIA, research spending must be concentrated on excellence, which would allow other researchers to contribute directly to the quality of university education.
- Project funding should be more widespread, as it is a particularly good lever for promoting excellence; in particular, there is a need for more thematic (rather than open) calls for tender so that research can effectively be attuned to national priorities. Consideration should be given to adjusting the status of staff in PROs where the funding allocated is no longer consistent with the staff allocated.
- Evaluation of public research should continue on a regular basis and be rendered more effective, e.g. by introducing a reporting obligation for the organisations evaluated by the AERES – now the High Council for the Evaluation of Research and Higher Education (HCERES); it should be extended to teacher-researchers.

Knowledge transfers

Knowledge transfers between public research and businesses have been a major objective of French policy for the past 15 years or so, as is the case in other countries. A wide variety of measures have been taken to that end: commercialisation units within the universities in 1998, ANR transfer programmes, Carnot Institute label (which promotes research contracts), doubling the CIR for R&D outsourced to public laboratories, etc. Partnership research, collaborative research, commercialisation of intellectual property, business start-ups and staff mobility are the main instruments that have been put into play for this purpose. A transfer culture has developed, driven by an increased number of stakeholders and specialised institutions. Yet the results since 2010 remain modest. The few available indicators, covering staff mobility, income from intellectual property and partnership research, do not point to any significant progress over the past 15 years or so.

The main obstacles to the development of knowledge transfers are to be found within public research itself, in that it does not offer researchers enough incentives to transfer knowledge and choose research that is likely to have a social and economic ripple effect. Overall, the policies pursued have not been consistent enough, and multiple measures have been adopted without the respective fields of application always being clarified. This has resulted in a very complex overall system that is costly and not very transparent to its users (in particular SMEs) and is ultimately less effective. The PIA itself has created new stakeholders, notably in the form of technological research institutes (IRTs), energy transition institutes (ITEs) and technology transfer acceleration companies (SATTs), although the way they tie in with the existing system of operators has still not been completely clarified. Finally, in France, as in the other countries, transfers have often been based on an administrative approach (*filing* patents and *creating* businesses are administrative measures) rather than economic measures (*commercialising* patents and *encouraging business growth* are industrial, market activities).

Recommendations:

- Offer more incentives to universities and PROs so that researchers will turn towards commercialisation rather than confine themselves solely to scientific publications. This means including transfer indicators in researchers' career files.
- Seek to clarify and harmonise the body of transfer mechanisms, by carefully evaluating the scope and impact in each case, consolidating or removing the least effective mechanisms, and clarifying the advantages of each mechanism. In that light, industrial property management poses particular challenges. A single management mandate must certainly be implemented (including the right to transfer a patent), but the respective roles and rights of the various stakeholders, such as SATTs and IRTs, also need clarifying.
- Professionalise and offer adequate incentives to the institutions and staff in charge of commercialisation: these are market activities that require stakeholders to have the relevant qualifications and experience and to do their best to respond to the signals received, especially from the market. From that point of view, the creation of SATTs is a step forward that should be built on.

R&D and business innovation

Businesses in France spend less on R&D than private sector businesses in Germany or other leading countries in the field of innovation. The difference can be explained by France's sectoral structure, particularly the small size of its manufacturing sector. French businesses tend to be more competitive in sectors that are less R&D-intensive (luxury articles, agri-food, tourism, value-added services, etc.). Furthermore, French industry has shrunk perceptibly since the early 2000s because it has become far less competitive. It is made up of small firms that are relatively more numerous and more R&D-intensive than their German (or British) equivalents and of large businesses that are smaller and less R&D-intensive than their German counterparts. The sectoral distribution is partly to blame, but this difference in size is clearly reflected within individual sectors (e.g. the automotive industry). In terms of innovation (as measured by innovation patents or surveys) and science, France occupies an intermediate international position, behind northern Europe, Germany and the United States, but ahead of southern Europe. In terms of internationalisation, it would appear that France as a country does not much attract the R&D of foreign firms, whereas French firms tend to locate a significant share of their R&D in the United States.

The CIR tax credit is among the most generous in the world. In itself, the CIR is a good measure – which is one of the reasons most OECD countries, and other countries, have adopted it. It has a positive impact on corporate R&D, although this probably does not match its cost to the State. Cost is, in fact, only one of the determinants of R&D, and lower cost would not entirely remove the other obstacles to R&D growth (i.e. enterprise capacity, demand, industrialisation costs, etc.) Rather, the real impact of the CIR seems to be in helping firms that do R&D to survive better than those that do not. Its generosity is justified largely by a tax environment (corporate tax, etc.) that is difficult and complex for enterprises, but with limited adverse effects on R&D firms.

A wide variety of public programmes and organisations ensure strong public intervention in innovation, with some considerable successes in a number of areas: competitiveness clusters, refundable advances from the French innovation agency OSEO, sectoral aid programmes, etc. The main beneficiaries are small businesses on the one hand and large

businesses on the other, while ISEs receive less support. Competitive support measures (based on open invitations to tender) are becoming increasingly common. Overall, however, public intervention is very fragmented, not always consistent and does not follow a clear and single strategy.

Recommendations:

- Make the higher education and research "sites" and the competitiveness clusters more consistent among themselves, by adjusting their total number in keeping with this need for consistence.
- In the context of future tax changes, make the CIR less generous, especially for large companies, and reduce the corporate tax rate; this would make the CIR less likely to have a distorting effect on sectors where innovation rests relatively little on R&D.
- Given that national schemes to support innovation in France do not fully take into account France's sectoral structure and services, schemes that could benefit businesses in sectors such as agri-food and tourism should be developed.

Entrepreneurship

Judging by the available statistics, innovative entrepreneurship in France has grown to a level comparable to that of other countries. While the rate of business survival is high, few businesses are growing in size. Examples of successful growth (such as Criteo's listing on Nasdaq in 2013) remain rare. That is France's main issue in this area.

Venture capital funding is reputedly inadequate in France, as in other European countries. In terms of absolute amounts, it is higher in the downstream (expansion) stages than in the upstream (seed funds) stages, which admittedly require far less investment. Yet stakeholders report that it is difficult for French start-up businesses that have succeeded in the initial stages to complete the "third round", which generally requires higher funding (several tens of millions of euros). In fact, more venture capital is collected than invested in France, with a difference of about EUR 100 million per year since 2008. The reasons for this net export of capital remain to be identified. The level of capital injection is higher in France than anywhere else in Europe, but it goes hand in hand with this net export of capital and the persistent difficulty encountered during the third round. An in-depth analysis of these conditions is needed to optimise public intervention and target market segments with the highest demand while avoiding any crowding-out effects, such as private capital moving abroad in search of better projects while leaving the least profitable French projects to the State.

Greater and more dynamic innovative entrepreneurship has gradually become a central objective of French innovation policy. Public intervention is extremely thick on the ground in this field, with the State intervening at all levels of the chain (training, business start-up, taxation and social security contributions, funding, etc.), which seems to be making a real impact on the number of young innovative enterprises and their capacity to recruit researchers. Nevertheless, the far higher level of public intervention compared with other countries does not seem to be reflected in these businesses' growth and performance – which raises the question of the intervention's overall effectiveness.

What factors restrict the creation and, above all, the growth of innovative businesses in France? Lack of capital is often cited to justify the injection of large amounts of public funding into venture capital through funds of funds. The impact of the lack of capital is

all the stronger in the absence of a stock market for growth companies, which would provide them with an additional source of funds, together with the exit capital needed by private investors.

A second limiting factor is the range of framework conditions that encourage businesses not to grow beyond a certain size, and especially the effects of the established thresholds (e.g. in terms of social legislation, taxation, access to public support) in relation to size.

A third factor is that some public support measures are not selective enough and last too long. A company can accumulate a variety of public support measures for years, even though its project is making no progress. The prolonged and artificial survival of poorly performing businesses inhibits the growth of other businesses by making them compete against one another for public and private funding, as well as access to skilled labour and the market.

Recommendations:

- Examine the actual venture capital requirements in France sector by sector, at a time when the much-cited shortage of venture capital does not seem to be general, and adjust the amounts the State allocates to the corresponding funds and funds of funds.
- Examine the fiscal and legal conditions that give small businesses, in particular innovative start-ups, less incentive to grow.
- Make the strategy to encourage the creation of innovative enterprises by means of taxation and public sector support more selective. Following the methods used by venture capital professionals or by Small Business Innovation Research in the United States, funding granted to each young business could be reviewed on a regular basis in the light of its prospects of success, with those passing the test successfully entitled to higher funding in line with their growth needs.

Governance

Governance refers to all the mechanisms involved in managing and co-ordinating a country's research and innovation policies. It implies co-ordination among stakeholders with responsibilities at different levels of the system. In France, the highest level (strategic, interministerial) is the President of the Republic and the Prime Minister, usually advised by a "High Council" made up of major figures in research and innovation. In the past, High Councils of this kind never worked well in France, because their responsibilities were limited and unclear and because they did not have enough legitimacy in the eyes of some stakeholders who were not involved in their appointment and operations.

The ministries, especially those in charge of research and industry, must co-ordinate if the system is to work properly, including in formulating research and innovation strategies. This has not always been the case in the past. The recent (2013) creation of an interministerial body in charge of innovation policy should improve matters.

The situation was complicated by the creation of the General Commission for Investment (CGI), which developed its own strategy – derived from the "Juppé-Rocard report" and endorsed by the President of the Republic – on the basis of which it allocated significant funds to the PIA without creating any organic link with the ministries in the affected areas of competence. This resulted in systemic friction between old and new institutions with overlapping missions and different operating methods.

Vertical co-ordination relates to the steering/supervision of research organisations and operators (e.g. OSEO) by ministers. Basically, the PROs decide on their plans themselves, without any *ex ante* guarantees of overall consistency or compliance with the policy priorities. Potentially powerful instruments have been put in place (PIA, ANR) to remedy this. It is now time to make full use of them.

Positive developments have recently taken place in regard to the evaluation function, which has long been a weak point in France; new mechanisms have been established to ensure the independent evaluation of players and policies, in the form of the AERES, the CGI (for PIA investments), the increased powers of the French Court of Auditors in the field of research and innovation, and the creation, in 2014, of a policy evaluation committee under the General Commission for Strategy and Foresight.

Recommendations:

- The High Council that is being created under the Law of July 2013 should be given real operational independence in relation to the SFRI stakeholders, in particular the PROs.
- Specific procedures should be put in place to promote regular co-operation among the key SFRI ministries, so as to align the various strategies with the corresponding political measures. That calls for interministerial co-ordination.
- The ministries that supervise the PROs, particularly the MESR, will have the capacity to orient their strategies, by setting goals aligned with national strategy and implementing them through multiannual plans signed with the PROs for achieving those objectives.
- Independent evaluation should continue and be developed, and the prerogatives of the AERES should be confirmed in the new HCERES. Evaluation should become more effective and have a direct influence on the subsequent orientation of the evaluated policies and measures.

The PIA

Genesis and content of the PIA

The PIA was established in 2009, on the initiative of President Sarkozy, following the Juppé-Rocard report and as an immediate follow-up to the SNRI. The PIA covers the period 2010-20.

The aim of the programme is to prepare France for the challenges of tomorrow (competitiveness, environment, health, etc.) and increase its growth potential by investing up to EUR 35 billion in higher education and training, research, industry and SMEs, sustainable development and digitisation. All in all, assuming it has the desired multiplier effect on other funding, and especially on private sector co-financing, the target investment programme will be worth between EUR 60 billion and EUR 65 billion, to be spent as follows:

- research (EUR 7.1 billion)
- higher education and training (EUR 11.0 billion)
- digitisation (EUR 4.5 billion)
- sustainable development (EUR 5.1 billion)
- industry and SMEs (EUR 6.5 billion)

Each of these fields includes a number of different programmes, combining various methods of funding (loans, own resources, subsidies) and different approaches per sector, per object (creation of new objects, such as the SATTs, ITEs, IRTs) and per technology linked to a target issue (e.g. car of the future). The PIA is piloted and co-ordinated by the CGI. The bodies responsible for disbursing the funds under special programmes are existing entities, which as a result now have additional responsibilities. Chief among these are the ANR, the Deposits and Consignment Fund (CDC), the Environment and Energy Management Agency (ADEME) and OSEO, the French innovation agency.

Part of the allocated funding is paid outright to the beneficiaries ("consumable funds"), but another part is given in the form of an endowment, with beneficiaries receiving only the interest on the investment, namely an annuity amount to about 3.5% of the endowment. Some programmes may definitively receive the investment capital after ten years, when the programme comes to an end, under terms that remain to be defined.

The PIA stands out among public policies relating to research and innovation in terms of both its objectives and methods.

The PIA sets thematic objectives. The main target is research and innovation, which absorbs more than half of the funding. The PIA also pursues excellence and allocates funding to stakeholders and projects that it considers the most able to produce value.

The method for pursuing these objectives is based on openness and selectivity. Most of the funds are allocated on the basis of open tenders, arbitrated by expert juries (which include foreigners) who base their decision on the expected value of each tender submitted. Selectivity means that there is a restricted number of beneficiaries, to avoid scattering funding, effectively rendering it inoperative. This method deliberately disregards institutional barriers, such as PROs/universities or universities/*grandes écoles*. The PIA has created new entities to drive certain projects, e.g. Idex, SATTs, IRTs, etc. In line with its selective and transparent approach, the PIA also gives pride of place to evaluation, which is included at all planning levels (individual projects, programmes, operators, overall level).

Table 1.2. PIA 1: Programmes and activities

Programme	Amount	Content, operator
Centres of excellence (EUR 12 billion)		
Equipment of excellence	EUR 850 million	Approx. 100 pieces of research equipment
Laboratories of excellence	EUR 1.94 billion of which EUR 1.8 billion in capital	Managed by ANR
Initiatives of excellence (Idex)	EUR 7.1 billion	Aim: create 5-10 interdisciplinary clusters of global excellence
	of which EUR 6.9 billion in capital	Managed by ANR
Plateau de Saclay	EUR 1 billion consumable	Establishment of a research cluster of excellence comprising about 14 schools and universities
		Managed by the ANR
Plan Campus	EUR 1.3 billion	Supplement to the EUR 3.7 billion from Plan Campus to renovate university buildings across ten French campuses; the PIA contributes in two instances (Paris and Saclay)
Heath and biotechnologies (EUR 2.45 billion)		
Health and biotechnologies	EUR 1.55 billion	Fund the most advanced research in these fields
University hospital institutes (IHUs)	EUR 0.9 billion in capital	Fund five clusters of excellence in research, education and commercialisation
Commercialisation of research (EUR 3.5 billion)		
Carnot Institutes	EUR 500 million in capital	Public-private partnership research
IRTs	EUR 2 billion, of which 75% in capital, plus estimated EUR 1 billion in multiplier funds	Create a dynamic of public-private co-operation
SATTs	EUR 950 million in own funds	Technology transfers, commercialisation
France Brevets (patents)	EUR 50 million (plus EUR 50 million from the CDC)	Patent funds
Energy and circular economy (EUR 3.15 billion)		
Institutes of excellence for carbon-free energy, now ITEs	EUR 1 billion, of which 75% in capital	Associate the public and private sectors
Energy and green chemistry demonstrators	EUR 1.2 billion	Managed by ADEME
Circular economy	EUR 200 million	Innovation and deployment
Nuclear	EUR 800 million	R&D
"Green tech" investment fund	EUR 150 million	Investment in innovative "green" enterprises
Transport (EUR 3 billion)		
Aeronautics	EUR 1.5 billion	R&D
Automotive, maritime, rail, space	EUR 1.5 billion	R&D
Employment, equal opportunities (including boarding schools of excellence, co-operatives, etc.) EUR 1.1 billion		
Urban planning, housing (EUR 1.5 billion)		
City of tomorrow	EUR 850 million	Demonstrators for planning, energy, transport, etc.
Digital industry (EUR 4.5 billion)		
Support for new digital services and uses	EUR 2.25 billion	Support for research and innovation in ITCs
Support to enterprises (EUR 3.1 billion)		
National seed capital fund	EUR 600 million	CDC
Competitive clusters	EUR 300 million	OSEO
Other support for innovative SMEs	EUR 1.4 billion	OSEO

Source: http://investissement-avenir.gouvernement.fr/content/action-projets/les-programmes/centres-dexcellence.

In July 2013, the government replenished the PIA with EUR 12 billion. This study does not discuss what is known as "PIA 2".

The PIA combines two kinds of instrument to address the issues of creating a larger, more specialised pool of human capital geared more closely to innovation:

1. The "Idex" scheme has committed EUR 7 billion in non-consumable endowments to create between 5 and 10 world-class multidisciplinary clusters of excellence in higher education and research. This scheme, which began in 2011, led to the selection of eight projects that could spawn fully-fledged research universities by combining on a given site the forces of excellence of all the stakeholders.

   With the launch of the second PIA scheme in 2013, Idex was completed by a new tender for projects designed to support sites which, while they cannot pretend to achieve a high overall position in the scientific disciplines, have some strong points that are closely linked to the economic actors in the field.

   With these two instruments, which together account for more than EUR 10 billion in funding, the PIA encourages:

   - structuring: through closer governance of shared strategic projects, taking into account global competition;
   - differentiation: by distinguishing between universities and schools on the basis of the assets of the respective sites, recognising these strengths by awarding selective labels, and encouraging them to focus more directly on the economic activities of their territory;
   - decompartmentalising: between universities, *grandes écoles*, organisations and enterprises, which are often co-founders of new projects for unified universities;
   - openness: by opening up to global competition, thanks to a policy of attracting researchers and establishing partnerships with top foreign institutions.

   For projects already selected, this "championship" policy includes a policy of excellence in research-based training; it also often features an in-depth reform of undergraduate education. The PIA provides substantial long-term funding, in exchange for governance and a strategic project based on excellence that ensure proper use of the resources. The PIA thus reflects a systemic ambition.

2. The PIA has also embarked on several experimental projects designed to test and, where appropriate, demonstrate the viability of innovative pedagogical models.

   With its "scientific and technical culture", "boarding schools of excellence" (for middle and high school students) and "initiatives for excellence in innovative training" (IDEFI) projects, the PIA has created more modest but highly innovative instruments; some time will be needed to assess how far they have succeeded in each case and whether they can be reproduced on a larger scale.

   Small as they are, the IDEFIs could still serve as an important breeding ground for innovation on which the MESR could capitalise in years to come. This kind of large-scale support is the only means of exerting a lasting influence on higher education training.

   The PIA has also funded measures related to apprenticeship.

Conditions for a successful PIA

Within the research and innovation landscape in France as described above, the PIA is the strong but natural follow-up to the reforms initiated some 15 years ago. Its objectives – thematic research orientation, pursuit of excellence, public-private links for innovation and development of entrepreneurship – reflect all the reforms initiated at the time. Yet the PIA ushers in two new dimensions. First, as something that has been created from nothing, it effectively sets up all the institutional mechanisms required for this agenda. Second, it draws on a substantial budget, which potentially gives it a more direct impact on the SFRI than the earlier reforms. The amounts involved certainly need to be considered in relative terms: a large part of the approximately EUR 20 billion allocated to research and innovation is made up of allocated capital, meaning that the amount actually available per year is about EUR 1 billion – some 5% of the public budget allocated to this area. However, it will offer considerable financial leverage, since these funds will mobilise existing resources (researchers, infrastructure) financed under existing budgets. In particular, concentrating funding on "excellent" stakeholders not only boosts their chances of success but may also promote change within the SFRI culture, for even those not initially selected will have an incentive to improve their performance. In this way, the PIA could not only speed up France's convergence towards a new growth path, but also contribute to reforming the SFRI beyond its own scope of action.

Even though the PIA has clear direction and all the necessary resources, its success is not guaranteed. Two major and closely connected difficulties need to be overcome first: the complexity of the mechanism itself and its role in combination with the other components of the SFRI. The PIA has created new programmes and new entities (Idex, etc.). Although the tasks and objectives of each have been clearly identified, the way in which they are co-ordinated is not always properly defined *ex ante*. For example, the tasks of the SATTs and the IRTs overlap to some extent and will prove rather difficult to co-ordinate. An additional issue is that the PIA is actually an addition to the system, rather than a replacement for it; it has created new programmes and new players alongside the existing mechanisms. This means that the efforts of the PIA to simplify the situation will only have an impact if the State and the establishments concerned agree to adjust or remove structures that the projects funded by the PIA are intended gradually to replace (e.g. SATTs vs. transfer services in place) or whose rapprochement it is meant to accelerate (e.g. the Idex initiative of excellence, which is aimed at bringing together certain educational establishments). Otherwise, the PIA will simply be adding to the prevailing complexity and segmentation – especially in relation to the mechanisms established and operated by the PROs – whereas in fact one aspect of the SFRI that the PIA seeks to correct is this segmentation of structures, which creates a kind of "silo" system.

If the PIA is to have its full impact, the reforms initiated must therefore continue: university autonomy at all levels (research and training policy, including during the first cycle, management of human and financial resources); transfer of the management of joint research units to the universities; specific measures to strengthen research universities; groups of universities and *grandes écoles* – these reforms must be taken further so that the recipients of PIA funds can use them to the fullest extent and produce the expected excellence. It is also clear that the programmes designed for businesses at start-up, commercialisation or partnership research stages rely on the French economy becoming increasingly globalised at both the macroeconomic (tax burden on businesses) and microeconomic (obstacles to business growth, labour market) levels. From that point of view, measures such as the "competitiveness agreement" and the "responsibility agreement" are extremely important.

The French research agenda also needs to be clearly defined, which means that the various agendas currently in place or in preparation (the PIA and National Research Strategy (SNR) in particular) must be closely aligned, since the dispersal of resources would remain a problem otherwise. The State cannot afford to pursue several strategies in parallel if they are not properly co-ordinated.

If the PIA is to succeed, further changes will therefore have to be made to the system in order to reform and simplify it. This will require major strategic choices upstream to ensure that the juxtaposition of similar mechanisms does not detract from their overall success. At every stage, existing institutional forms, operations and entities – whether or not linked to the PIA – will need to be assessed and measures taken in line with their performance so as to strengthen those that meet their objectives and re-orient or restructure those that do not.

Failing that, resources will continue to be dispersed and the system will remain complex, rendering the PIA far less effective – hence the importance of both evaluating the system and implementing the findings, which calls for strong political commitment. The importance attached by the CGI to evaluation is a step in the right direction. Co-operation could be established with the HCERES, which evaluates the PROs and the universities implementing the PIA.

Assessing the success of the PIA

The PIA seeks to steer research and innovation in France towards specific objectives and to promote excellence in those fields; it is also an instrument aimed at transforming the SFRI in order to render it more capable of achieving its objectives. In the light of that definition, the success of the PIA is indissociable from the progress of the SFRI, and will therefore be assessed both in terms of direct objectives (thematic successes, global excellence, public-private links, entrepreneurship) and of the indirect objective (transforming the SFRI).

Provided the PIA achieves its objectives, the main features of the SFRI in 2020 could be as follows:

- *Research and higher education:* the balance between recurrent funding and project funding has shifted towards the latter, with projects selected in an open and competitive manner; recurrent funding is concentrated on a few institutions of excellence and on the research infrastructure; France has improved its ranking in excellence (higher impact index, higher number of ERC grant winners, larger share of European funding); France has become more attractive and welcomes many high-level foreign researchers; France has several (five to ten) large, world-class research universities providing an education that meets the highest international standards; the other universities focus on quality education that meets economic and social needs, on research focused on several quality subject areas, and on developing close partnerships within the economic and social fabric.
- *Transfers:* partnership research has become a standard activity of universities and laboratories, whose choices of research areas are guided chiefly by the State (SNR, ANR) and by socio-economic stakeholders, including businesses; intellectual property is commercialised so as to optimise the economic value created; the joint entities (IRTs, ITEs, etc.) make breakthroughs which are then implemented by the participating enterprises.

- *Innovation:* French industry retains its position in high-tech sectors such as aeronautics and space; new sectors based on environmental innovation emerge. The most technology-intensive sectors (automotive, etc.) regain their position by moving upmarket. French industry becomes more R&D-intensive as a result of its restored competitiveness in certain industries (e.g. automotive). The sectors where France currently has the strongest presence (agri-food, services, luxury goods, etc.) broaden their (technological or not) innovation base, making them more competitive. (Although the PIA does not target them directly, improved innovation conditions in France and in particular, relations between universities and business should have an impact on these sectors, which are economically strong and potentially heavy users of innovation).
- *Innovative entrepreneurship:* because capital is more widely available and framework conditions have improved, a greater number of innovative firms – particularly many web-based businesses – experience growth.

The alternative – a failure of the PIA and an end to the reforms – would mean that France maintains at best an intermediate position in research and innovation. This position would most likely worsen gradually, since currently less well-positioned countries – especially emerging countries, like China, which are dynamically catching up with more advanced countries – are carrying out the necessary reforms. The decline would probably be slow, because France has considerable available (human, scientific, technological) capital and a number of institutions are already obeying or moving closer to the new logic, but it would be a decline nonetheless.

Conclusion

With the implementation over the past 15 or so years of a number of major reforms and the formulation of a plan – the PIA – with significant financial clout to back those reforms, the SFRI has clearly improved its capacity to meet the economic and social challenges of today's new technological and global landscape. The system has become more open and flexible. Yet it has come up against some limitations that became increasingly obvious as the French economy became less competitive in the 2000s. When the PIA was established in 2010, the SFRI had already embarked on a change process. However, the fact that the reforms were incomplete and sometimes inconsistent and were not adequately funded tended to reduce the system's capacity to meet its objectives, i.e. to produce radical innovation in cutting-edge fields, together with incremental innovation in other fields – not necessarily based on high technology – where France has a tradition of excellence.

The challenge for 2020 is to finalise the changes to the SFRI, by selecting from among the measures in place those that make the system more open and flexible while removing or re-orienting the others in a bid to simplify France's research and innovation policies and make them more coherent. The pursuit of these objectives under the PIA should effectively accompany the broader economic measures (reduction of public deficits and less tax pressure, establishment of a more flexible and open product market and labour market) that are being taken to make businesses more competitive. That will create the conditions for economic stakeholders to invest more in innovation activities, for new innovative firms to renew the French productive fabric, and for innovation to help satisfy social and environmental needs. The PIA must play its part in providing the necessary policy models and financial base for pursuing this agenda. Conversely, a return to the "old-style" SFRI would ultimately make public investment in research and innovation unproductive, with a direct impact on France's competitive position in 2020.