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# Getting the Balance Right

**Basic Research, Missions and Governance for Horizon 2020**


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# Getting the Balance Right: Basic Research, Missions and Governance for Horizon 2020

## Summary

The question 'What is the right balance between basic and applied research?' is often asked but has no single answer that would be valid at all times and in all places. Rather it depends upon the state of development of an individual economy and the extent to which it comprises science-based versus other kinds of industry. The discussion is made no easier by the politicised nature of the term 'basic research', which can at once mean research dealing with fundamental phenomena and researcher-initiated research. To tackle the question, therefore, this paper addresses both the cognitive and the political or governance dimensions of 'basic research'. Our discussion starts with what we know about the question from the history of science and the research-on-research literature, moves on to look at some examples of how countries make the trade-off and then uses the findings from these to shed light on the composition and governance of Horizon 2020.

*The science lobby and basic research*

Periodically, representatives of the scientific community choose to lobby with the aim of raising the share of funding that goes to basic research. A typical recent example is the 'Aarhus Declaration', which argues that providing more money for the scientific community to spend on 'excellent' basic research is the only way to guarantee the health of the research and higher education system and therefore economic prosperity. It concludes that the scientific community should itself allocate this funding to its members based solely on excellence, without bureaucracy or consideration for societal relevance. There is no empirical evidence that would justify such a claim, which conflates 'basic research' as a cognitive category or type of research with 'basic research' as a style of research governance.

More generally, however, we depend upon the scientific community to distribute basic research funding through organisations such as research councils. This is based on its ability to make judgements of scientific quality. Between the Second World War and the 1960s-70s, the 'social contract' between the scientific community and society left a lot of control in the hands of that community. Since then, there have been increasing demands from society for a more explicit return on its scientific investment. Compromises have emerged in which the 'excellence' style is used to govern some of the national research effort while the balance is thematically programmed towards

societal needs (sometimes referred to as 'missions'). Two governance styles therefore co-exist, usually in separate organisations. Both actually fund basic research and while the researcher-governed channels tend to pay for a much higher proportion of fundamental work, there is generally also a lot of fundamental work done in support of societal missions.

Scientists often disagree about what 'basic research' is, as a type of activity. Generally, it is seen as relating to fundamental phenomena and often it is linked to the idea of curiosity-driven research – to such an extent that the statistical definition is that research is basic research if the scientist doing it cannot specify how it would be applied. This has the paradoxical implication that the same experiment done by two scientists can at once be basic and applied, providing only one of them knows why she or he is doing it. In reality, large amonts of 'basic' research are done with pretty clear ideas about purpose: Pasteur, for example did his work on food safety in order to protect human health – his basic research was not just driven by curiosity.

In theory, the more fundamental research is, the less willing industry will be to fund it, because it is hard to appropriate and monopolise the results. Hence, the state steps in and pays for most of the cost of basic research. When things are more applied, industry funds a growing share of the cost. As more and more research-capable people work in various parts of the economy, so an increasing proportion of research is done in industry, typically in order to solve problems. Some of this is actually basic research, in the sense of being fundamental. In practice, industry does basic research in areas where it sees opportunities to get a return on investment, even if that is only a small part of the total returns on the research.

*How research relates to innovation*

Discussion of the relationship between science or research and innovation is bedevilled by mythology and bad history. In the popular imagination, science leads to the development of technology. Historically, however, technology has tended to encourage the emergence of science. Some like to debate whether basic or applied research has more impact. The evidence is that both have societal impacts, but on different timescales and across much longer periods than one would imagine (or, indeed, than policymakers who have to argue for research funding would like).

In terms of economic and social development, the key issue is not necessarily the distinction between basic and applied work but the separation of innovation and research activities from production. We can think of this separation occurring in history through two stages: first, a separation of the innovation function from production through the creation of specialised design, engineering, machine building and technology functions whose business is to improve production but not themselves to do production;

second, the development of fields of science that shed further light on innovation opportunities but that operate at a much higher level of generality. Once both the specialised technology and the more generic science systems are in place, it becomes increasingly difficult to untangle their roles in industrial and societal progress – they are both involved. However, it is clear that **new** scientific ideas have no market or societal impact unless and until they are coupled to users and their needs. The stock of **existing** knowledge remains immensely important in innovation.

The 'science tribe' argues that good science is done without reference to potential application. The corollary that relevant science is bad science does not hold water, empirically. The research-on-research literature contains large numbers of studies that show complementarities between scientific publication, patenting, contract research and consulting in relevant fields. Academics who co-operate with industry tend to do better than their colleagues on conventional measures of academic quality and productivity.

Once we look at the respective impacts of basic and applied research, it becomes clear that both are important. It can often take longer for the societal impacts of basic research to become visible than those of applied research but basic research is connected to use by applied activities – whether they take place in specialised research organisations like institutes and universities or within companies. Generally, the timescales involved are very long – decades, rather than the short periods within which politicians and policymakers prefer to see the results of their actions.

*Basic and applied research at the national level*

If we look at research at the level of national R&D statistics, we see some suggestive shifts in the relative importance of basic research, applied research and development. At the overall level, there is a clear pattern that richer countries spend more of their GDP on R&D than poorer ones. This relationship is complex: many other factors such as resource endowments affect GDP and efforts to identify short-term relationships between growth in R&D and growth in GDP have not been successful. There is also a relationship between the proportion of GDP spent on R&D in the business sector and in the higher education sector. In general, the mix between state and business spending on R&D changes during the process of economic development. Typically, the state is the dominant spender in poorer countries and the share of total spending coming from business increases, as countries get richer. It seems that there is an 'entry ticket' countries need to pay in the form of a higher education sector that provides the human capital needed to do R&D in both the state and in business. As business R&D grows, so the higher education sector must grow (albeit at a slower rate) in order to keep up the supply of people. Inherently, the higher education sector tends to do basic research, thus as the business R&D effort increases, so does the amount of basic research done. This may not mean that the **proportion** of basic research done in the economy grows – for example, in China this has stuck obstinately at around 5% through the past quarter century of extremely rapid growth in the R&D system.

However, there is a second pattern, which is that during the process of development countries play catch-up, putting a lot of effort into applied as well as basic research in order to acquire and apply knowledge. As they approach the 'frontier' in technology and science, they need increasingly to generate new and sophisticated solutions so the share of basic research tends to go up. The broader trend towards technology becoming more science-intensive probably reinforces this shift towards the basic. The pattern of overall and government R&D activity in highly successful innovating countries, however, shows that it is important to do the development work needed for innovation. Here Europe is well behind the leaders.

The bulk of governments' own R&D spending goes to fund particular missions – only a small fraction is spent on researcher-initiated projects through research councils or similar organisations. However, a lot of basic research is actually done within mission-driven research programmes that aim to meet specific societal needs. The successful US and Chinese examples show the importance of coupling research capacity and activity to these missions.

The numbers therefore tend to confirm the interdependence of the basic and applied parts of the research system. To secure growth and development, it is crucial that the business R&D system expand so that the nation is strong in innovation – and this naturally drives an expansion in higher education and basic research, though at a lower rate. There needs to be significant investment in development-based innovation activities in both industry and the state. Basic research funding needs not only to come from researcher-directed sources but also to be embedded in thematically programmed missions. The real policy choice is not therefore about the balance between basic and applied research but about the extent to which these are pursued using a bottom-up or a programmed style of governance.

*The Framework Programme and Horizon 2020*

There has for some time been a discussion of a 'European paradox', where it is claimed that Europe does a lot of basic research but fails to get value from it in terms of innovation and economic success. Of course, this is only a paradox to those who believe innovation is driven by basic research. A more current and systemic view would emphasise the need for the parts of the system that actually do innovation and production to be healthy and well functioning, with high levels of business R&D, strong state R&D investment in industrial and societal missions and high participation in higher education. Nor, in fact, is EU R&D as good as we like to imagine. In particular, EU scientists are significantly less well represented in the 10% of the most highly cited scientific publications than their US counterparts, though they do quite well compared with the rest of the world. Horizon 2020 is positioned to tackle these challenges not only of research quality but especially of weaknesses in the innovation-orientated part of the European research and innovation system. Horizon 2020 has three 'pillars': Industrial Leadership; Societal Challenges; and Excellent Science.

Historically, the Framework Programme – which Horizon 2020 will replace – has many successes in strengthening research and innovation networks in Europe. In the past it has funded missions that largely correspond to the industrial and societal pillars of Horizon 2020, generating advances in both research and industry. It has been a strong force coordinating and consolidating the European R&D effort and communities. The recent addition of the European Research Council (ERC) to the Framework Programme means it now also funds individual researcher-initiated projects as well as mission-orientated networks. It brings a new style of governance to the Framework Programme, using project-level priority setting with the aid of the scientific community in addition to the traditional style of stakeholder-driven programming. The ERC seems to have had a large and positive influence on national research councils' quality standards and proposal review processes, so it is exerting a strong leverage over the European 'basic' research funding system as a whole.

An important novelty of Horizon 2020 is the 'downstream' extension of its remit to strengthen innovation processes at the European level. This cannot mean that it will 'take to market' ideas developed in more research-orientated parts of the programme. Rather, it must tackle innovation needs case by case, on their merits, so as to improve the infrastructures and framework conditions necessary to improve European innovation performance. While this part of Horizon 2020 will also 'leverage' Member States' activities and assets, it also requires significant expenditures at the European level.

The diagnosis of European needs in this paper and those that underlie Horizon 2020 are similar: while the quality of research also needs to be improved, the key weaknesses of the European research and innovation system are in innovation activities. Doing more science will not repair those weaknesses. Rather, there is a need to expand mission-driven R&D for tackling industrial and societal needs. The ERC seems already to be doing a good job of encouraging quality improvements, in partnership with national research councils. The implications for Horizon 2020 are clear.

- Focus resource increases on the innovation-relevant parts of the industrial and societal missions
- Continue to fund a mixture of basic and applied research within those missions, but increase the effort on development and related functions

- Maintain but do not increase the ERC effort; instead work in cooperation with national research councils to leverage the European level so as to raise national as well as European quality levels

Not least because Horizon 2020 involves setting thematic priorities, it is important that the Member States complement it with clear national strategies. The point of Horizon 2020 is partly to 'optimise' the European research and innovation system at the European level. Member States therefore need to ensure that their own policies complement the European strategy in ways that serve the national interest. In many cases, this will involve setting priorities that are not the same as the overall European ones.

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# 1. About this paper

This document presents the results of a short study undertaken on behalf of EARTO. It is intended partly as a contribution to the debate about how national governments should fund R&D but especially about to how to think about R&D funding at the level of the European Union, where we discuss aspects of implementing Horizon 2020[1] – the set of EU-level research and innovation activities that will follow on from the Framework Programmes in Research and Technological Development that have run since the mid-1980s.

The question 'what is the right balance of funding between basic and applied research?' is often asked. We can say something about this at particular places and times, but the question has no absolute or permanent answer. There is no theoretical basis for saying what such a balance should be. Rather, what we know about national research and innovation systems suggests that if there is such a thing as an ideal balance it will be context-dependent and will therefore change over time in any particular innovation system. The question is further complicated by the fact that there are multiple definitions of its terms – especially of 'basic' research, which has some cognitive meanings but also has meanings that relate to politics and governance. In terms of their cognitive meanings, it is clear that a well-functioning research and innovation system needs both applied and basic research. In the more political sense, where 'basic research' tends to mean 'research whose funding is governed by the scientific community' (for example, through research councils), it is clear that such researcher-governed research is also important but cannot alone be the whole story.

Here, we argue that a more useful distinction is between general research intended to maintain national capability in a wide range of basic and applied disciplines and more specific research aiming to support the knowledge needs of stakeholders such as industry and the public service. These imply different governance mechanisms. In the last part of the paper, we analyse Horizon 2020 and use this distinction as a basis for discussing the desirable balance of effort within it. We argue that the key contribution of Horizon 2020 will be to 'structure' the development of the European research and innovation system through actions at the European level that 'leverage' Member State efforts while respecting the principle of subsidiarity.

[1] Throughout this paper we deliberately omit Euratom from the discussion and from budget statistics. Euratom has a different intervention logic and trajectory from the larger Framework Programmes on research and technological development and the equivalent part of Horizon 2020

Europe's global role is changing as large, hitherto 'developing' countries move centre stage in global production and research. This is no reason for Europe to be marginalised; rather, it represents a challenge for Europe to build on its historic strengths to continue to be a cornerstone and to contribute to the sustainability of a much larger and wealthier global economy. Horizon 2020 – the successor to the long-running EU Framework Programme – represents an important policy reform, bringing more closely together industrial innovation, research and tackling societal 'grand challenges' in an effort to strengthen the competitiveness and sustainability of European research, industry and society. It offers the opportunity to reduce the past fragmentation of the EU effort and build a more balanced research and innovation system in Europe, overcoming some of the well-known bottlenecks in the system such as the so-called 'European Paradox' and the fragmentation of the research community and institutions.

# 2. The science lobby and basic research

Research and innovation policy spans the interest on the one hand of the scientific research community in pursuing its own agendas and on the other the needs of other societal stakeholders for knowledge to solve problems in innovation and more widely in society. These two communities often act – certainly when they lobby for resources – as 'two tribes' with different cultures, values and goals. Institutionally, we can see this in the traditional battle between education and industry ministries in most countries, which often boils down to a fight for budget. In policy debate, we see it in the frequent refusal of the scientific community to recognise any other criterion than 'excellence' by which to judge research. Conflating the types of research with the mechanisms used to fund them normally complicates the argument. Scientific tribe members tend to like to use agencies ('research councils') like the ERC that they themselves govern and where all members of the republic of science are free to make proposals on any subject they like from which their scientific peers select the most excellent. Such researcher-initiated, 'curiosity-driven' research tends to be described as 'basic' – even though in fact some of it is applied and there are many other mission-orientated channels that fund research that is fundamental in nature.

In this Chapter, we first draw attention to a repeating pattern in which the 'basic research' community lobbies for resources, either without considering the systemic role of basic research or by asserting that basic research is all that matters. Next we discuss the cognitive meaning of 'basic research' and point out that to conflate the cognitive and governance meanings of 'basic research' is illegitimate. We explain that the terms of the social contract between science and society have been shifting against the 'basic research' community – a possible explanation for its continuing need to lobby for resources. Finally, we consider strengths and weaknesses of mission-driven versus researcher-driven research funding and draw conclusions.

## 2.1 Renewed demands and claims

Periodically, the argument is proposed (more or less seriously) that policy should re-focus on funding excellent basic research and that given such funding the rest of the research and innovation system will pretty much take care of itself. There have been extreme variants of this argument – such as the proposal in a Swedish Green Paper in 1998[2] to stop funding innovation and to

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[2] Slutbetänkande av Kommittén för översyn av den svenska forskningspolitiken (Forskning 2000), Stockholm, 1998 - Final report of the Committee to Review Swedish Research Policy (Research 2000)

give all the money to the universities – an idea with which the government flirted for a while but then rejected.

The UK Royal Society[3] (in effect, the UK's academy of science) recently produced a more balanced argument in favour of basic research funding as an attempt to head off likely funding cuts in the wake of the financial crisis. It places basic research in the context of innovation and competitiveness but even this assumes rather than explains a link from basic research to competitiveness.

More frequently, the applied research and innovation side of the coin is simply ignored and an argument is laid out for increasing money for basic/excellent research. A conspicuous recent European example is the 'Aarhus Declaration' at a conference organised in connection with the Danish EU Presidency with the apparent purpose of influencing the development of research funding policy at the European level, specifically in Horizon 2020.

The Excellence 2012 conference declared

> *It is essential that Europe strengthens its science base, with excellence as the guiding principle. In order to be recognised as an attractive partner and a competitive area for research, innovation and higher education in a global knowledge-based economy.*

To achieve this, the declaration goes on to say that it is necessary to use unbureaucratic, non-thematic instruments and let the very best researchers evolve and pursue the research ideas they are most intrigued by. Europe should be the scene for scientific breakthroughs that open up for unforeseen opportunities for humankind. Research excellence has, time and again, changed our lives and our thinking. Excellence remains essential to the future of Europe. Excellence is the essential foundation that secures the development and availability of human capital to meet the needs of the future[4].

Such claims by the basic research lobby have traditionally been founded on two ideas.

> *First, there was a linear assembly line model of innovation (basic research leading to applied research leading to product development). It is commonly attributed to Vannevar Bush, though it is also a somewhat distorted picture of his real views. Second, there was the idea of the unpredictability of the eventual applied spin-offs from basic research. Taken together, these two*

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[3] Royal Society, *The Scientific Century: Securing Our Future Prosperity*, London: Royal Society, 2010

[4] *The Aarhus Declaration: Investing in Excellence – Preparing for Tomorrow*, University of Aarhus, 2012

> *notions justified governmental support of basic research without an initial evaluation of its potential societal benefits. If basic research is the fountainhead of societal innovation, and if it is unpredictable which basic research will lead when to what (if any) societal benefits, a wide array of basic science projects … should be sponsored without initial regard for applicability.*[5]

Rejecting any consideration of impacts in research funding effectively means rejecting any sort of thematic prioritisation, leaving quality or 'excellence' as the only usable funding criterion. Thus Helga Nowotny (President of the European Research Council – ERC) roundly rejected the idea of imposing an 'impact' agenda on the ERC at its recent fifth anniversary conference. She admitted that this approach created an "inherent tension" with "the demands of policymakers for practical innovation, seen as the undisputed motor of...economic growth ... One answer is to target resources...to look to strategic sectors, to put science to work on the most pressing problems ... But frontier science does not work like this. We cannot programme scientific breakthroughs or order them from a menu... We can't foresee the consequences of what we discover."[6]

While, as we go on to show, these one-sided 'pitches' for basic research fly in the face of many years of research policy research and rely on the long-discredited idea of a linear relationship from basic research to societal impact, they reappear frequently. Basic research does indeed play a lot of important roles in the national research and innovation system. Understanding these is key to a more balanced and holistic research policy. However, understanding the needed role of 'basic research' in the mix of research funding is hard because (a) cognitively the term has many meanings and is often used in a variety of imprecise ways while (b) it has highly politicised meanings in the governance and funding of science.

## 2.2 Understanding 'basic' research in cognitive terms

In terms of a cognitive definition, we are used to distinguishing between three components of R&D

- Fundamental research: work undertaken primarily for the advancement of scientific knowledge, without a specific practical application in view
- Applied research: work undertaken primarily for the advancement of scientific knowledge, with a specific practical aim in view

[5] Lewis Branscomb, Gerald Holton and Gerhard Sonnert, Science for Society: Cutting-edge basic research in the service of public objectives: A blueprint for an intellectually bold and socially beneficial science policy, Report on the November 2000 Conference on Basic Research in the Service of Public Objectives, available at http://www.cspo.org/products/reports/scienceforsociety.pdf

[6] *Times Higher Education Supplement (THES)*, 8 March 2012

- Development: the use of the results of fundamental and applied research directed to the introduction of useful materials, devices, products, systems and processes, or the improvement of existing ones[7]

This is the definition the OECD uses for the collection of international R&D statistics. The distinction between fundamental and applied research is quite odd. It literally means that the same piece of research can be applied if the researcher knows why she or he is doing it and fundamental if not. These days the OECD tends to refer to 'basic' rather than 'fundamental' research but the meaning is the same. Godin, not unreasonably, argues that the idea of 'basic' research would have been dropped as incoherent a long time ago were it not for the fact that most of the developed world is committed to collecting statistics about it[8].

Alternative definitions have been attempted. One recurring idea is that basic research produces knowledge that is **general**. Applied research is needed in order to build on that knowledge in ways that make it ready to apply it to particular situations, such as the development of a specific product[9].

One powerful (but unresearched) idea is that progress in fundamental research opens up new territory within which applied researchers and innovators can then create value. Some, like Geim who recently shared the Nobel Prize for research on graphene, argue[10] that over the longer term slowing the rate of investment in basic research will reduce the rate of innovation and therefore economic development and growth, as the economic potential of the new 'seam' of knowledge is gradually worked out.

Research on the nature of 'basic research' shows that the concept means different things in different sciences and to different actors. Nonetheless, the idea of basic research is meaningful to the bulk of the scientific community. In a rare study of the subject, Calvert and Martin interviewed 49 UK and US researchers to explore how they meant and used the term. Figure 1 summarises the responses.

Two-thirds of the researchers went along with the definition based on intent but as many thought there was something specific about the character of the knowledge that distinguished it from other research, ie that it in some ways

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[7] Organisation for Economic Cooperation and Development, *The Measurement of Scientific and Technical Activities: Proposed Standard Practice for Surveys of Research and Development* (Frascati Manual), DAS/PD/62.47, Paris: OECD, 1962

[8] Benoît Godin, 'Measuring science: is there "Basic Research" without statistics?' *Social Science Information*, 42 (1), 57-90

[9] Keith Pavitt, 'What makes basic research economically useful?' *Research Policy*, 20, 1991, 109-119; Mario di Marchi and Giovanni Napolitano, 'Some revised definitions of Aplied Research and Experimental Development', *Science and Public Plicy*, 20 (4), 1993, 281-284

[10] *Financial Times,* 5 January, 2012

provides foundations for other kinds of knowledge. One third of the researchers emphasised distance from application as a defining characteristic. Three essentially regarded only physics as basic research, perhaps harking back to the logical positivist school of philosophy of 100 years ago, which maintained that all knowledge is reducible to physics. For them, the existence of 'sciences of the artificial'[11] such as information theory that describe fundamental phenomena in artefacts that do not exist in nature (e.g. computers) would presumably pose a problem.

Figure 1 Researchers' Definitions of 'Basic Research'

| Criteria for distinction | No. interviewees |
|---|---|
| Epistemological | 33 |
| Intentional | 32 |
| Distance from application | 15 |
| Institutional | 8 |
| Disclosure norms | 7 |
| Scientific field | 3 |

**Note:** Total number of interviewees = 49
**Source**: Jane Calvert and Ben Martin, *Changing Conceptions of Basic Research?* Background Document for the Workshop on Policy Relevance ad Measurement of Basic Research, Oslo 29-30 October 2001, Sussex University: SPRU, 2001

"Basic science"— curiosity-driven research without regard to applicability — usually carries a higher prestige than "applied science"; and even a certain snobbery of the basic toward the applied scientist can sometimes be observed[12]. The argument appears, for example, in the evaluation of Finnish participation in the Fifth Framework Programme, with sections of the scientific community effectively arguing that the FP is low quality **because** it tends not to involved basic research[13].

Stokes has shown that a lot of what we commonly call 'basic' research is not 'blue skies' or curiosity driven but is rather pursued with the explicit aim of solving problems (Figure 2). He cites Niels Bohr as a leading and productive example of pure, curiosity-driven research. Bohr's Quadrant is important, both because curiosity about fundamental things has a cultural value and because it often turns out to produce useful results as well. And it is certainly a good training school, as the wealth of socially and economically useful work that physicists do in other fields amply illustrates.[14] Stokes is a bit derisive about Edison's Quadrant – pure applied research – saying that Edison

[11] Herbert A Simon, *The Sciences of the Artificial*, 3rd edition, MIT Press, 1996

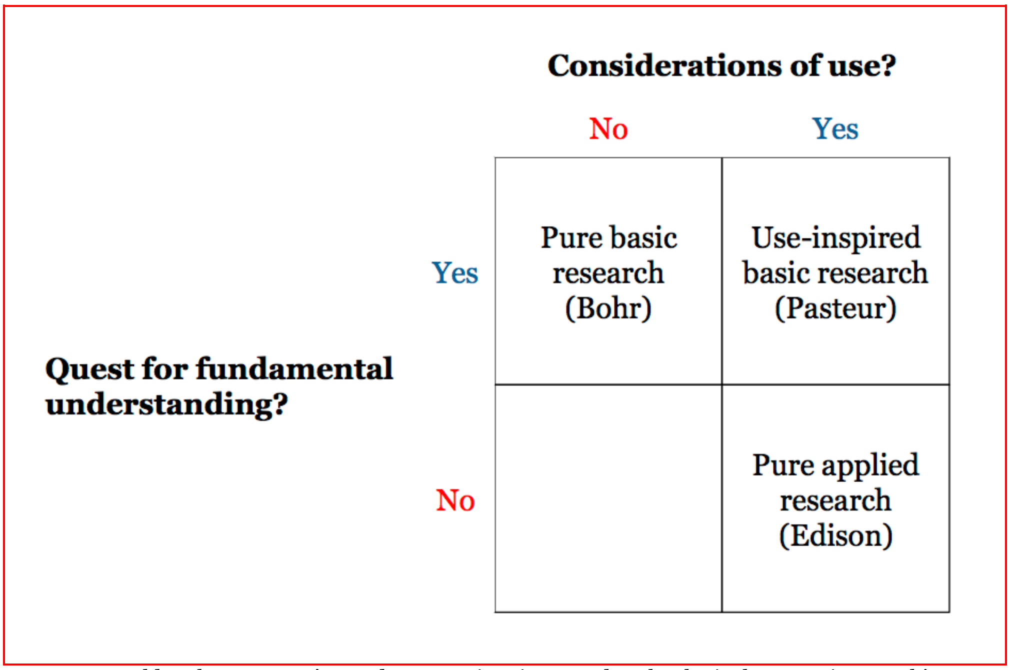
[12] JD Bernal, *The Social Function of Science,* Cambridge, MA: MIT Press, 1967, first published 1939

[13] Pirjo Niskanen, *Finnish Universities and the EU Framework Programme – Towards a New Phase*, VTT Technology Studies, Helsinki: VTT, 2001

[14] Keith Sequeira and Ben Martin, *Physics and Industry*, Brighton: SPRU, 1996

ruthlessly avoided fundamental explanations of scientific phenomena, focusing always on invention based on the existing state of scientific knowledge. Yet this is where the bulk of industrial R&D lives. While the basic research community likes to equate 'basic' with 'blue skies' or 'curiosity-driven' research, Stokes' important contribution is to remind us of 'Pasteur's Quadrant' – use-inspired basic research – which has huge economic and scientific importance. He argues that very large amounts of 'basic' research properly belong in this quadrant rather than Bohr's.

Figure 2 Sources of Research Inspiration

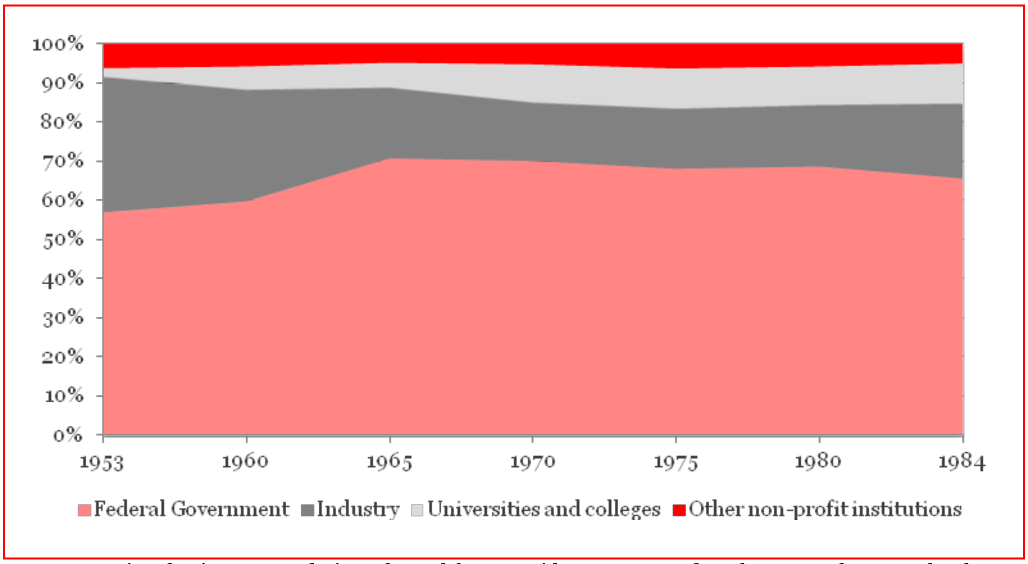



**Source**: Donald Stokes, *Pasteur's Quadrant: Basic Science and Technological Innovation*, Washington DC: The Brookings Institution, 1997

In economic terms, knowledge is a 'non-rival' good – meaning that many people can consume it at the same time. Most goods, for example cake, are 'rival'. If I eat the cake, then you cannot. Knowledge is one of the special cases where you **can** have your cake and eat it, too. Knowledge is also 'non-excludable' – it is hard to stop people getting access to it. Non-excludable, non-rival goods are 'public goods'. In economic theory, the results of basic research are such public goods (though there are also other categories of public goods). In theory the market cannot produce these, so since we need them the state must pay. Thus, basic research in universities is fully funded while work intended to lead more directly to industrial applications is typically funded privately, or may be cost-shared between the state and industry when risks and potential spillovers are high.

We could on this basis propose a definition of basic research as 'research that industry will not fund'. One of the problems with this approach is that industry has historically shown that it **will** fund an amount of research that is basic (in the sense of being general, far from application and hard to appropriate) when that is the only way to solve a particular problem or when there appears to be a good chance of appropriating **enough** of the benefits to justify the investment – for example through first-mover advantage rather than more permanently monopolising research results[15]. OECD statistics suggest that basic research formed some 3% of company R&D activities in the late 1980s and had risen to about 5% by 2009.

Figure 3 Funding of Basic Research, USA, 1953 – 1984




**Source**: National Science Foundation, charted from David C Mowery and Nathan Rosenberg, *Technology and the Pursuit of Economic Growth*, Cambridge, Mass: Cambridge University Press, 1989

US data suggest that basic research may have made up a greater proportion of industry R&D in an earlier period. A survey of US R&D performing companies in 1951 found that they spent 8% of their internal R&D budget on basic research[16]. Figure 3 shows that in terms of basic research **funding**, industry's contribution was even higher in the past. Historically, at least in the USA, industry performed a very significant proportion of basic research – it is only in more recent times that this has tended to become the preserve of the universities.

The related issue is not only **who** makes knowledge, but also **how** they do so – and in particular how the production process is governed. Gibbons and colleagues[17] have brought together a lot of thinking about this in a distinction

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15 Nathan Rosenberg, 'Why do firms do basic research (with their own money)?' *Research Policy*, 19 (2), 1990, 165-174

16 RN Anthony, *Selected Operating Data: Industrial Research Laboratories*, Harvard Business School, Division of Research, 1951; cited from Benoît Godin, 'Research and development: how the "D" got into R&D', *Science and public Policy*, 33 (1), 2006, 59-76

17 Michael Gibbons, Camilla Limoges, Helga Nowotny, Schwartzman, S., Scott P. and Trow, M., *The New Production of Knowledge*, London: Sage, 1994

between the two modes of knowledge production shown in Figure 4. This is a simplification of a complex reality, but one that gives us some useful concepts for tackling policy and research administration.

Figure 4 Mode 1 and Mode 2 Knowledge Production

| Mode 1 | Mode 2 |
|---|---|
| Problems set and solved in the context of the (academic) concerns of the research community | Problems set and solved in the context of application |
| Disciplinary | Transdisciplinary |
| Homogeneous | Heterogeneous |
| Hierarchical, tending to preserve existing forms of organisation | Heterarchical, involving more transient forms of organisation |
| Internal quality control | Quality control is more socially accountable |

Mode 1 (Figure 4) is disciplinary science, and can often be basic science, though applied science can be done in Mode 1, too. Its logic comes from its internal organisation and control mechanisms. Its institutions tend to be centralised and stable. In terms of education, Mode 1 tends to provide 'basic training' and a disciplinary 'entry ticket' (such as a PhD) for people to qualify as credible researchers in either Mode. However, Mode 1 is not the same as 'basic science.' Research that is in some sense fundamental or long-term can be done in either Mode.

Mode 2 includes not only the practice of applied science in universities and other research institutions but also the generation of research-based knowledge elsewhere in society. Mode 2 work tends to be transient. It forms and re-forms around applications problems. Calling on different disciplines and locations at different times, it is hard to centralise. Since Mode 2 work is performed in an applied, social context, it is normally subject to social and economic evaluation, and not solely to traditional quality reviews by scientific peers. To the occasional irritation of those used to the Mode 1 tradition, this means that relatively frequent evaluation – in part by non-scientists – is normal in Mode 2 work, and has become part of the new social contract between scientific researchers and society.[18]

The sharp distinction between Mode 1 and 2 can make it seem as if they are alternatives. Many researchers, however, do both, so they take closely related research problems to different research agencies to ask for funding. Thus, coordination between theory- and problem-driven research often takes place at the level of researchers and research groups. Gibbons and colleagues also get their history wrong, claiming that Mode 2 is new. In fact, it is Mode 1 that

18 Ben Martin, Ammon Salter et al, The Relationship Between Publicly Funded Basic Research and Economic Performance, report to HM Treasury, Brighton: *Science Policy Research Unit*, 1996

is historically new, while Mode 2 is the traditional form of science, as practised for many hundreds of years[19].

## 2.3 Defining 'basic research' in governance terms

'Basic research' in the governance sense is important (a) because it connects to the idea of academic freedom and (b) because it relates to who steers the allocation of resources and therefore the ability of the individual researcher to follow her or his personal research trajectory.

The right of academics to say things unpalatable to church and government involves a battle going back hundreds of years that is well beyond the scope of this paper. However, in the European university tradition, the emergence of 'Humboldtian' universities in the early nineteenth century marked the legitimisation of the role of universities in research as well as in teaching and the principle that university teachers' academic freedom consists not only in saying what they want but also in researching what they want. As long as research was cheap and could be done without external funding, this was not very contentious and the scope of university research could be increased through patronage. Alexander von Humboldt himself was a man of considerable independent means who paid for most of his research expeditions out of his own pocket.

Societal influence over the direction of university research began to be applied in the nineteenth century through the innovation of 'land-grant colleges' in the USA, where the state granted land to build universities for agriculture, engineering and technology[20]. In this parallel tradition research was highly influenced by societal needs and was later driven in other mission-orientated directions by external state funding[21]. In 1939, JD Bernal famously moved this idea of societal influence over science from the descriptive to the **normative**, proposing that governments should use science for social ends through selectively funding some areas but not others[22].

Vannevar Bush's 1945 report *Science, the Endless Frontier*[23] was an explicit rejection of the Bernalian view. Bush – himself one of the architects of nuclear weapons – was a member of a generation of scientists that was horrified by the recruitment of science into the military service of society and who wanted to pull back from the societal role of science – whether as fascist science, socialist

[19] Benoit Godin, Writing performative history: the new new Atlantis?, *Social Studies of Science*, vol 28, 1998, pp 465–483

[20] David Noble, *America by Design*, OUP, 1979

[21] David Mowery and Nathan Rosenberg, *Technology and the Pursuit of Economic Growth*, Cambridge, Mass: Cambridge University Press, 1989

[22] JD Bernal, *The Social Foundations of Science*, London: RKP, 1939

[23] Vannevar Bush, *Science, the endless frontier: a report to the president on a program for postwar scientific research* National Science Foundation, 1945.

science or science in the service of the Allies in World War II. Bush's report proposed not only to create a new funding institution for research but that members of the community appointed by the President – not those responsible for societal missions such as health or defence –should govern that institution, arguing that "Scientific progress on a broad front results from the free play of free intellects, working on subjects of their own choice, in the manner dictated by their curiosity for exploration of the unknown. Freedom of inquiry must be preserved under any plan for Government support of science." His manifesto for post-war science was **basic** science and he argued that increasing science funding would automatically increase product and process innovation and therefore national competitiveness as well as military preparedness. It seems odd to those of us who have lived with the term all our lives, but the idea of 'basic research' is therefore a rather new construct – "a rhetorical creation on the part of scientists anxious to justify their social position."[24]

For five years after Vannevar Bush delivered his report to the President, there was debate about how to fund research. Bush wanted most government-funded research to be financed through a researcher-governed organisation but one by one the main 'missions' of government were taken out of the discussion. Finally, the National Science Foundation was created to fund researcher-initiated research under a system of governance 'owned' by the scientific community. Most Western countries had and still have similar 'research council' arrangements in parallel with mechanisms to fund 'mission' orientated research. These institutions channel only a small proportion of total government spending on R&D but they are in practice controlled to a large degree by the scientific community.

What emerged in the post-war years was a 'social contract' that gave the scientific community a high degree of control in running the 'basic' science funding system, bolstered by the 'linear model' idea that there was an automatic connection between doing basic, researcher-initiated research and social and economic welfare, just as Bush claimed. The essence of that social contract was that "The political community agrees to provide resources to the scientific community and to allow the scientific community to retain its decision-making mechanisms and in turn expects forthcoming but unspecified benefits."[25] To some degree, this social contract is forced upon the political community because it lacks the skills and knowledge needed to manage the details of science. Instead it hands over that management to the scientific community, despite the problems inherent in such a 'principal-agent'

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[24] Michael Gibbons, Camilla Limoges, Helga Nowotny, Schwartzman, S., Scott P. and Trow, M., *The New Production of Knowledge*, London: Sage, 1994

[25] DH Guston, *Between Politics and Science: Assuring the Integrity and Productivity of Research*, Cambridge University Press, 2000

relationship where the principal lacks the ability to test the agent's honesty and effectiveness[26]. The degree to which the scientific community formally governs basic research funders varies. In Sweden, the research community elects the majority of the governing board members. In most other countries the control is less overt than this but the scientific community nonetheless makes most if not all of the specific funding allocation decisions.

During the 1960s and the 1970s, there grew up once again a more active desire to harness science – and especially technology – to societal needs, leading to the creation of innovation agencies, innovation-focused industry policies and other new ideas such as *grands projets* aiming to shift control more towards society. The OECD was instrumental in establishing the legitimacy of what it called 'science policy'. In 1963, a working group led by Christopher Freeman (a great admirer of JD Bernal and who later founded the Science Policy Research Unit at Sussex University and introduced the idea of 'national systems of innovation') produced the Frascati Manual[27], which defined how to collect R&D statistics. The same year, the OECD organised the first international meeting of ministers of science and two years later it established a committee and an internal department for science policy, led by Jean-Jacques Salomon, which promoted the idea of a 'technology gap' between the USA and the rest of the world, which justified the need for science policy. The 'OECD line' came to be that

1. Research should help reach national, politically-determined goals
2. Research should be planned and organised to that end
3. Research should be more interdisciplinary, in order to solve real-world problems
4. The universities were rigid, organised by discipline and unable to change themselves. They should be 'reorganised' in order to contribute more to the solution of societal problems and to reach national goals[28]

The increased state R&D budgets had high mission content and new terminologies such as 'strategic research'[29] and 'targeted research'[30] began to emerge. The continued roll-out of the 'new public management' has arguably

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[26] D Braun, 'Lasting tensions in research policymaking– a delegation problem,' *Science and Public Policy*, 30 (5) 2003, 309-321; B van der Meulen, 'Science policies as principal-agent games: Institutionalisation and path dependency in the relation between government and science, ' *Research Policy* 27 (4), 1998, 397-414

[27] *Proposed Standard Practice for Surveys of Research and Development*, Paris: OECD, 1963

[28] Edgeir Benum, 'Et nytt forskningspolitisk regime? Grunnforskningen, OECD og Norge 1965-72', *Historisk tidsskrift*, 86 (4), 2007, 551-574

[29] J Irvine and BR Martin, *Foresight in Science: Picking the Winners*, London: Frances Pinter: 1984; Arie Rip, 'Strategic research, post-modern universities and research training,' *Higher Education Policy*, 17 (2) 2004, 153-066

[30] A Elzinga, 'The science-society contract in historical transformation: with special reference to 'epistemic drift',' *Social Science Information*, 36 (3) 1997, 411-455

reinforced the trend for this drift to continue[31], noticeably through the introduction of 'performance-based research funding systems'[32] that count scientific and non-scientific research outputs and towards new funding practices among UK research councils that ask researchers to **predict** (and in the Research Excellence Framework to **demonstrate)** the societal impact of their work. In short, the terms of the social contract have shifted sharply against the 'basic research' community's traditional values. Unsurprisingly, that community is largely not in favour of this development.

This shift in the social contract is likely to be one of the reasons that – when the mission-orientated and traditional scientific communities interact, and certainly when they lobby for resources – they can appear as 'two tribes' with different cultures, values and goals. The position of the 'basic research tribe', however, is not only built on its desire to govern research funding but also touches on the older, raw nerve of academic freedom.

While Sweden is one of the places where the battle between the two tribes is noisiest, it is also the place where the need for all the different styles was most clearly and early recognised, when a new innovation agency (Styrelsen för Teknisk Utveckling – STU) was set up in 1968 to act as a 'change agent' and combat the stagnation in national research identified by the OECD review of Swedish science policy in 1964. STU came to argue that Sweden needed the conventional research councils to fund bottom-up research and to foster excellence across a very wide range of disciplines in order to keep the university teachers current, make sure the foreigners could not fool the Swedes, and to ensure that any field that proved promising could quickly be expanded, based on the human capital already in place. This it called 'Programme 2'. STU saw its own role as 'Programme 1': funding research activity in the parts of the system that underpinned industrial and other societal needs – connecting non-academic actors like the major Swedish companies with the academic research community and making sure that enough knowledge and people were generated in the areas of contact between the scientific and other societal systems. Note that the idea of 'basic research' was not part of the discussion: the research to be done was the research that was needed, irrespective of its nature.

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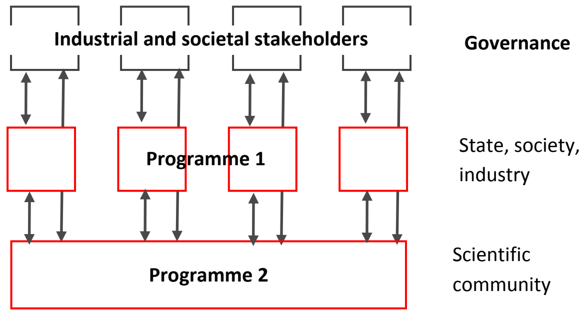
[31] Laurens K Hessels, Harro van Lente and Ruud Smits, 'In search of relevance: the changing contract between science and society,' *Science and Public Policy*, 36 (5) 2009, 387-401

[32] Katherine Barker, 'The UK Research Assessment Exercise: the evolution of a national research evaluation system,' *Research Evaluation* 16 (1) 2007 3-12; OECD 2011; Diana Hicks, 'Performance based university research funding systems', *Research Policy*, 41 (4) 2011, 251-261; Erik Arnold, Fritz Ohler, Barbara Good Brigitte Tiefenthaler and Niki Vermeulen, *The Quality of Research, Institutional Funding and Research Evaluation in the Czech Republic and Abroad*, Annexe 3 to the final report of the International Audit of Research, Development and Innovation in the Czech Republic, Prague: Ministry of Education, Youth and Sport, 2011

Figure 5 Programme 1 and Programme 2




Making a judgment about the respective virtues of politically governed mission orientated research and researcher-governed research is complicated by differences in evaluation traditions. Mission-orientated research tends, reasonably enough, to be evaluated in terms of its impacts. It is done in order to change things in society, so evidence of such change is logically the main interest of the evaluator. A check on scientific quality is often done – whether by peer review, bibliometric or other means – but this is inherently a secondary consideration. Researcher-initiated research is generally funded on the basis of its scientific quality; its relevance to societal needs is considered at best stochastic and at worst uninteresting. It seems highly likely that the UK style of trying to establish the 'relevance' even of rather fundamental research will steer the system towards work of short-term usefulness at the cost of long-term applicability let alone knowledge generation.

What we do know is that the researcher-governed style has weaknesses as well as strengths

- The exclusive use of peer review promotes conservative decision making, tending to lead to the funding of 'normal' rather than radical science – thus an increasing number of research councils are experimenting with 'high risk' funding instruments.
- It tends to favour the old over the young – hence, equally, the proliferation of 'young researcher' schemes among research councils. (The recent evaluation of the National Science Foundation of China showed that most winners of the 'Distinguished Young Scholar' grants were just below the age limit[33])

[33] *International Evaluation of Funding and Management of the National Natural Science Foundation of China*, Beijing: NSFC, 2011

- It tends to lead to reproduction of existing structures and specialisations rather than promoting change and restructuring of the scientific base[34]
- Governance of research-funding organisations by researchers also appears to have unfortunate effects. The Sandström report[35], evaluating the Swedish research and innovation funding agencies points out that researcher governance prevented the comparatively new Swedish Science Council from acting as change agency in science funding; instead it conserved the pre-existing spending pattern. Sandström also showed that the two other Swedish researcher-governed research councils (FAS and FORMAS, whose task is to fund a mixture of mission-orientated and researcher-initiated projects) were prevented by the dominance of researchers on their governing bodies from performing their mission-orientated roles.

The same is of course true of mission-orientated funding. Depending on the specific governance style, it can also 'lock in' research funding to existing structures, themes and beneficiaries[36]. Ramping up capacity to do mission-orientated research can involve a period when the researchers produce less, or work of a lower quality, than at the point where the research community is mature (see, for example, the comparatively low but improving quality of research in the rapidly-expanding Chinese science system in Not only the volume but also the quality (measured as a bibliometric Relative Impact Indicator) of Chinese publications has been increasing. However, it remains somewhat below the world average (Figure 21).

In Sweden, the decision dramatically to increase energy R&D as a response to the Oil Price Shock of 1973 led to a period when many people new to the field were finding their feet – and prompted a storm of criticism from other parts of the scientific community, to the effect that the state should not invest in poor science but should have added it to university core funding or let the research councils distribute the money in the usual way – and by implication not specifically to energy research.

Mission-orientated funders are normally trying to do a more complex optimisation than solely on quality, making their decisions prone to error (especially if judgments are needed about markets) – one consequence of which has been a shift in funding style within many organisations from focusing on single beneficiaries towards networks, clusters and portfolios. The Framework Programme has probably led the way in funding a mixture of

34 Arie Rip, 'Aggregation machines – a political science of science approach to the future of the peer review system', in Matthijs Hisschemöller, Rob Hoppe, William Dunn and Jerry Ravetz (eds), *Knowledge, Power and Participation in Environmental Policy Analysis*, Policy Studies Review Annual No 12, New Brunswick: Transaction Publishers, 2001

35 Madeleine Sandström, *Forskningsfinansiering – kvalitet och relevans*, Stockholm, SOU 2008:30

36 Rajneesh Narula, *Globalisation and Technology*, Oxford: Polity Press, 2003; Hans Weinberger, *Nätverksentreprenören*, Stockholm: KTH, 1997

fundamental and more applied effort within a single programme and through the European Institute of Innovation and Technology. This is also to a growing extent being done at national level, both through 'competence centres' programmes that build long-term academic/industry consortium relationships spanning basic and applied research and in thematic programmes at the national level.

## 2.4 Conclusion

The balance of effort between basic and applied research is an important question not only so that we can understand and improve the ways we generate knowledge and relate it to societal needs but also because it has become a shorthand for the allocation of resources between different stakeholder groups.

The economics of research imply that the state has to be the major funder of basic research and more generally of research that produces public goods. While some members of the scientific community like to assert that leaving that community itself to decide to whom to allocate research funding is the most effective way to achieve societal benefits, there is no evidence to support such a claim. Basic research is done both based on such research-council style funding and in connection with mission-driven R&D. Most countries maintain parallel systems for funding researcher-initiated and mission R&D. This is a rational response to the fact that both styles of funding and governance have advantages and drawbacks.

# 3. How does science relate to innovation?

Many people like to discuss technology as if it were a consequence of science. Historically, however, technology came first, after a time prompting scientific investigation, so a lot of science is prompted by societal need. Science and research more generally become socially useful and play roles in innovation where they are coupled to needs and users. While some see a contradiction between doing high quality research and doing relevant research, the evidence suggests the opposite. The major impacts of research – whether basic or applied – can take a surprisingly long time to become apparent.

We first discuss the relationship between technology and science. Next we talk about the relation between science and innovation. In the third section, we discuss the idea that societally relevant research cannot be good research. Finally we look at the long-term impacts of basic and applied research.

## 3.1 Technology causes science, but is getting more scientific

There is a long stream of empirical evidence about the role of industry and society in shaping the development of science. An old anecdote is about Galileo being commissioned to improve telescope design so as to increase his patron's ability to wage naval war; Galileo then turned the new telescopes on the stars and got himself into all sorts of trouble with the Church. In an excellent essay on 'Marx as a student of technology', Rosenberg quotes Marx and Engels saying that "from the beginning, the origin and development of the science has been determined by production". Recent work on the patterns of industrial and scientific specialisation at the country level does indeed confirm that there is a systematic relationship between the two[37]. For a range of reasons its seems rational to regard this as a result of 'co-evolution' of the scientific and industrial systems rather than as a result of a strong determinism[38] but it does also provide evidence that science is not wholly independent of society but is to a degree 'socially constructed'[39].

Technological change has for a long time been understood as a driving force in

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[37] A Arundel and A Geuna, 'Does localisation matter for knowledge transfer among public institutes, universities and firms?' paper presented at 8th Joseph Schumpeter conference: Change, Development and Transformation, University of Manchester, 28 June – 1 July 2000 Keld Laursen and Ammon Salter, 'The fruits of intellectual production: economic and scientific specialisation among OECD,' *Cambridge Journal of Regions, Economy and Society,* 2005 (29) 289-308

[38] RR Nelson, 'Economic growth via the co-evolution of technology and institutions,' in L Leydesdorff and P v d Besselaar (eds.) *Evolutionary Economics and Chaos Theory: New Directions in Technology Studies*, London: Frances Pinter, 1994

[39] Peter L Berger and Thomas Luckmann, *The Social Construction of Reality: A Treatise in the Sociology of Knowledge*, Garden City, NY: Anchor Books

economic development. Adam Smith wrote[40] of improvements in production and the division of labour being driven by "philosophers or men of speculation whose trade it is not to do anything but to observe everything; and who, upon that account, are often capable of combining together the powers of the most distant and dissimilar objects." Marx placed the transformation of social relations and of technology at the centre of his analysis of capitalism, while Schumpeter[41] connected technology with the "gale of creative destruction" that drove capitalist progress.

Writing in 1776, Smith's observation was particularly acute. He lived in a time of dramatic industrial and social change enabled by technological changes (notably increased access to coal, the transition from wind and water to steam power and developments in the textiles industry) as well as changes in the supply of commodities and in markets. His analysis of pin-making is famous – explaining how division of labour and more specialised tools could be used to increase productivity while exploiting existing knowledge. His "philosophers" were not scientists in the modern sense but experimenters and his point was that in order to improve production you have to stand back from the productive process and develop the technologies you use.

1776 was a good year for technology also because that was when the first separately condensing steam engines designed by James Watt entered industrial service. Thomas Savery's primitive and unwieldy steam pump was introduced in the late seventeenth century and was overtaken by Newcomen's more effective 'atmospheric engine' in 1712. Watt's design was so dramatically improved compared with its predecessors that his company lived for quite a period by charging customers the price of one-third of the coal they saved compared with the earlier technology.

Watt was a mechanical engineer who learnt some of his skills repairing astronomical instruments for the University of Glasgow. After he became interested in steam he was asked to repair the University's model Newcomen engine and began to experiment his way towards a more efficient design. A "philosopher" in Smith's sense, Watt made technological process through experiment and calculation half a century before Sadi Carnot's book *Reflections on the Motive Power of Fire*[42] was published – the event that is conventionally seen as the start of the science of thermodynamics. Carnot's book is all about understanding and enabling others further to improve a technology that was, by the time he published, two centuries old.

[40] Adam Smith, *The Wealth of Nations*, 1776; reprinted, Harmondsworth: Penguin, 1974

[41] Joseph A Schumpeter, 'The instability of capitalism,' *Economic Journal*, 38, 1928, pp 361-86

[42] Sadi Carnot, *Réflexions sur la puissance motrice du feu, et sur les machines propres à developer cette puissance*, Paris: Bachelier, 1824

Carnot is a "philosopher" in a second sense. Working at a greater level of abstraction, his science produces much more general results than Watts' experimentation and can be used in many more applications than Watts' work, which was specific to particular engines. On the other hand, the user of Carnot's ideas requires both a high level of education (for example in mathematics) and also the ability to do design. Thermodynamics does not tell you about technology; it tells you things that help you produce technology. But it also lets you start the process of innovation from the 'supply side'. Now you can start with a general idea and see where you can apply it. Over time, our universal impression is that the growth of science and technology as research disciplines in their own right have massively increased the opportunities for innovation. By the late nineteenth century, we see the emergence of distinct intra-mural R&D laboratories[43] as well as a flurry of growth in the use of external R&D labs[44]. From this point, too, it makes sense to start talking about 'science-based industries' such as chemicals production or 'technology-based industries' such as electricals, vehicles and later aircraft. The balance of initiative between science and technology on the one hand and problem-based innovation within industry varies among industries and over time, but it is also reasonably clear that in most industries at least the amount of scientific and technological understanding needed in order to do innovation is increasing.

As the number of scientific fields has grown over time, the degree to which completely new disciplines are triggered by technological innovation is probably reducing but there continue to be areas where technological practice runs ahead of – and triggers developments in – science. Vincenti has documented the years of experimental effort the US NACA (predecessor of NASA) put into optimising propeller design by parameter variation ahead of the development of adequate theory to explain performance[45] and later how the Bell XS-1 (the aircraft that first broke the sound barrier) was developed by experimentation in wind tunnels 5-6 years before even the crudest theoretical model of an aerodynamic shape travelling above the speed of sound was developed[46]. Modern materials science was to a large degree triggered by the need better to understand semiconductors for industrial application[47]. Functional genomics is effectively an effort to systematise in a scientific way our understanding of what individual genes do, moving beyond the mix of practice and science in earlier selective breeding and genetics. Increasingly,

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43 Christopher Freeman and Luc Soete, *The Economic of Industrial Innovation*, (3rd edn), London: Frances Pinter, 1997

44 David Mowery and Nathan Rosenberg, *Technology and the Pursuit of Economic Growth*, Cambridge, Mass: Cambridge University Press, 1989

45 Walter Vincenti, *What Engineers Know and How they Know It,* Baltimore: John Hopkins University Press, 1990

46 Walter Vincenti, 'Engineering theory in the making" Aerodynamic calculation "breaks the sound barrier"', *Technology and Culture*, 38(4), 819-851

47 H Brooks, 'The relation between science and technology', *Research Policy*, 23, 477-486, 1994

science and technology co-evolve, as the examples of tissue engineering[48] and digital mobile telephony[49] show.

## 3.2 How science relates to innovation

Research on research and innovation has considerably improved our understanding of the role of science and technology in innovation during the past half century – even if that understanding is not always best used in policymaking, where the crude 'linear model' of innovation remains surprisingly influential. By the 1950s and 1960s the historical pattern of problems in technology prompting the development of science (as with thermodynamics) was all but forgotten and there developed a strong belief in a 'linear model' of innovation leading from science to wealth production. From the late 1960s, however, thanks to writers such as Carter and Williams[50], Schmookler[51] and Myers and Marquis[52], more emphasis came to be placed on the role of the marketplace in innovation, suggesting a linear model where market needs 'pull' knowledge out of research and into application.

A key weakness of the linear models is a failure to conceptualise how the links between successive stages of innovation are supposed to work. They also focus solely on the relationship between **new** knowledge and innovation. By the late 1970s, Mowery and Rosenberg[53] largely laid the intellectual argument between push and pull to rest by stressing the importance of **coupling** between science, technology and the marketplace. Recent models of the relation between innovation and research posit a more or less sequential process linking science with the marketplace (via engineering, technological development, manufacturing, marketing and sales), but with the addition of a number of feedback loops and variations over time in the primacy of 'push' and 'pull' mechanisms. Figure 6 shows an example of such a model.

Key to this new perspective is understanding the huge importance of the **stock** of existing knowledge. As, for example, the Community Innovation Survey (and other innovation surveys outside Europe that use a similar methodology) consistently show, the vast majority of the knowledge used in innovation comes out of this stock, and is not created afresh in the project that gives rise to the innovation.

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48 Fiona Murray, 'Innovation as co-evolution of scientific and technological networks: exploring tissue engineering', *Research Policy*, 31, 1389-1403, 2002

49 Erik Arnold, Barbara Good and Henrik Segerpalm, Effects of research on Swedish Mobile Telephone Developments: The GSM Story, VA 2008:04, Stockholm, VINNOVA, 2008

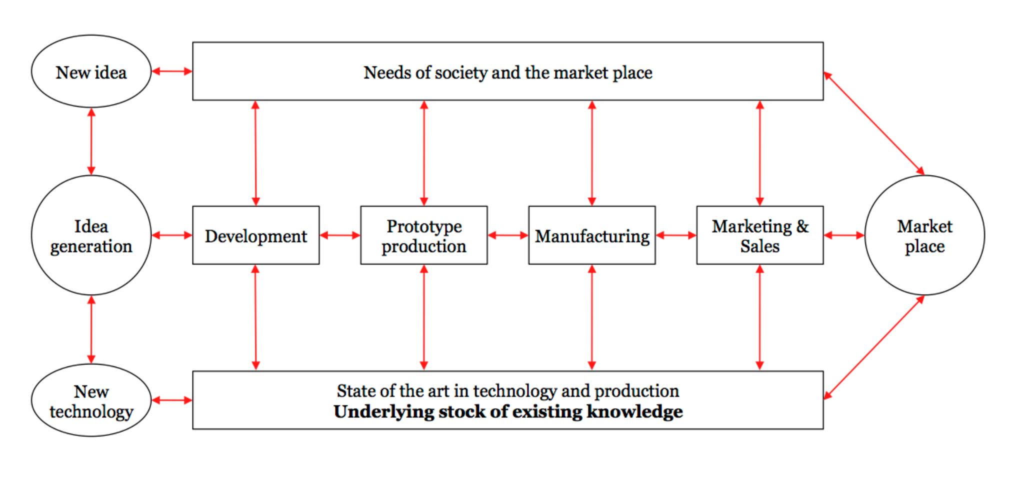
50 Carter, C. and Williams, B., *Industry and Technical Progress*, Oxford University Press, 1957

51 Schmookler, J., *Invention and economic growth,* Harvard University press, 1966

52 Myers, S. and Marquis, D.G., *Successful Industrial Innovation*, National Science Foundation, 1969

53 Mowery, D.C. and Rosenberg, N., 'The Influence of Market Demand upon Innovation: A Critical Review of Some Recent Empirical Studies', *Research Policy*, April 1978

Figure 6 Modern 'Coupling' Model of Innovation




**Source**: Modified from Roy Rothwell, 'Towards the Fifth-generation Innovation Process', *International Marketing Review*, 11 (1), 1994, 7-31

Modern models of innovation suggest that applied and more fundamental research are interlinked and interdependent as precursors of innovation; that the impulse to innovation can start anywhere from user need to fundamental discovery; that the presence of customers or users is a necessary condition for successful innovation; and that innovations only happen when there are good linkages among the actors and types of knowledge needed. A failure to connect research to areas of societal and industrial need has been suggested as the reason for the 'European paradox'[54]: namely, that Europe does a comparatively large amount of basic research but is able to get comparatively little industrial innovation and economic growth out of it. If there is 'information asymmetry' among actors in this process – that is, if lack of information means opportunities for innovation are untaken – then there is an opportunity for policy to promote innovation and growth by coordinating and strengthening information links. At the European level, this has so far been one of the important roles of the Framework Programme[55].

Innovation models tend to focus on **ideas** or information but it has long been recognised that people are the key 'vectors' of knowledge and an absolute requirement for absorbing and using it[56]. In recent years, research on research has become more explicit about the role and importance of **networks** among

[54] European Commission, *Green Paper on Innovation*. Luxembourg: European Commission, 1995; High-Level Expert Group Report on Key Enabling Technologies, Brussels: European Commission, 2011

[55] Erik Arnold, Malin Carlberg, Flora Giaracca, Andrej Horvath, Zsusza Jávorka, Paula Knee, Bea Mahieu, Ingeborg Meijer, Sabeen Sidiqi and James Stroyan, *Long-term Impacts of the Framework Programme*, Brussels: EC, DG-Research, 2011

[56] Wesley M Cohen and Daniel A Levinthal, 'Absorptive capacity: a new perspective on learning and innovation,' *Administrative Science Quarterly*, Vol 35 (1), March 1990, pp128-152

people: in science in the form of 'invisible colleges'[57] in which leading scientists communicate about current research, sharing information ahead of wider publication; in innovation in the form of 'knowledge value collectives'[58], namely the networks of people in companies, universities, research institutes and elsewhere who work with a common set of knowledge. There is a lot more to learn about how such networks function best, but it is clear that they are important in both innovation and research and that they combat information asymmetries, providing an element of coordination that increases the rate of progress. The Framework Programme has dramatically boosted the amount of networking within the European R&D communities, both in industry and in the research sector, and is therefore likely to have made a significant contribution here.

## 3.3 Is relevant research bad research?

When provoked, members of the scientific tribe tend to dismiss non-basic research and therefore research funded through mechanisms not wholly under scientific control and as being of poor quality. This proposition is based on a tautology: since 'basic', researcher-initiated or 'blue skies' research is selected only on the basis of excellence, it must be the case that the use of other criteria reduces the quality of the work funded, compared with selecting only based on scientific quality. In fact, the evidence shows that high scientific quality and production and high societal relevance measured through outputs like patenting tend to go together.

In many if not most fields, university-industry links improve research performance. A UK study indicates that – except in the special cases of patenting and spin-off generation – most academics engage with industry to further their research rather than to commercialise their knowledge[59]. Industrial interaction provides important signals about what problems are of practical and industrial interest in research terms, as well as often leading to the provision of resources[60]. In the case of GSM-relevant research in Sweden, interaction between the research department of Ericsson Radio and three Swedish universities triggered significant growth in research and teaching activities, over time providing Ericsson with the R&D manpower it needed to take a leading position in mobile communications markets and inducing the

[57] Derek de Solla Price, *Little Science, Big Science*, New York: Columbia UP, 1963

[58] Barry Bozeman and Juan Rogers, 'A churn model of scientific knowledge value: Internet researchers as a knowledge value collective,' *Research Policy*, (31), 2002, pp 769-794

[59] Pablo D'Este and Markus Perkman, "Why do academics engage with industry? The entrepreneurial university and individual motivations," *Journal of Technology Transfer* (forthcoming)

[60] Edwin Mansfield, "Academic research underlying industrial innovations: Sources, characteristics and financing," *Review of Economics and Statistics*, 77 (1), 1995, 55-65; Siegel *et al.,* op. cit., 2003

number of professors working in relevant areas to grow from 3 to 41 over a couple of decades[61].

Recent evidence reveals that there is considerable complementarity between patenting and publishing as well as between the former and additional mechanisms, notably, joint and contract R&D, consultancy, spin-off and joint PhD training. This is the case in technology areas related to chemistry, computer science and sub-fields of engineering and physics[62].

The most productive Danish researchers in the life sciences are less sceptical than those who do not patent about any negative influence of industrial links or patenting on their research[63]. Male, tenured and research-grant active US researchers are more likely than others to engage in informal technology transfer activities with industry[64]. A survey of Italian academics found that those who published most in the scientific literature also patent the most[65]. Norwegian faculty in receipt of industrial funding publish more than other researchers[66]. Crespi et al[67] have shown that publication and patenting are complementary activities up to a maximum point, beyond which patents begin to substitute for publications. They have some (weak) evidence that in the physical sciences patenting can crowd out other forms of communication with industry, notably publication, whereas in computer science and engineering, patenting ‘crowds in’ other forms of communication.

More recent European work focusing on 87 European universities showed that larger universities patent disproportionately more than small ones, especially where they have medical schools and engineering departments. High levels of scientific production and contract research are both conducive to patenting. Broadly, therefore, “Top researchers succeed to publish and patent a lot; a high patent output does not seem to affect negatively the publication output of the most prolific researchers”[68].

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61 Erik Arnold, Barbara Good and Henrik Segerpalm, *Effects of research on Swedish Mobile Telephone Developments: The GSM Story*, VA 2008:04, Stockholm, VINNOVA, 2008

62 Gustavo Crespi, Pablo D’Este, Roberto Fontana and Aldo Geuna, *The Impact of Academic Patenting on University Research and its Transfer,* SPRU Electronic working Paper Series No. 178, Sussex University: SPRU, 2008.

63 P Lotz, MT Larsen and L Davis, “To what effect? Scientists’ perspectives on the unintended consequences of university patenting,” DRUID Conference, 2007

64 AN Link, DD Siegel and B Bozeman, “A empirical analysis of the propensity of academics to engage in informal university technology transfer,” *Industrial and Corporate Change*, 16 (4), 2007, 641-655

65 Valentina Tartari and Stefano Breschi, “Set them free: Scientists’ perceptions of benefits and cost of university-industry research collaboration” DRUD Conference, 2009

66 Magnus Gulbrandsen and Jens-Christian Smeby, “The external orientation of university researchers and implications for academic performance and management,” *Science and Public Policy*, 2003

67 Crespi et al, op. cit., 2009

68 Crespi et al, op. cit., 2009

There is plenty of evidence to suggest that research done with or influenced by industry, funded as 'mission' research, can be of excellent scientific quality and indeed that in many fields 'relevance' is associated with higher quality research. For example

- One bibliometric study shows that articles co-published between researchers in academia and industry tend to be published in journals with lower impact factors than academic-only publications, but that they receive many more citations[69]
- A bibliometric study of biotechnology in Italy shows that collaboration with industry is associated with a higher rate of citation. International collaboration consistently increases the citation rate[70]
- Another Italian study shows that university researchers who cooperate with industry have higher productivity and citation rates than their colleagues who do not[71]
- A third Italian study of patenting in microelectronics shows that industrial cooperation increases the rate of both discovery and invention and is characterised by high scientific quality[72]
- A study of the technical sciences in British universities showed that researchers from the best institutions collaborate the most intensively with industry[73]
- International scientific peer reviews of the 28 'competence centres' in a long-term Swedish programme promoting R&D collaboration between industrial consortia and industry found consistently high levels of quality, with many centres being regarded as among the international leaders in their fields[74]
- Swedish bibliometric evidence shows that Framework Programme participants have better bibliometric performance than their peers in their own universities[75]

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69 L-M Lebeau, M-C Laframboise, Lariviére and Y Gingras, 'The effect of university-industry collaboration on the scientific impact of ublications,' *Research Evaluation*, 17 (3), 2008, 227-232

70 S Labory, R Lorio and D le Paci, , The determinants of research quality in Italy: Empirical evidence using bibliometric data in the biotech sector,' paper presented at the 25 Celebration Conference onEntrepreneurship and Innovation – Organisations, institutions, systems and regions, CBS, Copenhagen June 17-20, 2008

71 G Abramo, CA d'Angelo, F di Costa and M Solazzi, 'University-industry collaboration in Italy: A bibliometric examination,' *Technovation*, 29 (2009), 498-507

72 M Balconi and A Laboranti, 'University-industry interactions in applied research: The case of microelectronics,' *Research Policy*, 35 (2006), 1616-1630

73 M Perkmann, Z King and S Pavelin, 'Engaging excellence? Effects of faculty quality on university engagement with industry,'*Research Plicy*, 40 (2011), 539-552

74 Erik Arnold, John Clark and Sophie Bussillet, *Impacts of the Swedish Competence Centres Programme 1995-2003*, Vinnova Analysis VA 2004:03, Stockholm: Vinnova, 2004

75 Erik Arnold, Tomas Åström, Patries Boekholt, Neil Brown, Barbara Good, Rurik Holmberg, Ingeborg Meijer and Geert van der Veen, *Impacts of the Framework Programme in Sweden,* VA 2008:11, Stockholm: VINNOVA, 2008

- Evaluation of FP6 participants confirmed that the programme attracted many of the leading scientists in their respective fields[76]

## 3.4 Impacts of basic and applied research

The world has in important ways changed since Adam Smith was writing. There are fewer and fewer kinds of production that do not have some association with scientific research. It has therefore become less obvious than it may have been before when and whether basic **or** applied research plays a role.

Studies have shown that the science-innovation relationship tends to differ between branches of industry, with some needing a lot of 'translational' or 'transfer' science before they can use fundamental research and others being able to exploit it in problem-solving more directly. We have begun to recognise the huge importance of the human capital (trained people, especially those with PhDs or equivalent experience) in enabling the conduct of R&D in industry and more widely in society, as well as in the scientific research sector. Indeed, in many smaller countries it is plausible to argue that the most important reason for national funding of basic research is not to produce knowledge but to generate the people that give the national research and innovation system the 'absorptive capacity' to exploit global science.

Some of the most interesting evidence about the importance of basic and applied research comes from the budget rivalry between the US National Science Foundation (NSF) and mission-orientated research in the 1960s. The US Department of Defense commissioned the Hindsight study, which traced the research antecedents of a number of weapons systems back for twenty years or so and concluded that the underpinning research was largely mission-orientated in nature. NSF retorted with the TRACES study, which traced backwards for up to fifty years from five important civil innovations and found critical connections to basic research. The unsurprising implication is that both sorts of research are at various times needed. Little more long-term tracing research has since been done until the last decade, when a series of long-term impact studies in Sweden has found[77]:

- VINNOVA and its predecessors have played important roles in identifying, defining and growing new areas of needs-driven R&D in a process of dialogue with the research and industrial communities. This would not have been achieved had the funding been under the unique control of either the research or the industrial community

76 Philipp Larrue, Yann Cadiou, Patricia Laurens and Erik Arnold, *Bibliometric Profiling of Framework Programme Participants',* Brussels: European Commission, 2007

77 Elg, Lennart and Håkansson, Staffan, *När Staten Spelat Roll: Lärdomar av VINNOVAs Effekstudier*, VINNOVA Analysy VA 2011:10, Stockholm: VINNOVA, 2011

- This has been achieved through a combination of 'bottom-up', responsive-mode funding and programming that permits promising areas to be scaled up
- Programmes need both to be flexible – reflecting the uniqueness and adapting to the evolution of each field – and 'patient': long programmes have greater effects on beneficiaries' strategies and learning than short ones
- Time constants are constantly under-estimated in R&D funding. It is not uncommon for 10-20 years to elapse before socio-economic effects of any size are visible
- Hence, it is important to avoid the 'project fallacy' (i.e. the idea that the contractually-defined project is necessarily a meaningful entity). Rather, longer-term interactions allow beneficiaries to pursue their 'real projects' and strategies
- Key effects of funding have been the development of new clusters of human capital and organisational learning so as to develop the capacity and capabilities of the innovation system, not just to underpin individual innovations
- While in many cases major economic effects have been obtained in large, existing companies, the creation of new firms is necessary in order to create a varied environment with many opportunities for experimentation and learning
- Since about 1990 (when many of the Swedish multinationals began to merge with foreign companies), globalisation has meant that a key aim of R&D funding is not to 'support' wholly-Swedish companies but to make the Swedish innovation system attractive to companies irrespective of their nationality or trans-nationality
- Where R&D programmes address societal needs, they have to connect with effective demand (i.e. users willing and able to pay)

### 3.5 Conclusions

History suggests that the idea of science causing technology is wrong: rather, technology historically prompts the creation of science. The two then co-evolve in a mutually reinforcing system. As a result, innovation may indeed sometimes be triggered by a scientific discovery or observation, but more often it is driven by problem-solving – and it is only successful at the point where it is linked to users and their needs. It is not **new** knowledge that drives innovation but the adoption and use of whatever combination of new and old knowledge is appropriate to problem solving in a particular case. It follows that we cannot only fund researcher-initiated research if we want science to contribute to the solution of societal problems – we need mission-driven research as well that focuses effort on problems. This need not involve any sacrifice of scientific quality. The route from research to societal impact is a long one and it is affected by many other factors than the scientific or technological content of the research, such as markets and the availability of the complementary knowledge needed to solve particular problems. It follows that mission-related research funding must not only be patient but also be sensitive to the context, interacting with people knowledgeable about needs and the state of the art in knowledge.

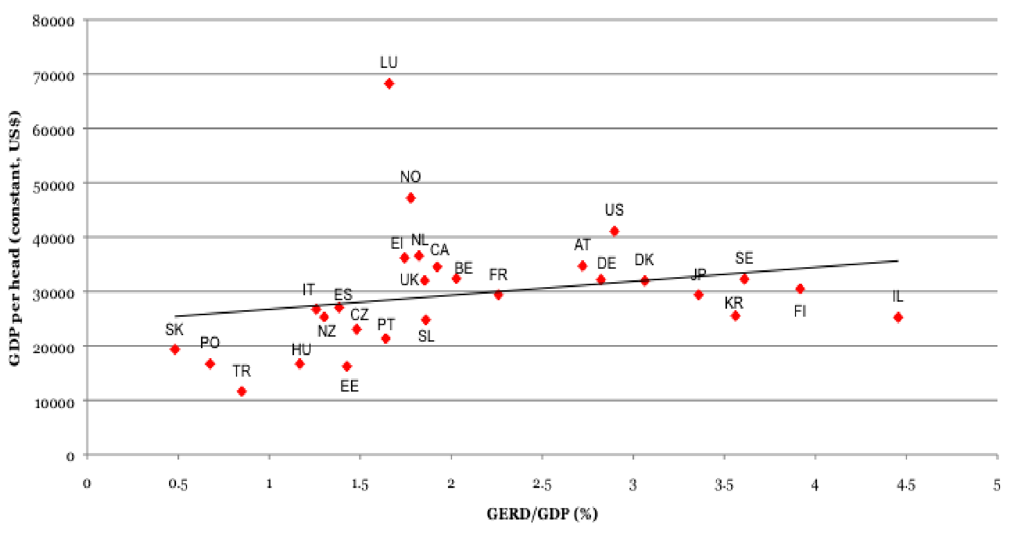
# 4. Basic and applied research at the national level

Richer countries tend to do more R&D than poorer ones. Business expenditure on R&D becomes increasingly important as incomes rise but needs to be supported by increased education and research activity in the higher education sector. Basic research is growing in importance as a function of development – advanced countries have to do more basic research because their opportunities for imitation decline – and because technologies are becoming more 'scientific'. However, the most innovative and dynamic economies maintain a balance between more fundamental research and activities associated with application and development via big mission-driven programmes where the state plays a large role.

First, we look at what national-level R&D statistics can tell us about the respective importance of basic and applied research in development. Next we look at how governments spend money on their own research before looking at how different kinds of activity are integrated into major mission-driven programmes in the USA and China.

## 4.1 Evidence from the national level

Figure 7 GERD/GDP (%) and GDP per head of population (US$), 2009



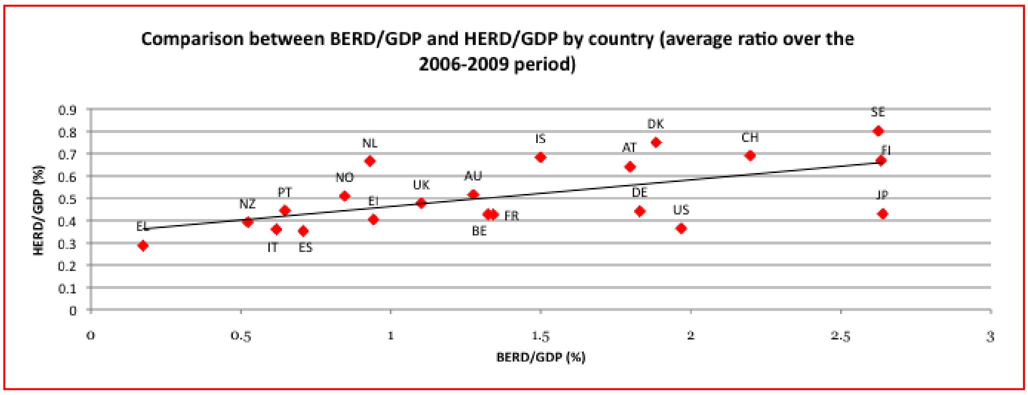

**Source** OECD Main Science and Technology Indicators

One of the best-known regularities in economic development is that the proportion of GDP spent on R&D tends roughly to rise with rising income

(Figure 7) [78]. There are important divergences from this norm: for example, Italy manages to have a surprisingly high GDP per head of population while devoting a comparatively small proportion of GDP to R&D; the inverse is true of Sweden. But since we can observe a rather clear relationship between R&D (as a proxy for innovation) and GDP, and since there is plenty of economic evidence to show that changes in technology drive a large part of growth in productivity and the economy as a whole, policymakers tend to regard this as a driving relationship – hence the EU's continuation of the old 'Barcelona Goal' of spending 3% of GDP on R&D in the new Europe 2020 strategy.

In very poor countries, the state tends to be one of a very small number of R&D performers. Hence, poorer countries typically do a high proportion of their R&D activity in government and the higher education system. As industrial development proceeds, so industry's R&D effort grows faster than that of the state.

Figure 8 Relative importance of BERD and HERD, 2006-9




**Source** OECD Main Science and Technology Indicators

Figure 8 shows the relative proportions of Business Expenditure on R&D (BERD) and Higher Education Expenditure on R&D (HERD) for a number of countries over 2006-9. It suggests that there is a certain minimal level of HERD necessary even at low levels of BERD. You need universities to train people and do research; otherwise business cannot start doing R&D. There is an 'entry ticket' to development, meaning that the state has to make the initial investment in research and learning. Second, the slope of the fitted line is shallow: growth in BERD is faster than growth in HERD. So once business starts doing R&D it still needs the universities to do teaching and research. HERD needs to grow in order to support BERD – but not at as fast a rate. In European policy, this is reflected in the fact that the 3% goal is made up of 1% from the state and 2% from industry. The interdependence of different parts

[78] Curiously, however, it has not been possible to establish a short term relationship between growth in R&D and GDP

of the innovation system is underlined by Brusoni and Geuna's work showing that high-performing countries such as the USA and Germany publish strongly across all types of research: basic, applied, development and engineering[79].

Because industry does R&D in order to access markets, this means the balance of R&D activity at the national level shifts over time increasingly towards applied research and experimental development. The balance of knowledge production shifts towards 'Mode 2'.

As long as national technologies remain behind the technological frontier, companies can operate in 'catch-up' mode and need to be supported by the state research infrastructure maintaining significant applied research capability. Once the frontier is reached, however, the way forward is no longer defined by earlier developers; companies and countries need to search more widely for knowledge and this typically leads to an increase in the proportion of fundamental research done, in order to generate or absorb knowledge from new directions. This proportion goes up not only in the research sector but also among companies. We can see this effect both in national R&D statistics and in the spending pattern of certain R&D funders at national level. The balance of basic and more applied research is very different in different circumstances.

Figure 9 shows the development of basic and applied research and experimental development over quite long periods of time in China, Japan and the USA. China's research and innovation system was largely destroyed by the Cultural Revolution and has been re-built almost from scratch. Since the opening up of China at the end of the 1970s, developing a well-functioning research and innovation system has been a cornerstone of national development policy[80]. Already in 1978, at a national conference on science that launched the reform and opening up of policy for S&T, Deng Xiaoping said that, "science and technology are primary productive forces". The 1985 Decision on the Reform of the Science and Technology Management System[81] stressed the need to orientate S&T development towards economic development. Basic research was seen as a needed component in such an environment. The 1985 Decision launched a series of reforms to decentralise and stimulate R&D funding and performance.

[79] S Brusoni. and A Geuna, Persistence and Integration: The Knowledge Base of the Pharmaceutical industry, in: C. C. Antonelli, D. Foray, G.M.P. Swann and W.E. Steinmueller (Editors), *Technical Choice, Innovation and Knowledge: Essays in Honour of Paul A. David*, Cheltenham: Edward Elgar, 2001

[80] *International Evaluation of Funding and Management of the National Natural Science Foundation of China*, Beijing: NSFC, 2011

[81] Central Committee of the Communist Party of China (CCCPC), *Decision on the Reform of the Science and Technology Management System*, March 1985

We can see from the figure that China's spectacular growth since opening up has been built on a massive expansion of the research and innovation system.

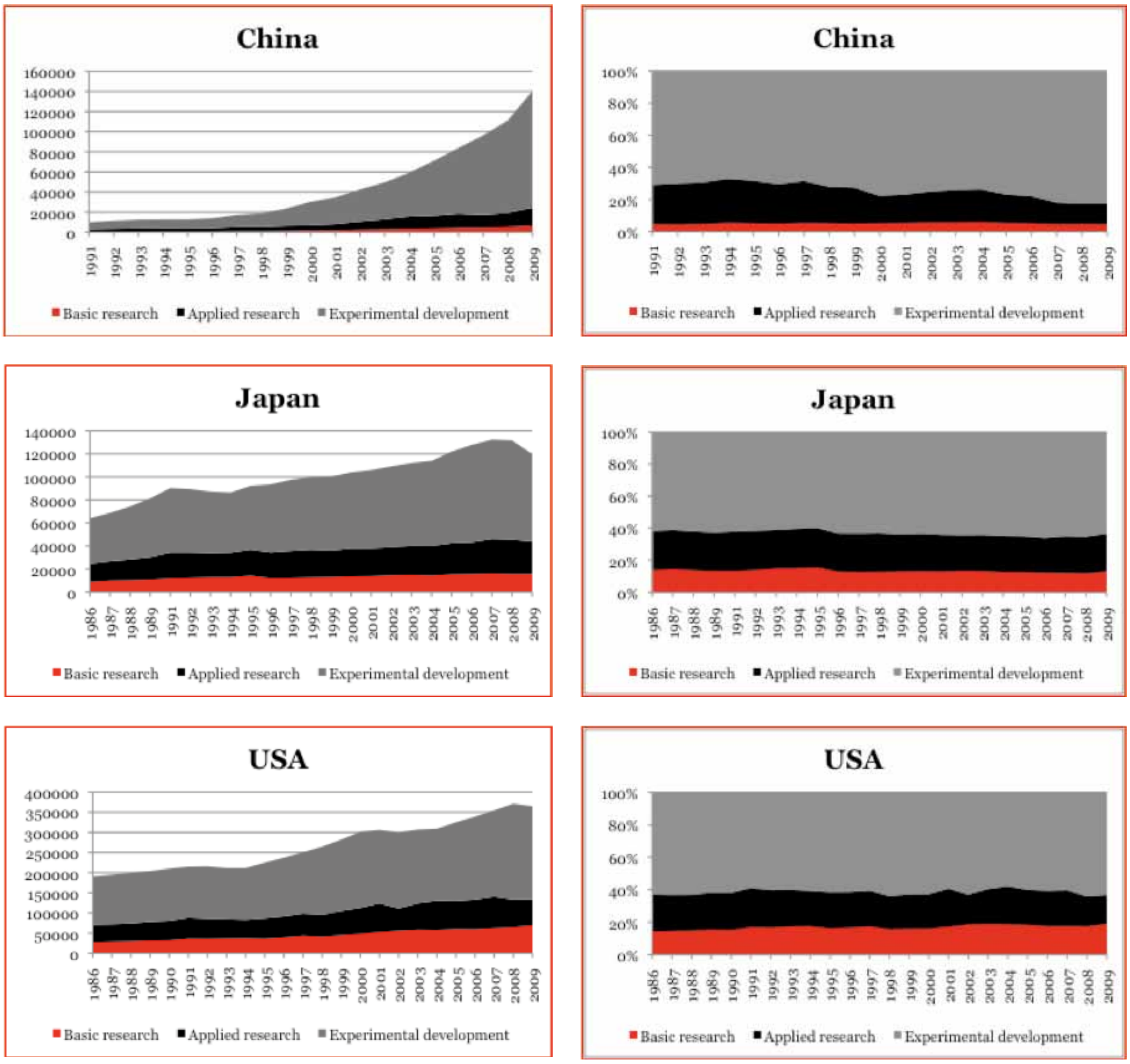



Figure 9 Absolute and Relative Development of Research by Type over Time: China, Japan, USA

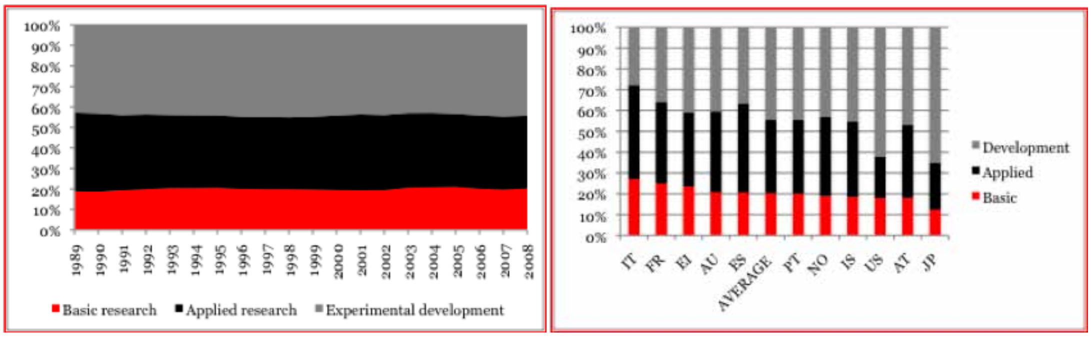
**Source:** OECD Main Science and Technology Indicators; China Ministry of Science and Technology

China is now second only to the USA in the number of scientific papers it publishes per year. Growth in basic research has been equally spectacular – but it has stuck obstinately at 5% of GERD. Overall, R&D is extremely focused on Development. There are parts of the system where Chinese science and technology are leading edge; but for the most part China still operates in catch-up mode, though the OECD advises that the low share of basic research will become unsustainable as science and industry move towards the frontier[82].

Japan is no longer the technological powerhouse of Asia and growth has tended to stagnate, but it remains an immensely successful economy internationally. The higher proportion of basic research testifies to its more developed position than that of China – but the basic share has drifted down very slowly from 14-15% in the late 1980s to 13% in 2009. In contrast, the US share of basic research has increased from the same level as Japan in the late 1980s to 19% in 2009 – during which period the USA has continued to maintain its global leadership in science, technology and innovation.

Many countries do not collect data that distinguish between different types of R&D. In Figure 10 we present a view of the division among types for the 'average country' in the basket of developed countries that do provide such data. (We have excluded the former Soviet Bloc countries because their expenditure pattern is dominated by the restructuring of their research and innovation systems since 1989. That produces patterns determined by reform rather than economic development.)

Figure 10 Absolute and Relative Development of Research by Type in 2006-9 for a Basket of Countries

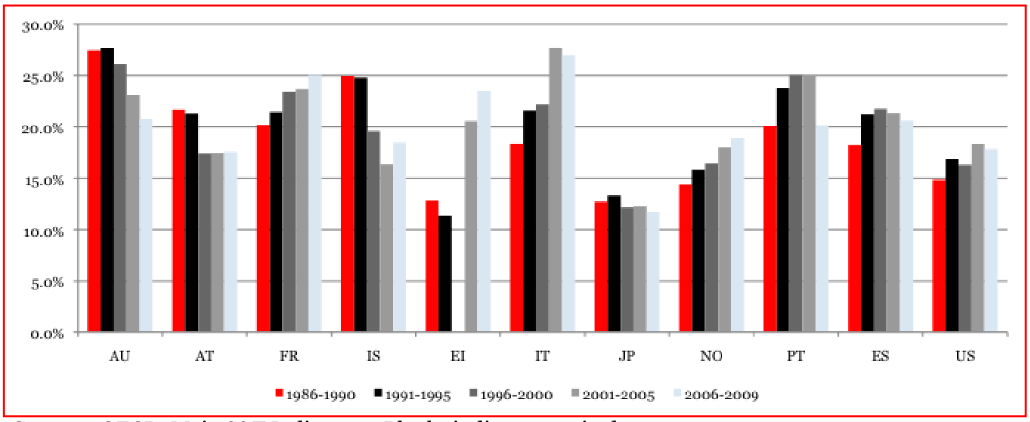



**Source**: OECD, Main S&T statistics, R-D expenditure by sector of performance and type of R-D (in Million 2005 Dollars - Constant prices and PPPs) **Note**: Due to gaps in data series, some data are interpolated. Data presented on the left are the mean of the percentages for each country considered – they are not weighted by the absolute amounts of R&D done in the different countries

[82] OECD, *Reviews of Innovation Policy: China*, Paris: OECD, 2007; *International Evaluation of Funding and Management of the National Natural Science Foundation of China*, Beijing: NSFC, 2011

Figure 11 shows how the share of basic research has changed over time. The movement among categories during the period is slight: basic research nonetheless increases as a percentage from 18.6% in 1989 to 20.2% in 2009.

Figure 11 Basic Research in the national GERD, 1986-2009

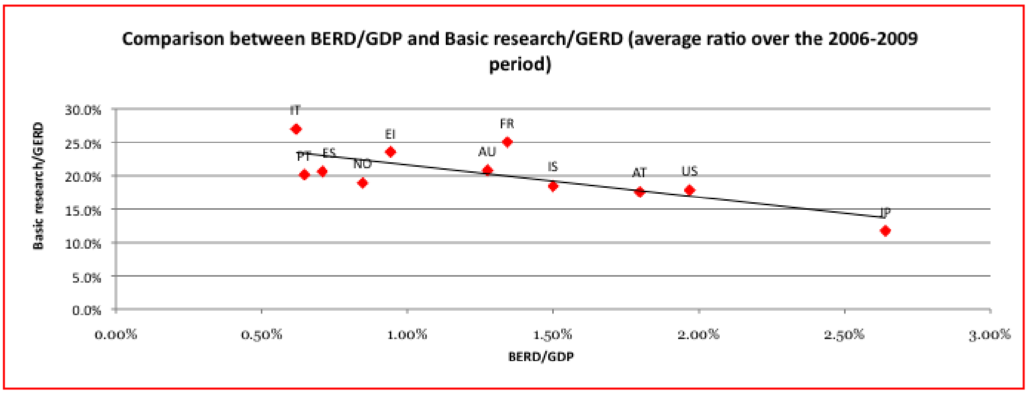



**Source**: OECD, Main S&T Indicators. Blanks indicate gaps in data.

Compared with other members of this country basket, US investment in basic research has been low in the past but is about the same now. A striking difference is the much greater importance of **experimental development** in the USA and Japan (and China) compared with the other European countries in the basket. If these three countries do especially well in innovating new products and processes, it seems that is because they put more effort into developing them – irrespective of whether their systems are in 'catch-up' or 'frontier' mode.

Figure 12 broadly suggests that the proportion of country's GERD that is devoted to basic research tends to decline as BERD rises – which is rather what one would expect.

Figure 12 Comparison between Basic Research/GERD and BERD/GDP,

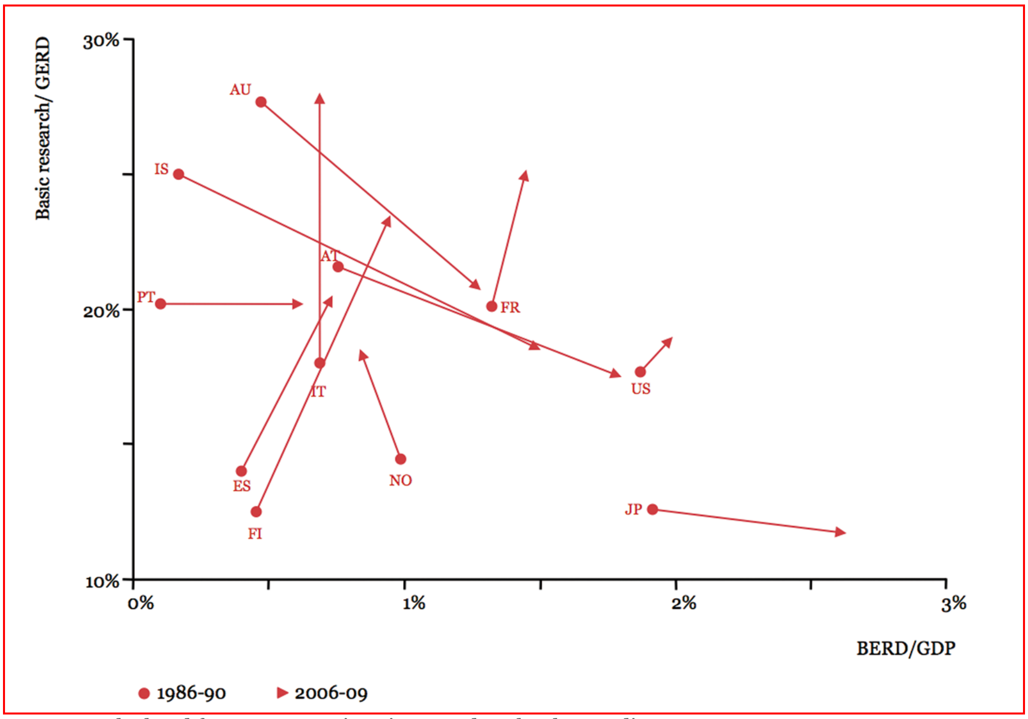



2006-9

**Source**: Calculated from OECD Main Science and Technology Indicators

However, Figure 13 suggests a more complex pattern. It looks at how the values for 2006-9 shown in Figure 12 compare with their equivalents in 1986-90, illustrating the change for each country as an arrow from the old to the new value. It shows two patterns of development. In countries where BERD has grown, the proportion of GERD devoted to basic research has declined, reflecting the changing balance of effort among different types of R&D performers. But in those countries where BERD has not grown, the proportion of effort going to basic research has increased. (In Norway, where BERD has shrunk, the balance of effort has also moved towards basic research.) So there seem to be two trends acting: one towards increased BERD; the other towards increased basic research intensity – consistent with the frequently discussed idea that innovation and technology are becoming more 'scientific'.

Figure 13 Changes in Importance of Basic Research and BERD, 1986-90 to 2006-9



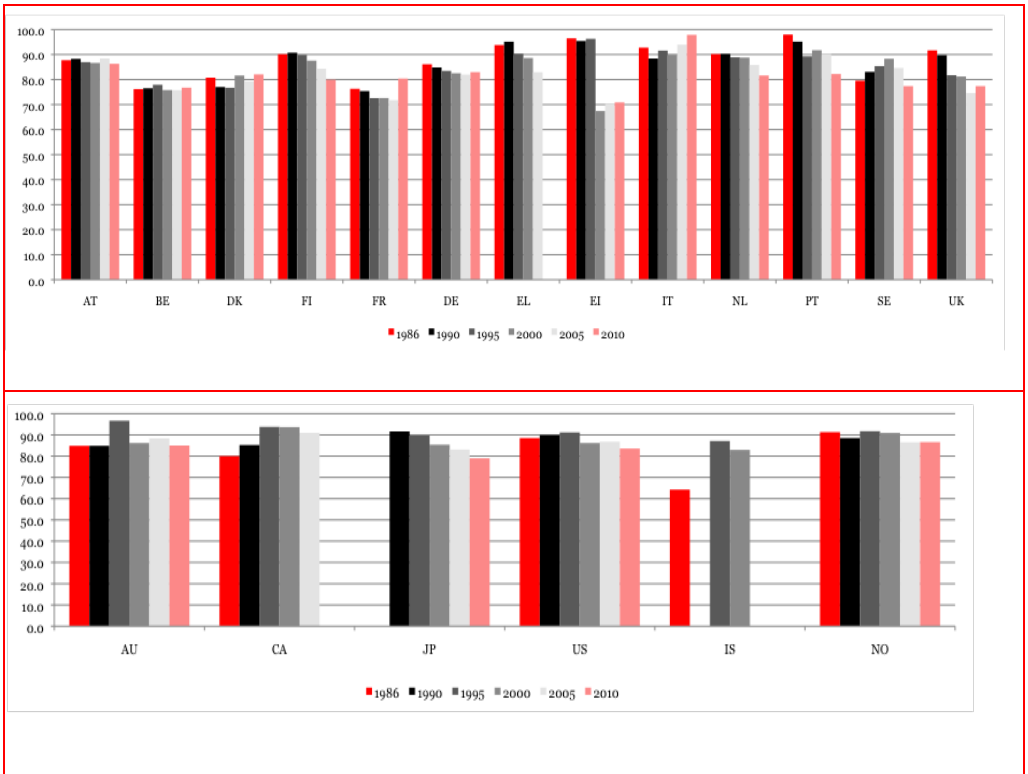

**Source**: Calculated from OECD Main Science and Technology Indicators.

## 4.2 Government R&D spending

If we look at how government spends money on R&D (Government Budget Appropriations or Outlays for R&D – GBAORD in the OECD terminology) in more recent times, it becomes clear that while most of the funding is mission-orientated, and spent through agencies with political rather than scientific governance, quite a lot of the work funded is basic research. The OECD statistics show that there is a very slight trend for this proportion of basic research to increase in the basket of countries discussed above.

Defence spending is a major distorting factor when looking at GBAORD because some countries spend massively on defence (historically, this is especially true of the USA, UK and France) while others do not. 'Civil GBAORD' is therefore a better guide to trends. Figure 14 presents the trends when looking only at the proportion of mission-orientated funding[83] in **Civil** GBAORD. The proportion of government spending that is mission orientated is in all cases strikingly high. The part of civil GBAORD not shown in the figure is the research part of block grant funding for universities and funding for general research councils or academies of science. Governments, then, take care to programme most of their R&D spending towards the achievement of rather specific goals – spending a considerably smaller proportion of the available money on undirected research, in fact, than is proposed in Horizon 2020.

Figure 14 Percentage of Oriented Research in Civil GBAORD (selected years between 1986 and 2010)




**Source** OECD, Main S&T Indicators, GBAORD. Blanks indicate non-availability of data.

It does not follow that orientated parts of GBAORD are spent wholly on applied research and experimental development. Sadly, few countries provide

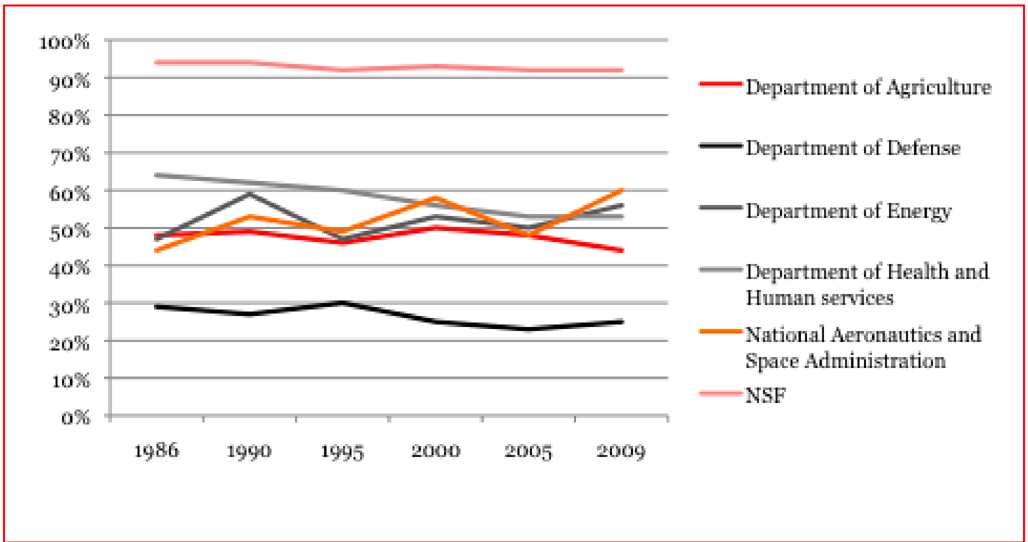
83 Mission-orientated funding is for: exploration and exploitation of the earth, environment, exploration and exploitation of space, transport, telecommunication and other infrastructures, energy, industrial production and technology, health, agriculture, education, culture, recreation, religion and mass media, political and social systems, structures and processes. Defence is already excluded since we are looking at civil GBAORD

data that show what **kind** of R&D is done with mission-orientated GBAORD money.

## 4.3 Missions and basic research in the USA

Fortunately, the USA does. More than half of the US government's national R&D budget comprises defence-related R&D and the US Department of Defense is the leading department based on size of public R&D expenditures, followed by the Department of Health and Human Services (i.e. more than 20% of the R&D budget is health-related). Space-related R&D accounts for 7% with another 7% involving general science. Energy-related R&D constitutes less than 2% of the R&D budget as does environmental R&D.[84] Figure 15 shows that a very substantial proportion of US mission-orientated expenditures is fundamental in nature.

Figure 15 Proportion of Basic Research in the main US Departments and Agencies involved in R&D funding (1986-2009)




**Sources**: Technopolis, based on National Science Foundation Division of Science Resources Statistics, Survey of Federal Funds for Research and Development

The US research system is large. Policy is fashioned in a decentralised manner through the activities of departments and agencies, through budgets, roadmaps and planning processes, and through open solicitations in targeted areas. For example, the National Science Foundation (NSF) accepts funding requests in programme descriptions, announcements and solicitations, plus at any time applicants may send in unsolicited proposals for research and education projects, in any existing or emerging fields. In the design of its calls and more generally in its operation, the NSF solicits advice from groups of experts to monitor which areas are most promising.

84 Erawatch, USA, country profile, online: http://erawatch.jrc.ec.europa.eu

Large national or cross-agency top-down programmes are less common than single-agency initiatives, although there are some thematic policies within the US research policy portfolio going across federal agencies. These programmes are often coordinated through national agencies such as the Office of Science and Technology Policy, which also serves a review and advisory function.[85] Two examples are presented below. In each of the cross-agency programmes, the involvement of the various agencies is different and tailored to their competencies and to the initiatives that are yearly supported by the programme. Funding vehicles are defined in a decentralised manner in each agency and department.

Figure 16 Example of mission-orientated funding delivered through national cross-agency programmes (USA)

| Name | Organisation | Targets and type of research supported | Objectives | Budget |
|---|---|---|---|---|
| **National Nanotechnology Initiative (NNI)** | • 25 participating agencies<br>• Parent organisation is the National Science and Technology Council (NSTC)<br>• Run through the National Nanotechnology Coordinating Office (NNCO) | • Support basic and applied research<br>• Key activities: research funding, support for the creation of university and government nanoscale R&D laboratories, education, support cross-disciplinary networks and partnerships, dissemination | • Dates back to 1998 with the formalisation of this Interagency Working Group on Nanotechnology (IWGN), raised in 2001, to level of federal initiative and changes name<br>• Mission is to accelerate the discovery, development, and deployment of nanoscale science, engineering, and technology | $2.1b in 2012 |
| **U.S. Global Change Research Programme (USGCRP)** | • Thirteen departments and agencies participate | • Key activities: research funding, participation to policy-making through information, communication, education, conducting sustained assessment | • Was mandated by Congress in the Global Change Research Act of 1990<br>• Mission is to conduct work aimed at understanding, assessing, and responding to global change | $2.6b in 2012 |

[85] Erawatch, USA, country profile, online: http://erawatch.jrc.ec.europa.eu

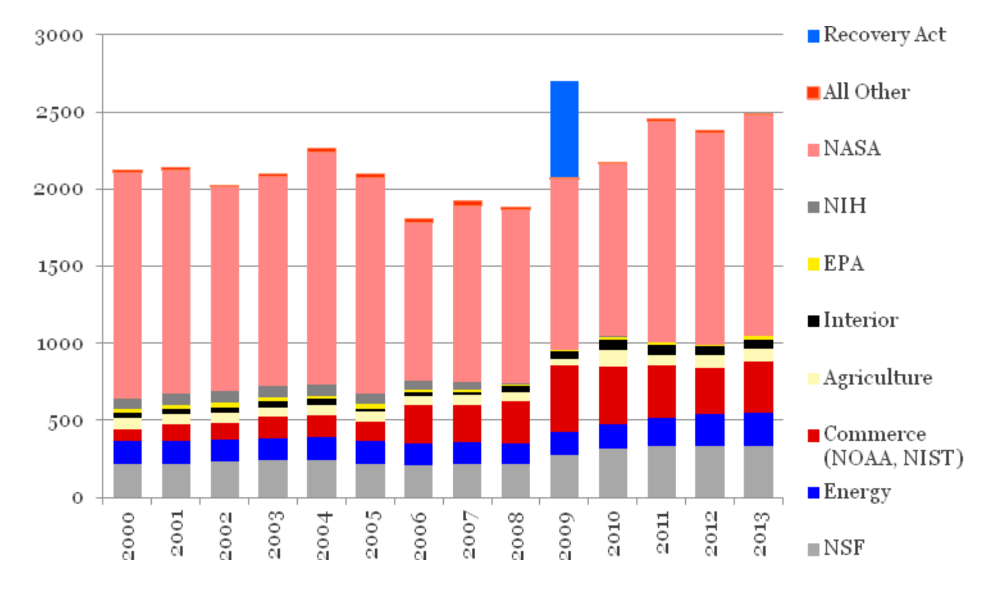
Figure 17 NNI budget by Agency (2001-2009)

**Table 2 NNI Budget History by Agency*** (dollars in millions)

| Agency | 2001 Actual | 2002 Actual | 2003 Actual | 2004 Actual | 2005 Actual | 2006 Actual | 2007 Actual | 2008 Actual | 2009 Actual |
|---|---|---|---|---|---|---|---|---|---|
| DOD | 125 | 224 | 220 | 291 | 352 | 424 | 450 | 460 | 459.0 |
| NSF | 150 | 204 | 221 | 256 | 335 | 360 | 389 | 409 | 408.6 |
| DOE | 88 | 89 | 134 | 202 | 208 | 231 | 236 | 245 | 332.6 |
| DHHS (NIH) | 40 | 59 | 78 | 106 | 165 | 192 | 215 | 305 | 342.8 |
| DOC (NIST) | 33 | 77 | 64 | 77 | 79 | 78 | 88 | 86 | 93.4 |
| NASA | 22 | 35 | 36 | 47 | 45 | 50 | 20 | 17 | 13.7 |
| EPA | 5 | 6 | 5 | 5 | 7 | 5 | 8 | 12 | 11.6 |
| USDA (NIFA) | | | 1 | 2 | 3 | 4 | 4 | 7 | 9.9 |
| DHHS (NIOSH) | | | | | 3 | 4 | 7 | 5 | 6.7 |
| USDA (FS) | | | | | | 2 | 3 | 6 | 5.4 |
| DOJ | 1 | 1 | 1 | 2 | 2 | .3 | 2 | 0 | 1.2 |
| DHS | | 2 | 1 | 1 | 1 | 2 | 2 | 3 | 9.1 |
| DOT (FHWA) | | | | | | 1 | 1 | 1 | 0.9 |
| TOTAL | 464 | 697 | 760 | 989 | 1200 | 1351 | 1,425 | 1,554 | 1,694.9 |

Source: Website of the NNI: http://www.nano.gov/about-nni/what/funding.

Figure 18 USGCRP budget by Agency (2001-2013)



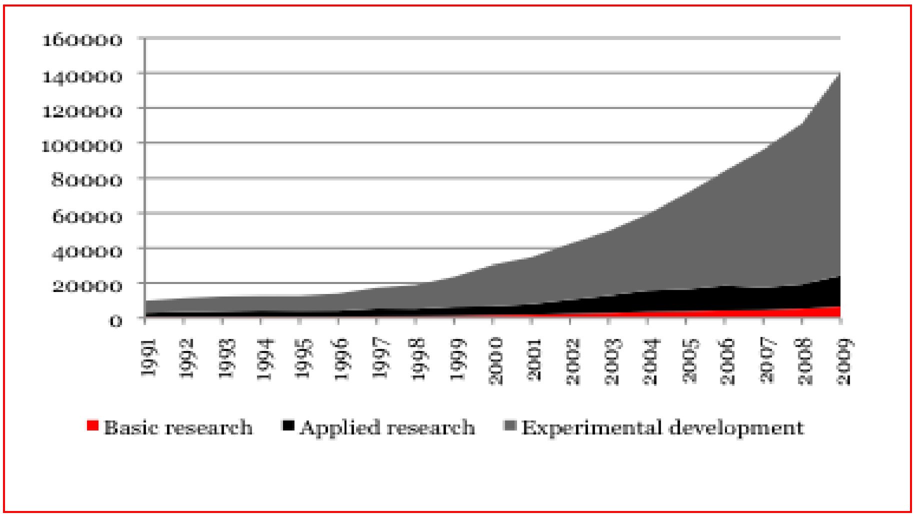

In millions of constant FY 2012 dollars. Executive Office of the president of the USA, Meeting the Challenges of Global Change, The U.S. Global Change Research Program in the 2013 Budget.

## 4.4 Missions and basic research in China

China's staggering progress in R&D as well as in industrialisation over the last 30 years or so is well known. Because this is to a fair degree a **planned** process, it is in many respects easier to understand the overall pattern of activity than in other countries. Figure 19 shows the growth of R&D

expenditures, within which the basic research component has been fairly constantly around 5%. This is a comparatively low proportion, reflecting the fact that China is playing 'catch-up' in many areas of science and technology.

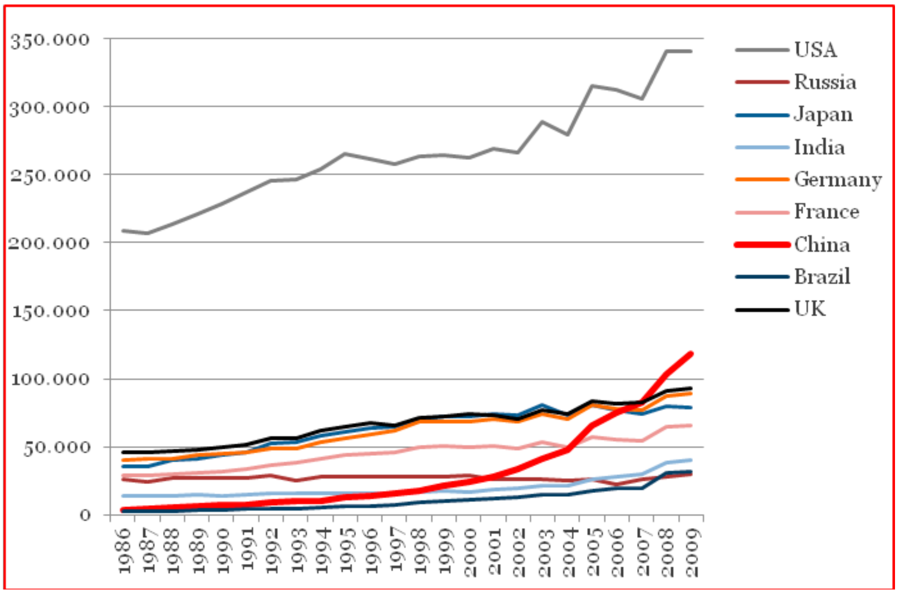
Figure 19 Growth in Chinese GERD by type of research supported (1991-2009) (Million 2005 Dollars - Constant prices and PPPs)




**Source**: Technopolis based on: OECD, MSTI, R-D expenditure by sector of performance and type of R&D.

Since 2007, China has been the most prolific producer of scientific publications after the USA (Figure 20).

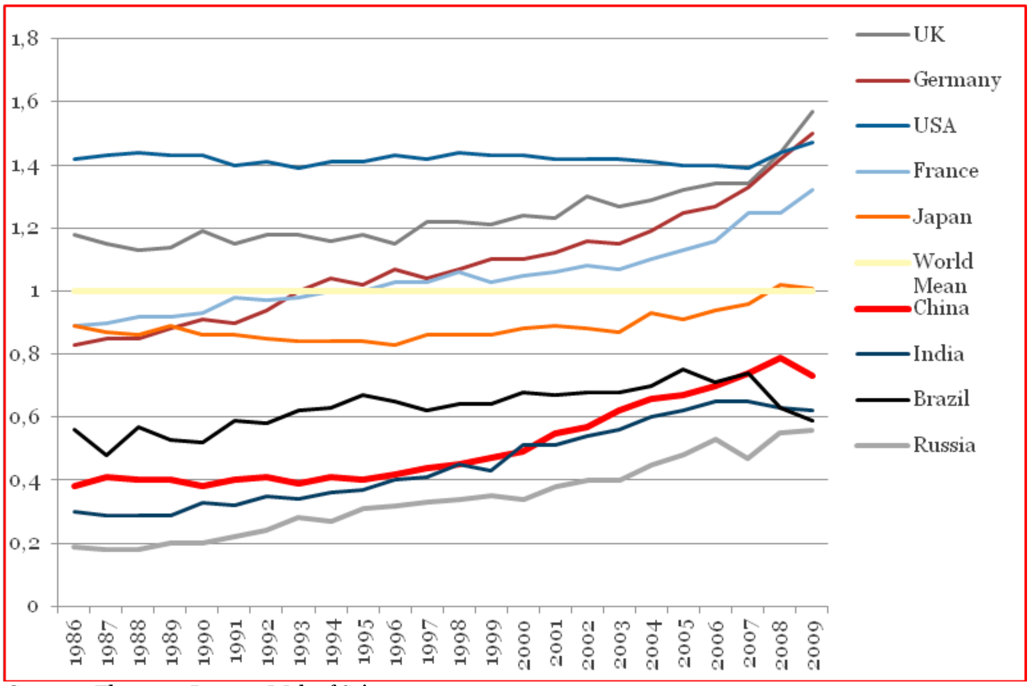
Figure 20 Chinese Publications in the Web of Science, 1986-2009




**Source**: Thomson Reuters Web of Science

Not only the volume but also the quality (measured as a bibliometric Relative Impact Indicator) of Chinese publications has been increasing. However, it remains somewhat below the world average (Figure 21).

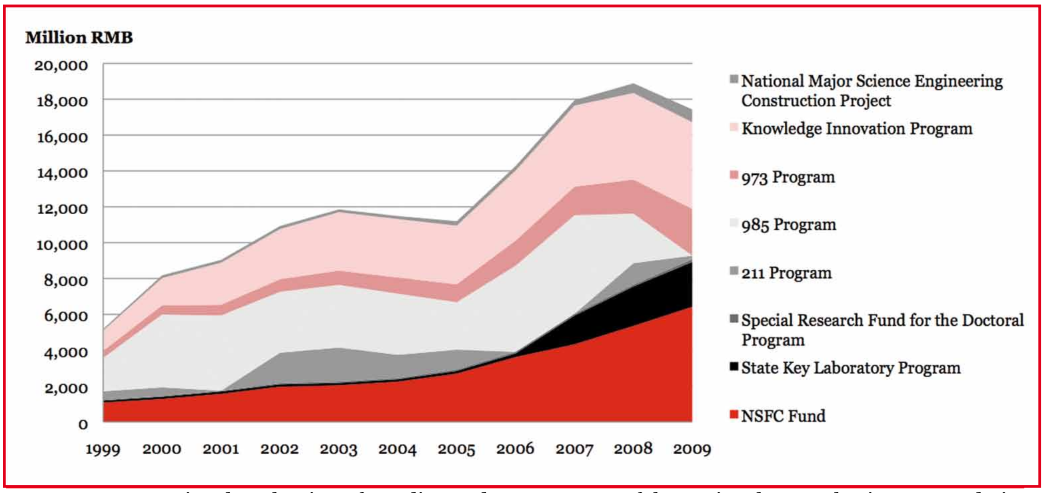
Figure 21 Relative Impacts of National Publications Relative to the World, 1986-2009




**Source**: Thomson Reuters Web of Science

The bulk of Chinese basic research is thematically orientated. Non-oriented funding in China is mainly provided through the National Natural Science Foundation of *China (NSFC*), which is the largest funder of bottom-up-initiated research, though it is smaller than the other basic research funding channels combined (Figure 22).

Figure 22 Main Basic Research Funding Channels in China (1999-2009)




**Source**: International Evaluation of Funding and Management of the National Natural Science Foundation of China, 2011

Within NSFC, small projects and young researcher programmes have no thematic priorities. Larger projects and centres of excellence in practice have to have some relation with national thematic priorities (which are rather broad, to be fair)[86]. Given that non-basic funding is thematically orientated, this means that China operates with the 'Programme 1 / Programme 2 structure described earlier.

China is currently implementing a 15-year 'Medium to Long-Term Plan for the Development of Science and Technology' (MLP). It aims to raise the proportion of GDP devoted to GERD from 1.5% or so in 2006 to 2.5% in 2020, dramatically to reduce dependence upon imported technologies and to induce a culture and practice of domestic innovation[87]. It also aims to raise the proportion of GERD devoted to basic research from the current 5% to a USA-like 15% by 2020 – remembering that in Chinese funding practice the bulk of basic research is thematically specified.

Key features of the MLP are five 'high priority clusters'

- Technologies for water, energy and environmental protection
- IT, advanced materials and manufacturing
- Biotechnologies and their applications
- Space and marine technology
- Basic sciences and frontier technology

These are implemented in part through twenty themes ranging from agriculture through service industries, high-technology industry and transport to urban development. These address China's weak record in commercialisation and innovation, the gap between national capabilities and needs in areas such as energy, water, environmental protection and public health, defence technologies and the modest quality of much scientific research. Some of these priorities are implemented through thirteen engineering and four science 'mega-projects'.

The thematic priorities of the MLP are spelt out in considerable detail. They are not the result of ivory-tower central planning, however, but build on consultation with more than 2000 scientists, engineers and corporate executives (including both social scientists and foreign researchers).

The MLP brings together an integrated set of measures intended to develop the national research and innovation system as a whole.

1. A boost for government investment in R&D

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86 *International Evaluation of Funding and Management of the National Natural Science Foundation of China*, Beijing: NSFC, 2011

87 Cong Cao, Richard P Suttmeier and Denis Fred Simon, 'China's 15-year science and technology plan', *Physics Today* December 2006, pp38-43

2. Tax incentives for science, technology and innovation
3. A government policy of innovative procurement
4. Deliberately assimilating and building upon imported technology
5. Increased use of patenting and other forms of intellectual property, combined with the implementation of an IPR regime and practice similar to that of Western countries
6. Building a mix of basic research infrastructure, infrastructure in the research institutes to enable them to collaborate more closely with industry, technology platforms to help enable innovation
7. Supporting capacity building in the Chinese R&D community by attracting foreigners and expatriate Chinese to work in the Chinese research system
8. Large-scale funding for innovation and engineering projects[88]

The fact that the Chinese research and innovation system is under development and that this development is clearly explained in a plan is very helpful to foreign observers. In particular it makes it clear that

- The balance of effort is firmly towards national and industrial missions, especially innovation
- Increased R&D investment is taking place in the context of a systemic pattern of intervention to secure the availability of human resources, adequate framework conditions and infrastructure across the academic and industrial R&D systems
- The proportion of basic research is planned to rise towards US levels – but most of that growth will be Pasteur's Quadrant work associated with national priorities – building on a foundation of bottom-up, excellence-based funding

It is a lot more difficult to coordinate all this in practice than it is on paper – but there is a clear picture of both the need for coordination and the balance of R&D effort required.

## 4.5 Conclusions

Despite some in-built conceptual weaknesses, the statistics collected by the OECD do tend to confirm our picture of an economy and an innovation process that is increasingly research and science based. Basic research becomes more and more important as countries become economically developed and as companies approach the 'technology frontier'. This happens independently of how the money to pay for these research activities is distributed. However, it is counter-productive to develop the research parts of the innovation system without at the same time maintaining significant activities to do with applications and development.

[88] Mu Rongping, 'China', *UNESCO Science Report 2010: The Current Status of Science Around the World*, Paris: UNESCO, 2010

In Europe, we have largely abandoned the historical role of the state in supplementing market coupling through 'development pairs'. Others – notably the USA but also China – have maintained a more developmental policy where large mission-driven programmes build and maintain capacity in areas of importance to industry and society more broadly.

# 5. The Framework Programme and Horizon 2020

Horizon 2020 in part reflects a realisation that the 'European Paradox' is not a paradox at all. Europe is bad at innovation because it is bad at innovation; the amount and quality of European research has little to do with this fact. Two of Horizon 2020's three 'pillars', and a number of its new instruments, address this fact, placing focus on industrial and societal missions and aiming to fill systemic gaps that have historically impeded the coupling of demand and innovation. To this extent it carries on the historically successful role of the Framework Programme in restructuring and improving the European innovation system and the bulk of any resource increases needs to be devoted to these areas. The European Research Council is having a positive effect on bottom-up basic research funding across the Member States and can exert even greater influence over quality by further 'leveraging' its coordinating role in partnership with Member State research councils.

We begin by discussing the challenges addressed by Horizon 2020 before pointing out some of the important and successful dimensions of past Framework Programmes. Next we show that much of Horizon 2020 is to be understood as a continuation of the Framework Programme tradition. We look at how the three pillars of Horizon 2020 contribute to meeting the challenges and conclude that the best way to use increased budget would be focus on mission- and innovation-related activities in order to tackle the central weaknesses in European innovation.

## 5.1 The key challenges

The idea of a 'European Paradox' was popularised in the Commission's Green Paper on Innovation[89] in 1995. Like the earlier UK Paradox and the later Swedish one, it comprises the idea that 'we' do excellent research but that paradoxically it does not make us economically successful. The evidence for the European paradox offered in the Green Paper was that EU produced slightly more publications per unit of non-business R&D than either the USA or Japan, while producing fewer patents per unit of business expenditure on R&D than these same countries. Even if the premise were correct, it would not follow that the combination of excellent research and poor innovation performance is in any way paradoxical. If you are bad at innovation, you innovate and compete badly. If you innovate, it is useful to have a rich and high quality research system around you, but that does not **cause** you to innovate. Despite this logic, the idea of a paradox remains attractive – perhaps because it allows us to flatter ourselves with the idea that we are

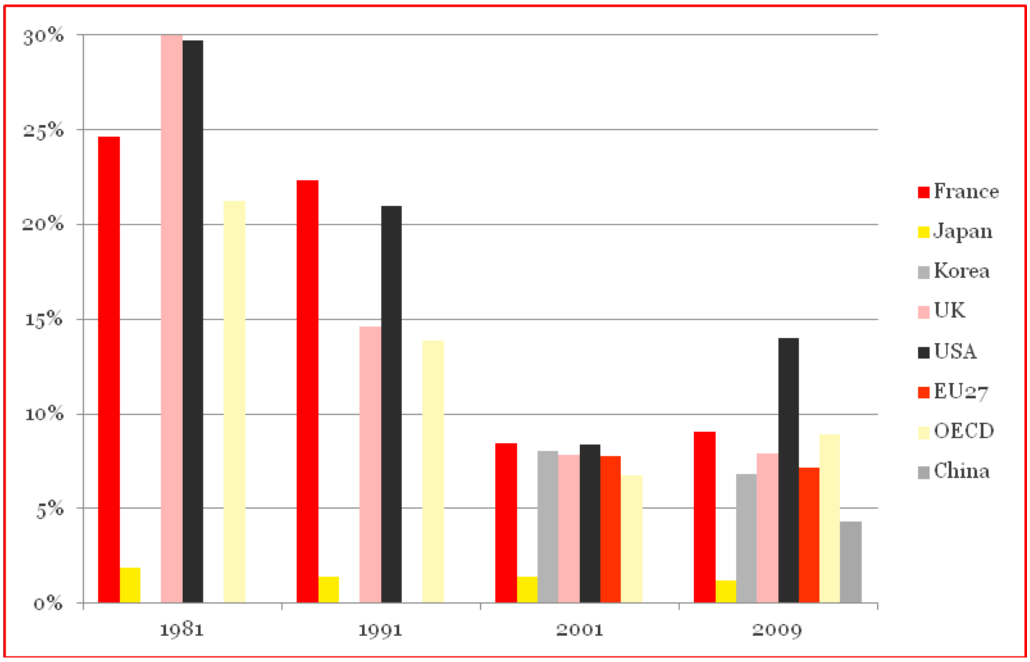
[89] European Commission, *Green Paper on Innovation*, 1995

clever while blaming foreigners for 'stealing' our clever ideas and making all the money. Members of the Swedish research community love to tell the story of the flat screen display being invented in Sweden but then exploited in the Far East. The current equivalent at the European level is the idea that most of the important research on crystalline solar photovoltaics was done in Europe while most of the production has moved to China[90].

In fact, the idea that European research is excellent is undoubtedly true in some areas of science, but at the overall level on a range of bibliometric indicators including those shown in Figure 24, it is not. What makes the big difference between EU and US innovation performance is

- Substantially higher Business Expenditure on R&D (see Figure 8)
- A level of government funding of R&D in industry about twice that of the EU (Figure 23)
- The presence of a large number of technology and research-based missions, ranging from defence through energy and transportation to health that generate a mixture of basic and applied research and a substantial quantity of development
- Significantly better participation rates in higher education[91]

Figure 23 Proportion of BERD Funded By Government, 1981-2009



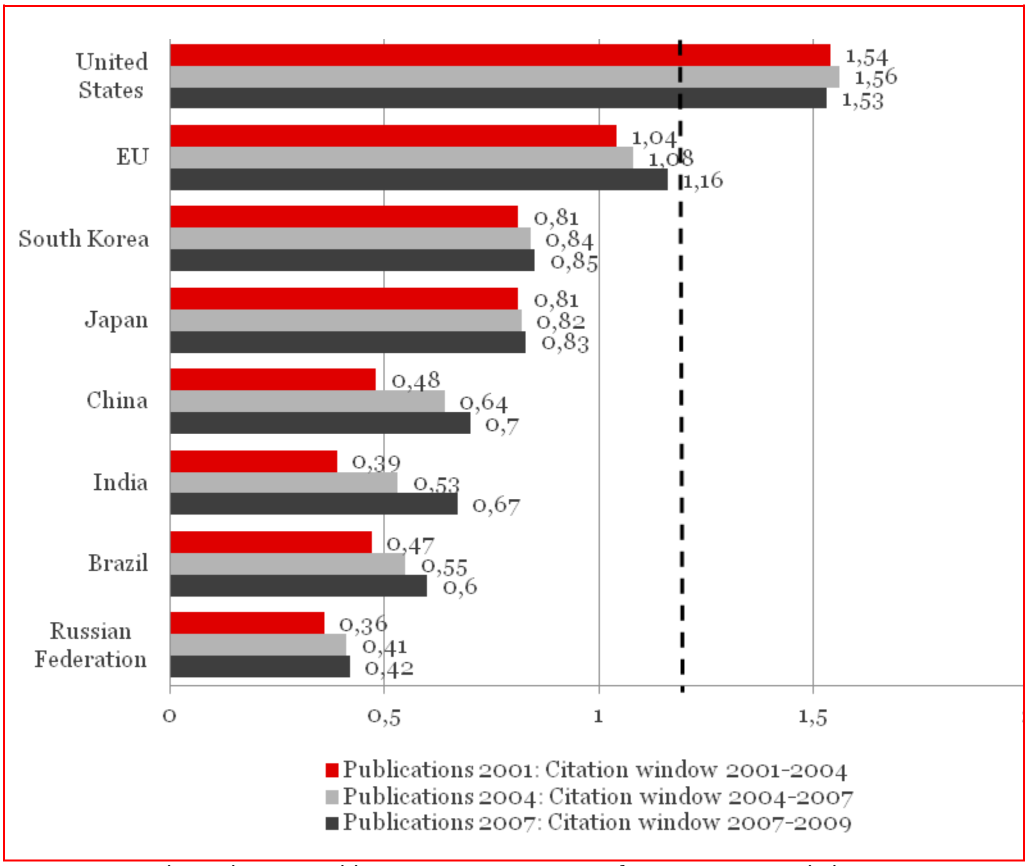

[90] High-Level Expert Group Report on Key Enabling Technologies, Brussels: European Commission, 2011

[91] Giovanni Dosi, Patrick Llerena and Mauro Sylos-Labini, ;The relationships between science, technologies and their industrial exploitation: An illustration through the myths and realities of the so-called "European Paradox"', *Research Policy*, 35(10), 2006, 1450-1464

**Source**: OECD, Main Science and Technology Indicators

Bibliometric evidence suggests there **is** a problem in the quality of EU research. For example, Figure 24 shows that the EU contribution to the top 10% of most highly cited publications is barely better than the world average, relative to the number of publications – and well behind the US performance.

Figure 24 Contributions to the 10% most cited publications, 2001-9




**Source**: Innovation Union Competitiveness Report, 2011, Brussels, European Commission
Data: Science Metrix / Scopus (Elsevier)
Note: (1) The 'contribution to the 10% most cited scientific publications' indicator is the ratio of the share in the total number of the 10% most frequently
cited scientific publications worldwide to the share in the total number of scientific publications worldwide. The numerators are calculated from the total number of citations per publication for the publications published in 2001 and cited between 2001 and 2004, from the total number of citations per publication for the publications published in 2004 and cited between 2004 and 2007 and from the total number of citations per publication from the publications published in 2007 and cited between 2007 and 2009. A ratio above 1.0 means that the country contributes more to highly-cited high-impact publications than would be expected from it's share in total scientific publications worldwide.

In the detail it appears that European science is only quantitatively comparable to US science, but is weaker in overall quality and is severely under-represented in the upper tail of scientific quality. European science is strong in those fields characterised by slow growth and weak in those characterised by rapid or turbulent growth; it is strong in fields characterised by a convergent pattern of growth and weak in those characterised by a divergent or proliferating pattern of growth; and it is strong in fields where

Europe has built common research infrastructure but weaker in those fields reliant on cooperation but not infrastructure[92].

The latest Innovation Union Competitiveness report (2011) stresses four major challenges for Europe

1. Under-investment in R&D in Europe – not only by the state but especially by business
2. Weak knowledge exchange between science and industry
3. Improving but still far from adequate quality in research
4. Unfavourable framework conditions for innovation

Horizon 2020 addresses these, though the fourth also involves considerable additional effort in areas such as regulation. Behind the headline problems lies a diagnosis of stagnation in the level of European research and innovation effort (especially in business), failure to establish and grow enough new companies that shake up and renew the industrial structure (or to reinvent old ones to the same effect), failure to modernise research and education institutions and properly to link them to the rest of society and the persistence of fragmentation among Member States.

## 5.2 What has the Framework Programme done for us?

The main European instrument available to tackle these deficits is the Framework Programme, which is now extended to cover more innovation dimensions than before and renamed 'Horizon 2020'. The evaluation record shows that the Framework Programme has been a powerful instrument for tackling at least some of these issues. The evidence[93] suggests that the FP funds high-quality R&D. Its growth has been accompanied by growth in high-quality international co-publication. It attracts the more excellent researchers in their fields and the more research-intensive companies. It is pre-competitive, so it primarily produces 'intermediate knowledge outputs' as well as technical and market network relationships that are re-used in other R&D and business processes. Participants who enter projects with a deliberate product or process innovation objective are more likely to obtain short-term results than others.

With few exceptions, the FP is too competitive to allow capacity building – that has to be done with national resources. Most participants have only a fleeting relationship with the FP via one or two projects and then they move on. However, new participants appear to learn the value of networked R&D and

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[92] Andrea Bonaccorsi, 'Explaining poor performance of European science: institutions versus policies', *Science and Public Policy*, 34 (5) 2007, 303-316

[93] Erik Arnold, John Clark and Alessandro Muscio, 'What the evaluation record tells us about Framework Programme performance', *Science and Public Policy*, Vol 32, No 5, 2005, pp385-397; Erik Arnold, *Framework Programme 6: Meta-Evaluation,* Brussels: European Commission, DG Research, 2009

increasingly to participate in 'open innovation' activities. There is a strong core of established players and networks whose composition slowly shifts over time. You have to 'earn your spurs' in order to join these networks and to carry on delivering value to your partners if you want to survive. The FP is often associated with pre-normalisation R&D and the development of technical standards. Most participants believe that FP participation increases their competitiveness.

A recent pilot study of the **long-term** impacts of the Framework Programme[94] identified a range of 'impact mechanisms'. It included six substantial cases studies of themes impacted by the FP: Quantum Information Processing and Computing; brain research; atmospheric Ozone research ($O_3$); solar photovoltaics (PV); automotive industry technologies; and the Manufuture Technology Platform. The study found that the scientifically focused cases contain elements of discovery. The Framework is funding serious science and this leads in some cases to progress at a quite fundamental or basic level. Of course, discovery alone is not all that useful. To have societal effects, it must be placed in a wider system that connects it with needs, opportunities, production and eventually markets or other competitive arenas such as policymaking. In four of the cases, the FP made a clear contribution by increasing the volume of knowledge production, especially in relation to applications. This can involve 'translational research' (which 'pushes' fundamental knowledge towards applications) but perhaps more fundamentally makes connections with potential uses and users, often making the mix of work more interdisciplinary, since it is usually the case that the closer research gets to solving real-life problems the more disciplines need to be involved. In one case (QPIC) the Framework Programme appears to have made a decisive contribution to the development of a new discipline.

The study concluded that at the systemic level the Framework Programme does not provide the simple stimuli implied by the linear models but is a complex intervention addressing research and innovation networks and systems. As a pre-competitive, open innovation initiative, it transfers a lot of knowledge into and out of the **stock** of knowledge, an activity that inherently has high spillovers. Its increasing focus on coordination and re-optimising the European innovation system at the European level helps break national lock-ins and provides a way to increase the rate of innovation. Increasingly, it connects research and innovation to other concerns, moving towards a holistic approach to policy. By empowering stakeholder groups to develop and exploit their own strategic intelligence within a wider policy framework, it captures and exploits the power of self-organisation rather than central planning.

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[94] Erik Arnold, Malin Carlberg, Flora Giaracca, Andrej Horvath, Zsusza Jávorka, Paula Knee, Bea Mahieu, Ingeborg Meijer, Sabeen Sidiqi and James Stroyan, *Long-term Impacts of the Framework Programme*, Brussels: EC, DG-Research, 2011

The FP6 evaluation[95] stressed that the historical role of the Framework programme has been as a creator and amplifier of consensus. While this had led to many successes, the FP needed a countervailing force that challenged conventional wisdom and research directions, opening up new opportunities and argued that the Future Emerging Technologies programme and the New and Emerging Fields in Science and Technology programme (which was cancelled early in the life of FP6) were important prototypes for such convention-challenging instruments. Arguably, the ERC also responds to this need for a mix of researcher-initiated and programmed effort.

The ERC is too new to have been decisively evaluated. The EURECIA[96] project has recently produced preliminary evidence, suggesting that the ERC has some major successes to its credit. It has established itself as a 'model' research council, influencing the funding practices of others at Member State level and has established a reputation for having a very demanding quality standard. It has 'leveraged' national research council funding in several Member and Associated States, which have adopted a practice of funding nationally projects that have passed the ERC quality threshold but which the ERC did not then fund. It has provided a way for Member States to benchmark the quality of national research applications and increased the negotiating power of grantees with respect to their organisations, helping them attract more resources. While it is expected that the ERC will lead to an inflow of high-calibre scientists to the EU, there is not yet evidence that this is the case.

### 5.3 Horizon 2020

Horizon 2020 offers a new architecture for the Commission's interventions in research and technological development, comprising three 'pillars'

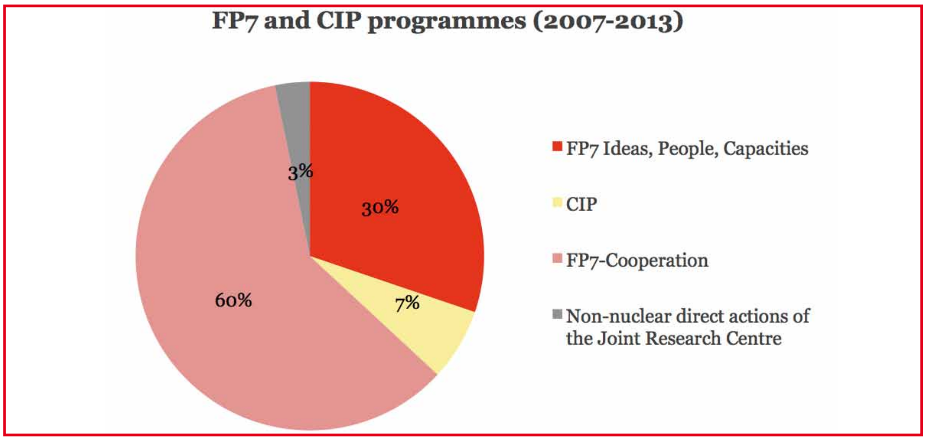
- Industrial leadership
- Societal challenges
- Excellent science

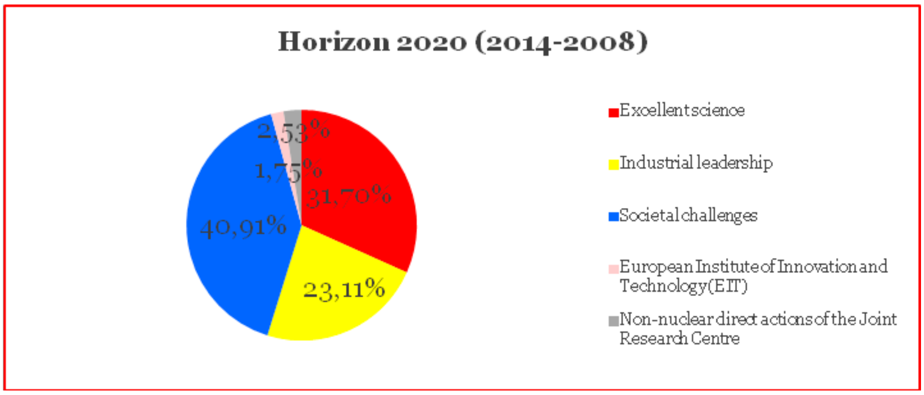
The Commission proposes that the research and technological development parts of Horizon 2020 should have a combined budget of some €78bn – 43% higher (in current money) than FP7's €54bn. At this aggregated level, we can regard the Industrial Leadership and Societal Challenges pillars essentially as a rearrangement of the effort described as 'cooperation' in FP7 (Figure 25).

[95] Ernst Th Rietschel (Chair), Erik Arnold (Rapporteur) et al, *Evaluation of the Sixth Framework Programmes for Research and Technological Development 2002-2006*, Brussels European Commission, 2009

[96] www.eurecia-erc.net/events/final-conference/ accessed April 2012

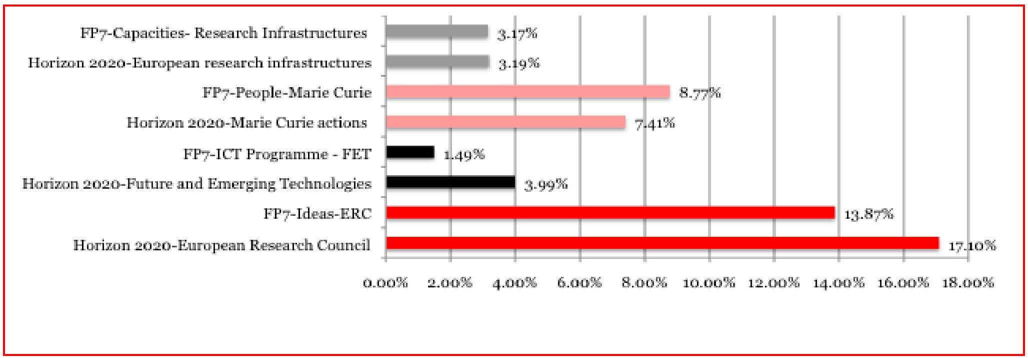
Figure 25 Main Pillars of FP7/CIS and Horizon 2020




The Excellent Science component grows a little as a proportion of the total, reflecting the fact that the ERC started small and grew through the life of FP7. However, once we look inside the pillars, somewhat less radical change is evident, though there are some significant readjustments. Figure 26 shows that inside the Excellent Science pillar, the ERC is the major beneficiary of change. In the Societal Challenges pillar, we can see that the individual challenge areas grow slightly as a share of the overall (much larger) budget, compared with FP7. The focus on sustainability issues clearly increases between FP7 and Horizon 2020 (Figure 27). In the Industrial Leadership pillar, the industrial technologies are in fact the great losers in the transition to Horizon 2020 (Figure 28) – which is surprising given the stated aim in Horizon 2020 to reverse the declining trend in industrial involvement evident since FP5.

Figure 26 Excellent Science Compared with FP7 Equivalents (% of respective budget)




**Note**: the FET FP7 budget is estimated (based on the draft orientations for the ICT work programme from January 2012)

Figure 27 Societal Challenges Compared with FP7 (% of respective budget)

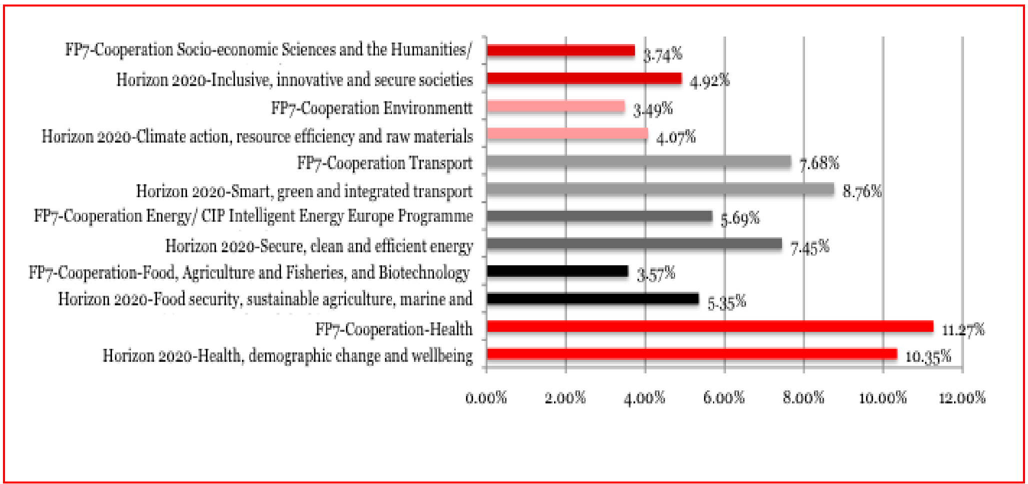
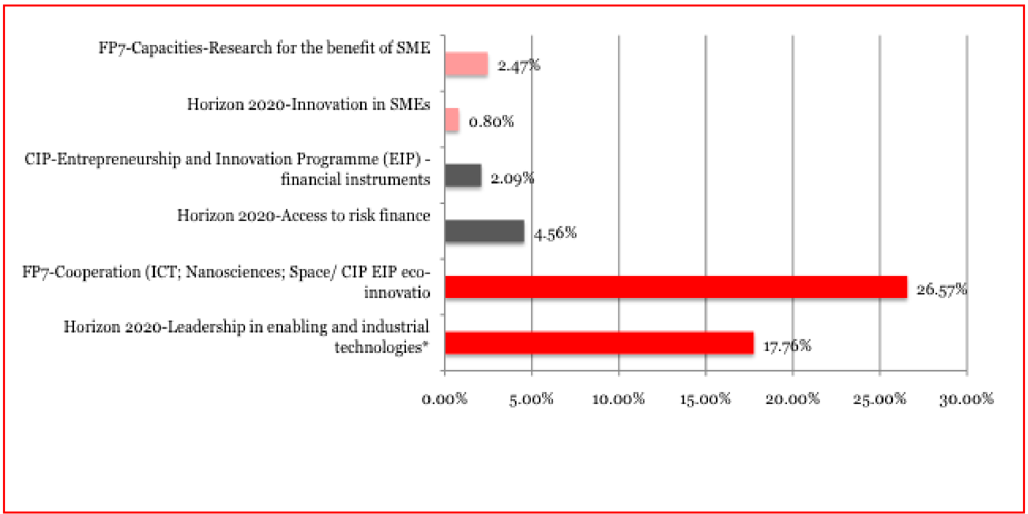



Figure 28 Industrial Leadership Compared with FP7 (% of respective budget)



The three pillars in effect offer the Commission's clientèle 'something for everyone': more researcher-initiated funding for the research community; tackling the 'grand challenges' for the political level; and increased efforts in innovation and commercialisation for the industrial community. Whether the large budget proposed to deliver all this can survive the reality of austerity among the Member States is not clear – and raises the question whether there is a 'right' balance among these lines of action, as opposed to seeking crowd-pleasing budget increases everywhere.

The historical justification for the Commission to pursue the Framework Programme has been the idea of 'European Added Value': the notion that together the Member States (MS) can achieve things that are impossible at the national level. Since the launch of ERA, European Added Value has increasingly shifted from networking MS-level activities to 'optimising' the European research and innovation system at the European level. Increasingly, the Commission aims to do this not only using European-level resources but also by coordinating or 'structuring' MS-level resources, in the form of both money and research performance. The Treaty now gives the Commission the right to legislate about research and technological development so this continent-wide influence will only increase, allowing the Commission to move beyond R&D funding to tackle framework conditions such as a proper common market in knowledge that are necessary in order to build the ERA and allow Europe's strengthened research actors to operate at the European scale.

While hitherto it has been possible to see European- and MS-level research R&D policies as largely independent, the European level increasingly influences the whole and will become a more important determinant of the continent-wide policy mix. A corollary of this increasingly European effort to optimise policy is the need for MS, singly and in variable-geometry groupings, to pursue specialised strategies in areas of comparative advantage. Many of the 'ERA instruments' innovated by the Commission in recent years support this specialisation and help empower stakeholders to develop and pursue variable-geometry strategies that serve the European interest by building larger, stronger, specialised, cross-border R&D communities. The growing importance of EU-level R&D policy makes it crucial not only to innovate new instruments that support the development of the ERA but also to foster a balance between fundamental and more applied research that is conducive to achieving both the Union's societal and its industrial goals.

This balance, however, needs to be determined not **within** Horizon 2020 but in relation to the needs of the European research and innovation system as a whole. That is one reason it contains thematic priorities – some things need EU-level intervention and will get it via Horizon 2020; others do not or are less important and they are not part of the grand design. Equally, while at the level of the European research and innovation system as a whole it is important that there is a range of effective support to different kinds of research and innovation activities – ranging from fundamental research to innovation financing – the Commission does not need to intervene in areas where others are doing a good job or where there is no need for intervention, simply in order to have a 'balanced' set of instruments. An oddity, therefore, is that Horizon 2020 inter alia aims at, "The integration of research and innovation by providing **seamless**[97] and coherent funding from idea to market." The implication is that – despite the best efforts of the MS – there are EU-level deficiencies in funding mechanisms at every step from idea to market. This is unlikely and it is well to note that few MS would try to offer such a set of funding instruments from a single programme or organisation. Commercialisation funding needs business judgements to be made at several stages. This is normally provided in such a way that technology funders do not risk throwing good money after bad by trying to assess the business prospects of ideas to which they are already committed. Generally, they try to involve private sector financing to an ever-greater degree the closer the funding need is to the end market because (a) the closer to market the less defensible state interventions are and (b) MS generally believe that the private sector tends to make better judgements about markets than the state. What **is** important, however, is to strengthen Horizon 2020 in ways that relate to the weaknesses in European innovation, such as the three pillars described in the KETs report[98]: technological research; product demonstration; and competitive manufacturing.

## 5.4 How do the Horizon 2020 pillars contribute?

Based on the problem diagnoses of the Innovation Union Competitiveness Report, the current thinking on European Added Value and what we can see from the evaluation evidence, Figure 29 analyses the expected contribution of each of Horizon 2020's three pillars to European policy objectives and Added Value. The categories used are not fully orthogonal, we have no way to weight them relative to each other and the judgements about the relative contributions of the pillars are qualitative so we must approach the analysis with caution. Nonetheless, the Figure gives a basis for discussing the relative payoffs to each pillar and the desirable relative roles of the European and national levels.

Figure 29 How Horizon 2020 Pillars Address European Policy Objectives and Added Value

| Policy Objectives / European Added Value | Industry | Society | Science |
|---|---|---|---|
| **Stimulates business R&D expenditure** | XXX | XX | |

97 Our emphasis

98 High-Level Expert Group Report on Key Enabling Technologies, Brussels: European Commission, 2011

| Policy Objectives / European Added Value | Industry | Society | Science |
|---|---|---|---|
| **Supports creation of high-growth firms** | XX | X | |
| **Addresses framework conditions for innovation** | XX | X | |
| **Stimulates science-industry knowledge exchange** | XXX | XX | |
| **Acts as a 'focusing device', road mapping, reducing uncertainty** | XXX | XXX | |
| **Builds on existing scientific and industrial strengths** | XXX | XXX | XXX |
| **Breaks down national industrial and scientific lock-ins** | XX | XX | X |
| **Induces or reinforces behavioural change by R&D performers** | XXX | XXX | X |
| **Supports the creation of critical masses and networks in R&D** | XXX | XXX | X |
| **Promotes research competition at the European level** | XXX | XXX | XXX |
| **Funds and stimulates high-quality R&D** | XXX | XXX | XXX |
| **Generates knowledge spillovers** | XXX | XXX | XXX |
| **Supports development of human capital in R&D** | XXX | XXX | XXX |
| **Helps establish new fields or disciplines** | XX | XX | X |
| **Supports scientific discovery** | XX | XX | XXX |
| **Leverages national funds into European configurations** | XXX | XXX | |
| **Supports improved policymaking** | XX | XXX | |
| **Supports internationalisation of the ERA** | XX | XXX | XX |
| **Addresses problems too big for individual Member States** | XXX | XXX | XX |
| **Addresses areas of major socio-economic importance for the EU** | XXX | XXX | |

The 'Industry' and 'Society' pillars have a lot in common because they emerge from the common Framework Programme history – originally through the traditional 'cooperation' projects; more recently supplemented by various variable geometry initiatives (ERA-NETs, Technology Platforms, Joint Technology Initiatives, Joint Programming, the SET and Recovery Plans, etc) that empower groups of stakeholders to establish their own programmes. These newer instruments make the previously rather implicit coordination role of the Framework Programme much more explicit.

As Figure 29 shows, the Industry and Society pillars tackle most of the challenges for European R&D set out in the Competitiveness Report. Their networked character is intended to overcome fragmentation in the European research and innovation system and to 'structure' that system better to ensure EU competitiveness and to meet EU-level needs. The logic of the Science pillar is very different. It relies on competition among individuals rather than cooperation among organisations to achieve impacts.

The Industry and Society pillars address policy objectives related to increasing business expenditures on R&D. Creating high-growth firms has not been a strong focus of the Framework Programme in the past; here and in improving the framework conditions for innovation it will be necessary to employ instruments (such as finance, for which some provision is made in Horizon

2020) that go beyond the traditional ones and also to tackle aspects of regulation that are not within the scope of Horizon 2020 but fit with the Commission's wider efforts to regulate for the ERA. Science-industry cooperation has been central to the FP since the start but has so far not been addressed by the ERC. Acting as a 'focusing device signalling to science and industry about important topics, research questions and ultimately funding and business opportunities as well as creating consensus about future technological developments and standards are long-standing contributions of the FP.

All three pillars tend to focus on building on existing strengths rather than creating new capacity. Only where new fields are explored, so that there are not already strong players able to win in competition, can competitive funding – whether in traditional FP mode or in research council mode – build capacity. However, the act of programming – and to a limited extent the act of raising the competitive pressure, as the ERC does – can jolt stakeholders out of established trajectories and lock-ins and change behaviour. Networking has been the traditional FP approach to building critical mass. While the Science pillar fosters individual researchers rather than organisations, it does also increase their negotiating power within their own organisations and their national research funding systems, so there may be some mass-building effect.

All three pillars are highly competitive, funding high-quality R&D and stimulating knowledge spillovers through various channels including the training and development of researchers. The FP has shown that it can help get new fields established, but this is not a primary activity. In principle, new fields can emerge from an individual scientist's research grant, but there is little machinery in Science for helping this to happen. Science is of course more focused on discovery than the other pillars.

Policy-related objectives, such as leveraging and coordinating the use of national funds in pursuit of specific themes or problems, improving policymaking and more generally addressing areas of socio-economic importance are more clearly addressed by the Industry and Society pillars. All three address the internationalisation agenda. Science tackles problems too big for individual Member States to handle, in the sense that it creates a European-scale competition arena. However, the ERC has demonstrated that it can achieve this by influencing the behaviour of MS research funders. The subsidiarity principle therefore implies that it should continue in this role rather than to expand. To the extent that the key defects in the EU research and innovation system concern innovation it is the Industry and Society pillars that need strengthening.

Especially with the addition of Science to the former FP activities, Horizon 2020 mixes up a number of governance modes.

- The old consultative logic of FP Cooperation often lacks transparency but nonetheless has produced significant results through networking and coordinating R&D. Here the Commission deals directly with stakeholders but after consultation itself decides on the thematic priorities, work programmes and calls (again with a lot of input from the stakeholders)

- The newer ERA instruments tend to involve steering committees of experts external to the Commission but who tend not to represent the Member States either. But they provide platforms for stakeholders to self-organise, define agendas and to varying degrees fund them
- The Industry and Society pillars use both modes of governance to address a range of challenges relevant to most Member States and therefore to Europe as a whole
- Science, especially the ERC, is more akin to traditional 'bottom up' scientific funding where the scientific community effectively sets priorities

This combination equips the EU to operate the 'Programme 2, Programme 1' logic described above.

In 'Programme 2' at the European level, the Science pillar complements and strengthens national efforts to maintain wide-ranging scientific capabilities (in both research and human capital development so as to enable both the generation and the absorption of knowledge) by setting higher quality standards. This is already 'leveraging' national funding at the project level through national research councils funding above-threshold projects that ERC itself cannot fund. This will have a beneficial effect on national quality while leaving space for the national level to take as much or as little of the ERC medicine as it thinks necessary. Diversity of funding sources is important in science. "If we want to grasp the real economic significance of science, we need to recognise it as a source of variety .... It causes new states of the world to proliferate."[99] The work funded will be a mixture of fundamental and applied research. Comparatively modest investment is needed at the EU level in order to exert this influence. Addressing the mobility challenge through European instruments is inherently more expensive.

In 'Programme 1 at the EU level, the other two Pillars build on the foundations of Programme 2 to focus resources and capacity on themes that have societal and industrial priority. Here, too, there is a mixture of fundamental and more applied work – with the fundamental work by definition being in 'Pasteur's Quadrant'. The mix of research types will be driven by the needs of the specific themes pursued, rather than being determined in advance according to some general principle. To the extent that these activities at the EU level are network building, they are inherently expensive to fund. Major effort is needed here in order to tackle industry's under-investment in R&D – especially D. This argues for extending the scope of Horizon 2020 more towards product procurement, demonstration and tackling the market risks of

[99] Michel Callon, 'Is science a public good?' *Science, Technology and Human Values, 19, 1994, 395-424*

the large-scale disruptive technologies needed, for example in tackling climate change. The trend towards 'leveraging' national resources through Joint Programming and attracting complementary funding from the national level is therefore positive but the value of the investment needed at the common European level is also high.

Operating these two programmes at the EU level requires considerable strategic intelligence – monitoring the quality and quantity of effort available across the two programmes as a basis for changing course when needed. A potential gap in the picture is the lack of EU-level responsibility for the development of disciplines. (An interesting comparator for ERC is the National Science Foundation of China, which has an active role in ensuring the health and development of disciplines. Doing something about this would, of course, require a more selective approach in pursuit of discipline development.)

At the same time, since the endowments and needs of the Member States vary, there are clear limits to what can or should be done from the European level. Each state in effect needs to construct its own pair of Programmes 1 and 2, using a mixture of national and EU-level instruments - including of course selective use of variable geometry instruments. Strategic intelligence therefore needs to be 'distributed'[100] – there need to be clear (indeed, generally clearer than is the case today[101]) national strategies about research and innovation more broadly and how to make best use of the European level in particular. That said, the complexity of defining such strategies is high, especially in the face of constant change in both the EU-level portfolio and national needs. The EU has established good planning practices in areas such as the Structural Funds and in various regional programmes, requiring and supporting the development of regional innovation strategies so as to improve the practice of development. While the OMC process has included both studies and peer reviews of national 'policy mixes' for innovation and research, these have not tended to produce policies or strategies that commit the Member States strongly. A useful measure to increase the effectiveness of Horizon 2020 would be a programme of further activity to encourage the Member States to develop such strategies.

[100]Stefan Kuhlmann, *Improving Distributed Intelligence in Complex Innovation Systems: Final Report of the Advanced Science & Technology Policy Planning Network (ASTPP)*, Karlsruhe: Fraunhofer ISI, 1999

[101]Ernst Th Rietschel (Chair), Erik Arnold (Rapporteur) et al, *Evaluation of the Sixth Framework Programmes for Research and Technological Development 2002-2006*, Brussels European Commission, 2009; Rolf Annergerg (Chair), Iain Begg (Rapporteur) et al, *Interim Evaluation of the Seventh Framework Programme*, Report of the Expert Group, Brussels: European Commission, 2010

## 5.5 Conclusions

The diagnoses of European needs in this paper and those that underlie Horizon 2020 are similar: while the quality of research also needs to be improved, the key weaknesses of the European research and innovation system are in innovation activities. Doing more science will not repair those weaknesses. Rather, there is a need to expand mission-driven R&D for tackling industrial and societal needs. The ERC seems already to be doing a good job of encouraging quality improvements, in partnership with national research councils. The implications for Horizon 2020 are clear.

- Focus resource increases on the innovation-relevant parts of the industrial and societal missions
- Continue to fund a mixture of basic and applied research within those missions, but increase the effort on development and related functions
- Maintain but do not increase the ERC effort; instead work in cooperation with national research councils to leverage the European level so as to raise national as well as European quality levels

Not least because Horizon 2020 involves setting thematic priorities, it is important that the Member States complement it with clear national strategies. The point of Horizon 2020 is partly to 'optimise' the European research and innovation system at the European level. Member States therefore need to ensure that their own policies complement the European strategy in ways that serve the national interest. In many cases, this will involve setting priorities that are not the same as the overall European ones.

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