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Science-Technology-Industry Links and the "European Paradox": Some Notes on the Dynamics of Scientific and Technological Research in Europe

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Science-Technology-Industry Links and the "European Paradox": Some Notes on the Dynamics of Scientific and Technological Research in Europe

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Abstract

This paper discusses, first, the properties of scientific and technological knowledge and the institutions supporting its generation and its economic applications. The evidence continues to support the broad interpretation which we call the "Stanford-Yale-Sussex" synthesis. Second, such patterns bear important implications with respect to the so-called "European Paradox", i.e. the conjecture that EU countries play a leading global role in terms of top-level scientific output, but lag behind in the ability of converting this strength into wealth-generating innovations. Some descriptive evidence shows that, contrary to the "paradox" conjecture, European weaknesses reside both in its system of scientific research and in a relatively weak industry. The final part of the work suggests a few normative implications: much less emphasis should be put on various types of "networking" and much more on policy measures aimed to both strengthen "frontier" research and strengthen European corporate actors.

JEL Classification: D80, O33, O38.
Keywords: Open Science, European Paradox, Science and Technology Policy.

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1 Introduction

We originally began this work simply meaning to address what is known as the "European Paradox". Such a paradox — which sounds quite similar to an earlier "UK paradox", fashionable around thirty years ago — refers to the conjecture that EU countries play a leading global role in terms of top-level scientific output, but lag behind in the ability of converting this strength into wealth-generating innovations. However, we soon realized, first, that the paradox mostly appears just in the flourishing business of reporting to and by the European Commission itself rather than in the data. Second, both the identification of the purported paradox, and the many proposed recipes suited to eliminate it, happen to be loaded with several, often questionable, assumptions regarding the relationship between scientific and technological knowledge, and between both of them and the search and production activities of business enterprises.

Hence we decided to move a couple of steps backward and start by making explicit where we stand in the long-lasting controversy on the nature and properties of scientific and technological knowledge and on the institutions supporting its generation (section 2). The proposed framework, we suggest, fits quite well with a series of robust "stylized facts", notwithstanding the multiple criticism recently undergone by the institutional setup which grew in the West over more than a century ago and fully developed after World War II (sections 3 and 4). Having spelled out the interpretative tools, we turn to the evidence supporting the existence of a "European paradox" (or a lack of it) (section 5) and discuss the European comparative performance in terms of scientific output, proxies for technological innovation, and actual production and export in those lines of business which draw more directly on scientific advances. Indeed, one does not find much of a paradox. Certainly one observes significant differences across scientific and technological fields, but the notion of an overall "European excellence" finds little support. At the same time one does find ample evidence of a widespread European corporate weakness, notwithstanding major success stories.

The interpretation bears also far reaching normative implications (section 6 and section 7). If we are right, much less emphasis should be put on various types of "networking", "interactions with the local environment", "attention to user need" — current obsessions of European policy makers — and much more on policy measures aimed to both strengthen "frontier" research and, at the opposite end, strengthen European corporate actors.

2 Science and technology: some interpretative yardsticks

One has written extensively elsewhere on the subject (Dosi, 1982, 1988; Dosi et al., 2004). Here, suffices to sketch out what one could call the *Stanford-Yale-Sussex* (SYS) *synthesis*, sure to displease almost everyone, as a shorthand for the confluence between works on the economics of information (including Arrow (1962); Nelson (1959); David (1993, 2004)) and works focussing on the specific features of technological knowledge (including Freeman (1982, 1994); Freeman and Soete (1997); Nelson and Winter (1982); Nelson (1959); Pavitt (1987, 1999); Rosenberg (1976, 1982); Winter (1982, 1987); and also Dosi (1982, 1988)). In such a *synthesis*, first, one fully acknowledges some common features of information and knowledge

— in general, and with reference to scientific and technological knowledge, in particular. Moreover, second, one distinguishes the specific features of technological knowledge and the ways it is generated and exploited in contemporary economies.

As to the former point, both information and knowledge share the following properties

- Some general features of public goods: (*i*) non-rival access (i.e. the fact that one holds an idea does not constrain others from holding it to); (*ii*) low marginal cost of reproduction and distribution, which *in principle* makes it difficult to exclude others from having access to newly generated information (except for legal devices such as copyrights and patents), as compared to high fixed costs of original production [The latter point applies primarily to *information, stricto sensu*].
- A fundamental uncertainty concerning the mapping between whatever one expects from search activities and their outcomes.
- (Relatedly) serendipity in the ultimate economic and social impact of search itself (Nelson, 2004a).
- Quite often, very long lags between original discoveries and "useful" applications.

However, scientific and even more so technological knowledge share, to different extent some degrees of *tacitness.* This applies to the pre-existing knowledge leading to any discovery and also to the knowledge required to interpret and apply whatever codified information is generated. As Pavitt (2001) puts it with regards to technological knowledge

- "*most technology is specific, complex . . . cumulative in its development*". "Specificity" applies in two senses: "*It is specific to firms where most technological activity is carried out, and it is specific to products and processes, since most of the expenditures is not on research, but on development and production engineering, after which knowledge is also accumulated through experience in production and use on what has come to be known as "learning by doing" and "learning by using"*" (Pavitt, 1987) (p.9).
- Moreover "*the combination of activities reflects the essentially pragmatic nature of most technological knowledge. Although a useful input, theory is rarely sufficiently robust to predict the performance of a technological artefact under operating conditions and with a high enough degree of certainty, to eliminate costly and time-consuming construction and testing of prototype and pilot plant*"(Pavitt, 1987)(p.9).

A distinct issue regards the relations between scientific knowledge, technological innovation, and their economic exploitation. In this respect, note that the *SYS synthesis* is far form claiming any linear relation going from the former to the latter. On the contrary many contributors to the SYS view have been in the forefront in arguing that the relationships go both ways (see Freeman (1982, 1994); Rosenberg (1982); Kline and Rosenberg (1986); Pavitt (1999), among others).

In particular one has shown that, first, technological innovations have sometimes preceded science in that practical inventions came about *before* the scientific understanding of why they worked (the engine is a good case for the point).

Second, it is quite common that scientific advances have been made possible by technological ones especially in the fields of instruments (e.g. think of the importance of the microscope).

Third, one typically observes complementarities between science and technology, which however "varies considerably amongst sectors of application, in terms of the direct usefulness of academic research results, and of the relative importance attached to such results and to training" (Pavitt, 1987)(p.7).

Having said that, it is also the case that since the Industrial Revolution, the relative contribution of science to technology has been increasing and its impact has become more and more pervasive, while the rates of innovation have often been shaped by the strength of the science base from which they draw (Nelson, 1993; Mowery and Nelson, 1999). In turn, "*this science base largely is the product of publicly funded research and the knowledge produced by that research is largely open and available for potential innovations to use. That is, the market part of the Capitalist Engine [of technological progress] rests on a publicly supported scientific commons*". (Nelson, 2004a)(p.455).

Together, the fundamental vision underlying and supporting such a view of publicly supported *open science* throughout a good part of the 20^{th} century entailed (*i*) a sociology of the scientists community largely relying on self-governance and peer evaluation, (*ii*) a shared culture of scientists emphasizing the importance of motivational factors other than economic ones and (*iii*) an ethos of disclosure of search results driven by "winner takes all" precedence rules[1].

So far so good. However, both the factual implications of the *SYS synthesis* and the normative implications of the *Open Science* institutional arrangements have been recently under attack from different quarters.

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[1] On those points following the classic statements in Bush (1945); Polanyi (1962) and Merton (1973), see the more recent appraisals in Dasgupta and David (1994); David (2004); Nelson (2004a) and the conflicting views in Geuna et al. (2003).

3 The Open Science system under threat

It is worth to start asking the question why the institutional set-up governing the generation of scientific knowledge and the relations between science, technology and industry has been put into question despite the fact that it has worked remarkably well through most of the 20^{th} century. [More detailed analyses from different angles, which we largely share, can be found in David (1997), Nelson (2004a), and Pavitt (2001)]. In that, note that the challenges to the "Open Science" institutions often have come confusingly folded together with plenty of remarks regarding the two-ways interactions between science and technology, offering the misleading impression that lack of smooth flows between science and its applications would bear any direct consequence in terms of the publicity of scientific results themselves.

Here are, telegraphically, what we consider major drivers and byproducts of the critique of the "open science" system.

First, as Pavitt (2001) succinctly puts it, the consensus to the institutional arrangement supporting publicly funded open basic science, *in primis* in the US, has been a sort of "social pact" catalyzed by the "fear of communism and cancer". Nowadays, half of the reasons have disappeared, substituted by "terrorism", which however can hardly play the same role. Indeed in Guantanamo times it is difficult to imagine "universalist" missions linking scientific research and political objectives akin those of the anti-communist era.

Second, the critique of the "linear model", the one, to repeat, naively suggesting unidirectional "trickle down" flows from science to technology to profit-driven production activities, has gone far too far. It has done so with the help of plenty of economists who did finally take on board some of the "economics of information" findings (cf. above all the pioneering works of Nelson (1959) and Arrow (1962)), while totally neglecting at the same time the differences between sheer *information* and technological *knowledge*, mentioned earlier. The result has been a widespread notion of "plasticity" of both scientific and technological search to economic incentives. Sure, if information bears public good features, than "market failure" problems are bound to arise. But whenever the incentive structure can be fixed — this story goes — then knowledge production should properly respond to incentives much alike the production of steel or automobiles. Together the fundamental specificities stemming from the very nature of the scientific and technological problem-solving activities disappear. "Incentives" can fix anything, from the cure to cancer to the proof of the last Fermat theorem, as easy as one can elicit a variation in any ordinary production. [On the contrary view which we largely share, cf. Nelson (2003); see also a critical review of parts of the discussion on technology and problem-solving in Dosi, Marengo and Fagiolo (2004)].

If one lets this dangerous stuff available in the hands of religious believers, one indeed gets an explosive mixture. An archetypical case is Kealy (1996) — properly reviewed by David (1997) —, disciple of the economist inspired *zeitgeist* on the "magic of market place" — as Ronald Reagan used to say —, and of the miracles of property rights. David (1997) warns us about how a "market ideology" in conducive times may easily become a "scholarly" reference for all those who are just eager to believe it, irrespectively of the soundness of the underlying evidence. And indeed our times seem particularly favorable to the spread of such ideologies.

Another point of attack against *Open Science* has been the extension of the Property Right System to the institutions generating scientific knowledge (in primis, universities) and the expansion of the domain of patentability.

Regarding the former, the Bayh-Dole Act (1980) in the US is considered a landmark, allowing (indeed encouraging) universities to take out patents on their (publicly funded) research results. Similar legislation is nowadays common throughout the world.

Concerning the domains of patentability, one has seen a progressive extension of what is patentable which has now come to include living entities, genes, algorithms, data banks, and even "business models" (!?). These institutional changes have been implicitly or explicitly supported by the idea that "more property rights are generally better" in that they cure the "market failure" associated with the *public-nature* characteristics of scientific knowledge (as if it were a problem!!). An outcome has been that "*important areas of science are now much more under the sway of market mechanisms than used to be the case. And in particular, in some important fields of science important bodies of scientific understanding and technique now are private property rather than part of the commons*" (Nelson, 2004a)(p.462).

The last challenge to the Open Science System — and to a significant extent also to the *SYS synthesis* — has come from quite distinct quarters, which could come under the heading of the "social constructivism/deconstructivism" perspective. The current is made of multiple streams which however share some similar notion of "plasticity" of science and technology, this time under the pressure of social forces and "political negotiation".

There is little doubt on the importance of the *social shaping of technology*, as MacKenzie and Wajcman (1985) put it (see also Rip et al. (1995)). However important controversies concern (*i*) the bounds which the nature of specific technical problems and of specific bodies of knowledge put upon the reach of "battling competing interests and more or less effective campaigns to capture the hearts and minds of (different constituencies)" (Nelson, 2004b) (p.514), and (*ii*) the degrees of "*social* determinism" driving technological and scientific change. And indeed many versions of "social constructivism" depart a long way from the SYS synthesis: pushing it to a caricature, sometimes one has the impression that with good bargaining skills even gravitation and thermodynamics laws may be renegotiate with nature!

Finally, on the institutional side it is suggested that the modes of organization of scientific and technological search — centered on universities, corporate laboratories, relatively structured disciplinary fields, peer review of the outcomes of scientific search, etc. — has been progressively replaced by what Gibbons et al. (1994) call "Mode 2 of knowledge production". In brief, as summarized by Martin (2003), such a mode involves "multi-or trans-disciplinary research carried out in a growing variety of institutions and with a blurring of the boundaries between the traditional sectors (university, industry, and so on...) and also between science and society...[and] knowledge is increasingly being produced "in the context of application [...] with societal needs having a direct influence from the early stage and with relatively explicit social accountability for the funding received by the government" (Martin, 2003)(p. 12-13).

4 Some Persistent 'Stylized Facts'

The empirical grounds for such a statement are of course crucial for the entire "revisionist" story to hold.

Consider the following pieces of evidence partly drawn from Pavitt (2001) and

Pavitt (2003).

1. Contrary to the claim that scientific and technological *knowledge* can be increasingly reduced to sheer "information", the distinction between the two continues to be highly relevant. A good deal of knowledge is and is likely to continue to be rather "sticky", organization- and people-embodied and often also spatially clustered. Related to this is the persistence of widespread agglomeration phenomena driven by top level research (see Jaffe et al. (1993) among many others and Breschi and Lissoni (2001) for a critical review).

2. *Useful academic research is good academic research.* "Systematic evidence from the US shows that the academic research that corporate practitioners find most useful is publicly funded, performed in research universities, published in prestigious referred journals" (Pavitt, 2001)(p.90) and frequently cited by academic themselves (on these points see Narin et al. (1997) and Hicks et al. (2000)).

3. *Government funding of basic research is responsible, especially in the US, for most major scientific advances*, including in the fields od information sciences and bio-sciences (Pavitt (2001) and the references cited therein).

4. The proportion of *university research that is business financed is very low everywhere* (typically less than 10%) and *lower in the US than in Europe* (see Table 7 and the discussion below).

5. *The expansion of US university patenting has resulted in a rapid decline of the patent quality and value* (Henderson et al., 1998)).

6. Increases in licensing income in leading US universities are concentrated in biotech and software, and have preceded the Bayh-Dole act. · Moreover, income flows from licensing are quite small as compared to the overall university budget: in most cases they are unable to cover even the administrative costs of the "technology transfer office" in charge of them!

   · At the same time still anecdotal evidence begin to hints at the ways the new appropriation regimes for public research tends to corrupt the ethos of researchers and twist their research agendas and in the US even

   > "*[s]ome of the nations largest and most technology-intensive firms are beginning to worry aloud that increased industrial support for research is disrupting, distorting, and damaging the underlying educational and research missions of the university, retarding advances in basic science that underlie these firms longterm future*" (Florida, 1999). [On many of the foregoing points see also Nelson (2004a)].

7. Interestingly, only very rarely a critique of the Open Science System and public funding of basic research has come from corporate users, except for peripheral countries and peripheral entrepreneurs — such as e.g. Italian ones — hoping to transform universities in sorts of free training subsidiaries. On the contrary, notably, "in the UK, where critical rhetoric is among the strongest, it comes mainly from government sources... In the US, companies like IBM have complained recently about the potentially armful effects on future competitiveness of reduction in public support to academic research in the physical sciences" (Pavitt, 1999) (p.90). At the same time there is an increasing perception also *among business firms* that "too much appropriability" hurts also firms themselves. In fact, as noted by Florida (1999),

> *"[l]arge firms are most upset that even though they fund research up front, universities and their lawyers are forcing them into unfavorable negotiations over intellectual property when something of value emerges. Angered executives at a number of companies are taking the position that they will not fund research at universities that are too aggressive on intellectual property issues.... One corporate vice president for industrial R&D recently summed up the sentiment of large companies, saying, "The university takes this money, then guts the relationship". [But also] [s]maller companies are concerned about the time delays in getting research results, which occur because of protracted negotiations by university technology-transfer offices or attorneys over intellectual property rights. The deliberations slow the process of getting new technology to highly competitive markets, where success rests on commercializing innovations and products as soon as possible*".

More generally, both upstream researchers and downstream product developers begin to perceive what Heller and Eisenberg (1998) have called the *anticommons* tragedy: the excessive fragmentation of Intellectual Property Rights among too many owners can slow down research activities and product development because all owners can block each other.

With this general background in mind, broadly supporting the *SYS* interpretation and the continuing effectiveness of Open Science institutional arrangements, let us turn to the comparative assessment of the mechanisms of generation and economic exploitation of scientific and technological knowledge in the EU.

5 In search of the purported ”European Paradox”

The central point of the ”paradox” is the claim that the EU scientific performance is ”excellent” compared with its principal competitors, while Europe's major weakness lies in its difficulties in transforming the results of research into innovations and competitive advantages.

One of the first official documents that popularized the ”paradox” was the Green Paper on Innovation (EC, 1995). The two pieces of evidence provided therein in support of it, and thereafter too often taken for granted, were, first, the (slightly) higher number of EU publications per euro spent in non-business enterprise R&D (nonBERD) and, second, the lower number of granted patents per euro spent in BERD *vis-à-vis* the US and Japan. Those phenomena, as important as they can be, do not shed much light on the substance of the ”paradox” and, as a matter of fact, even the European Commission seems to admit in its Third Report on Science and Technology Indicators (EC, 2003) that the ”paradox is vanishing”[2].

What does indeed the overall evidence tell us? In what follows, we shall illustrate some of the strengths and weaknesses of European Science and Technology (S&T) system, arguing that the paradox is nowhere to be seen.

First, let us briefly consider the claim on ”scientific excellence”.

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[2] One of the documents published by the Commission that present the results has a revealing title: ”From the 'European Paradox' to declining competitiveness”.

The pieces of evidence and myths on the European scientific leadership

A central part of the "Paradox" regards the width, depth and originality of European Science. Discerning wether the the data support the claims of a purported European leadership[3] is not a trivial task. Bibliometric analysis offers important insights, but also presents drawback and biases. To begin with, the main source of data, the Thomson ISI dataset, is itself a business activity of the Thomson Corporation responding to economic incentives. For example, the decision on weather to include a given journal, is focussed more on libraries (which have to decide which journal is worth buying) than on scientific reasons as such[4]. Second, comparing citation across disciplines is likely to be misleading, given different citation intensities (e.g. papers in medical research are much more cited than mathematical ones). Nevertheless, bearing in mind such limitations, measuring the *Scientific Impact of Nations* continues to be a revealing exercise. And indeed, as we show below, the picture that emerges from data on publications and citations is far from pinpointing a European leadership in science.

Advocates of the "paradox" notion have emphasized that, during the second half of the nineties, Europe has overtaken the US in the *total* number of published research papers. However, the latter indicator needs to be adjusted by a scaling factor due to sheer size: otherwise one could claim that Italian science base is better than Swiss one given the higher total number of papers published! The first column of Table 1 shows that, if one adjusts for population, European claimed

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[3] A view, again voicefully endorsed by most of the EU Commission: so, the chapter of the Third Report devoted to measure the European performance in knowledge production is titled "Scientific output and impact: Europe's leading role in world science"(EC, 2003).

[4] Eugene Garfield, founder and stock holder of the ISI, suggests indeed to use the Impact Factor based on ISI citations mainly to evaluate journals themselves, but not individuals or single works (Garfield, 1996). Straightforward unweighted citations may yield less of a bias.

leadership in publication disappears[5].

Moreover, in science, together with the numbers of publications, at least equally important, are the originality and the impact of scientific output upon the relevant research communities. Two among the most used proxies of such an impact are articles' citations[6] and the shares in the top 1% most cited publications.

As shown in Table 1, the US is well ahead with respect to both indicators. In particular, controlling for population, the *outstanding* EU output is still less than half than the US one.

In the second and third column of the same table, we decompose the output (i.e. number of publications, citations, and top 1% publications) per population indicator, into two components: a measure of scientific productivity of university researchers (i.e. output per university researcher) and a an index for the intensity of university researchers on population. The table clearly shows that US leadership is due to the quality of research published rather than on the sheer number of researchers.

Similar results are obtained from another measure of research performance based on individuals citations in distinct scientific fields. King (2004) reports that considering 14 scientific fields

> "*Of the top 1,222 scientists [...] 815, or 66%, are from the United States and only 251 from the sum of the United Kingdom (100), Germany (62), France (29), Switzerland (26), Sweden (17) and Italy (17)*" (p.315).

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[5] Certainly normalization by population is a very rough proxy which also averages across very different entities, ranging from Sweden, Germany and the UK all the way to Italy, Greece and Portugal (just sticking to EU-15). However also the US average over Massachusetts and California but also Mississippi and Idaho.

[6] Typically, they are very skewed: only a few publications are highly cited, while the overwhelming majority of articles receives zero citations.

Table 1: **Publications and Citations weighted by Population and University Researchers**

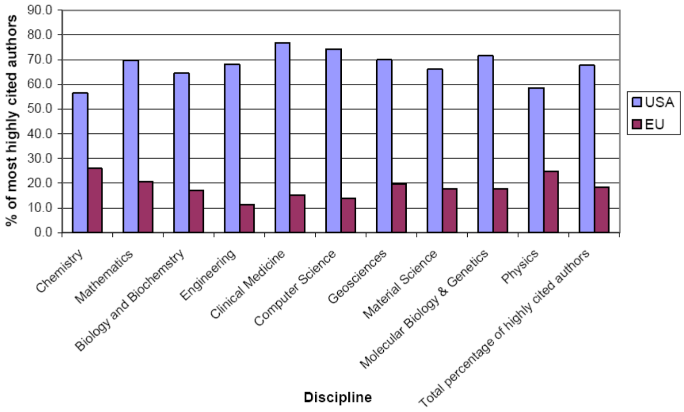
	$\frac{\textbf{Pubblications}}{Population}$	=	$\frac{\textbf{Publications}}{Researchers}$	×	$\frac{Researchers}{Population}$
US	**4.64**		**6.80**		**0.68**
EU-15	**3.60**		**4.30**		**0.84**
UK	5.84		6.99		0.84
Germany	3.88		4.77		0.81
France	3.96		4.09		0.97
Italy	2.58		5.83		0.44

	$\frac{\textbf{Citations}}{Population}$	=	$\frac{\textbf{Citations}}{Researchers}$	×	$\frac{Researchers}{Population}$
US	**39.75**		**58.33**		**0.68**
EU-15	**23.03**		**27.52**		**0.84**
UK	42.60		51.00		0.84
Germany	26.82		32.98		0.81
France	25.81		26.68		0.97
Italy	16.89		38.25		0.44

	$\frac{\textbf{Top1\%publications}}{Population}$	=	$\frac{\textbf{Top\%publications}}{Researchers}$	×	$\frac{Researchers}{Population}$
US	**0.09**		**0.13**		**0.68**
EU-15	**0.04**		**0.04**		**0.84**
UK	0.08		0.10		0.84
Germany	0.05		0.06		0.81
France	0.04		0.05		0.97
Italy	0.03		0.06		0.44

Notes: Our calculations based on numbers reported by King (2004) and OECD (2004a). Number of publications, citations and top 1% publications refers to 1997-2001. Population (measured in thousands) and number of university researchers (measured in full time equivalent) refer to 1999.

Figure 1: **Most cited authors**

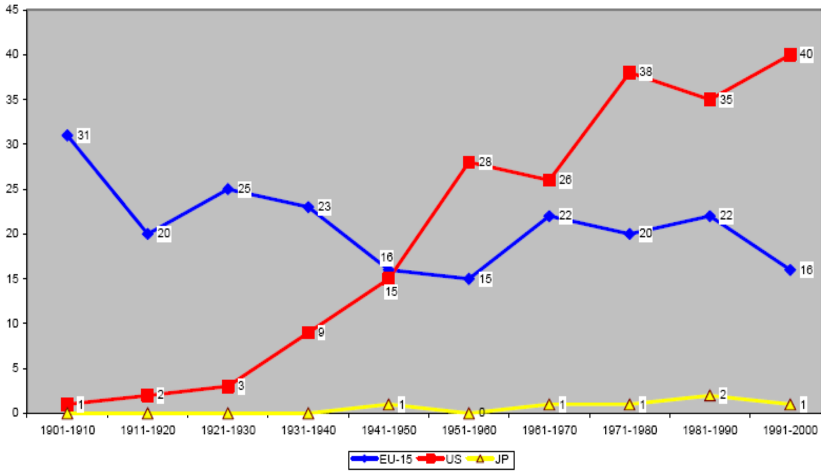


Analogously, Figure 1, based on a recent Royal Society report, shows that the overwhelming majority of the most highly cited authors in ten disciplines have US affiliations (Royal Society, 2004).

In line with the above is the evidence concerning Nobel Prize winners displayed in Figure 2. After the Second World War the gap between US and EU has been growing at an impressive rate.

Of course, despite the variety of ways of categorizing scientific disciplines, there is a high inter-disciplinary variation in the revealed quality of European research. Following EC (2003)(p.287), consider eleven subfields (Agriculture and Food, Clinical Medicine and Health, Physics and Astronomy, Basic Life Science, Chemistry, Mathematics and Statistics, Biology, Earth and Environment, Computer, Biomedicine and Pharmacology, and Engineering) and compare a composite index which takes into account the number of publication, number of citations and

Figure 2: **Nr. of Nobel Prizes in chemistry, physics, medicine or physiology by ten year periods, EU-15, US, JP**



Source: EC (2004).

relative citation impact score. Then, one finds that NAFTA (US plus Canada and Mexico) compared to EU-15, performs better in clinical medicine, biomedicine, and does especially well in chemistry and the basic life sciences. Using a different and more aggregate classification and comparing citations shares, King (2004) also finds US superiority in life and medical sciences, while Europe performs slightly better in physical sciences and engineering (see Figure 3). Incidentally, a few important distinctive patterns within the EU also emerge: for example France is strong in math, while Germany and UK do relatively well in physical and life science respectively[7].

Figure 4 focuses on the citation patterns in one of the knowledge drivers of the ICT revolution, namely computer sciences. Regrettably, the EU performance is on average rather disappointing.

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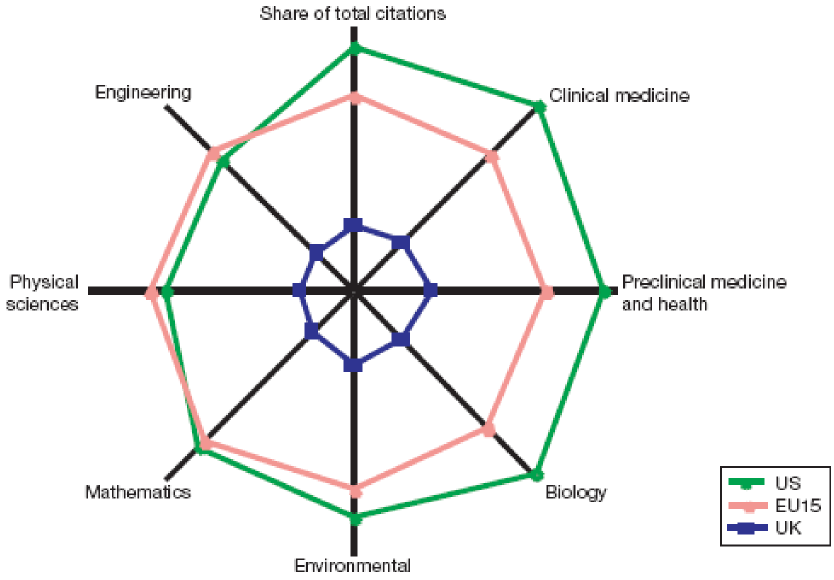
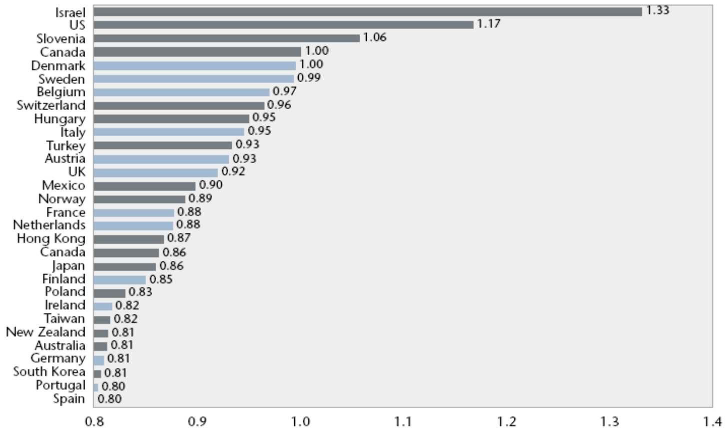
[7] See King (2004) for further details on this point.

Figure 3: **Strengths in different disciplines**



Notes: Plot shows research footprints based on the shares of citations. The distance from the origin is citation share. See King (2004) for sources (ISI Thompson) and details.

Figure 4: **Citation impact in Computer Sciences (1993-199)**



Source: DG Research
Data: ISI, CWTS (treatments)

The general message from bibliometric data is therefore far from suggesting any generalized European leadership. On the contrary, one observes a structural lag in top level science *vis-à-vis* the US, together with *some* average catching up and a few sectoral outliers in physical sciences and engineering and few single institutional outliers (such as Cambridge also in computer science and several other disciplines: but outliers are precisely outliers).

The first fact on which the paradox conjecture should be based is simply not there. Rather a mayor EU challenge regards how to catch up with the US in scientific excellence.

Poorer technological performances: R&D inputs and innovative outputs of the EU

In order to explore in detail the European performance in technology and innovation, one also needs to match European investments in science and technology (i.e. inputs typically proxied by education and R&D expenditures) with outputs (typically proxied by patents).

First, as shown in Figure 5, at aggregate levels the EU underinvests in R&D with respect with both US and Japan and, notwithstanding wide variation within EU itself (as showed by Figure 6), the gap is not shrinking.

Second, the usual claim concerning the higher share of government funded R&D in the EU as compared to the US is simply groundless[8]. On the contrary if one compares the shares of government financed R&D on GDP (Figure 7), EU is still lagging behind.

Third, the gap is much wider in business enterprise R&D (BERD) expenditures (see Figure 8). Again, despite diverse countries patterns, there is no sign of catching up (Figure 9).

Fourth, important factors in explaining the above asymmetries are the wide and persistent differences in the efforts devoted to knowledge production and absorbtion across industrial sectors. Table 2 shows that, if one measures the latter with R&D sectoral intensities, industries differ a lot. This in turn is partly due to inter-sectoral differences in technological opportunities and partly in the way the latter are tapped — which in some industries involves formal R&D activities

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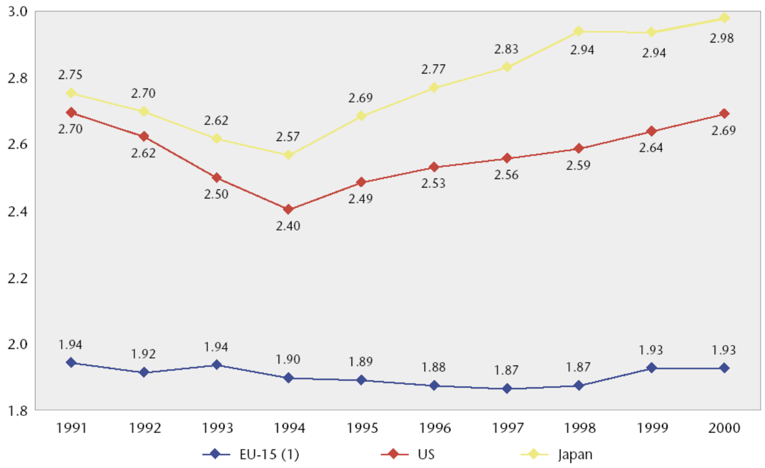
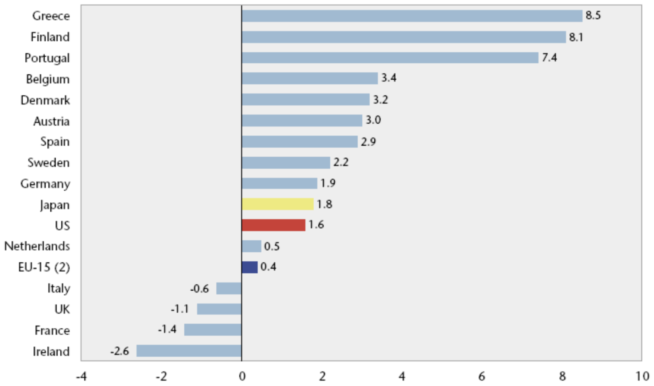
[8] The misunderstanding is usually based being on the use of the share of publicly funded R&D on total R&D expenditures, which does not carry much economic sense. The meaningful figures regard normalizations with the economic size of the economy.

Figure 5: **Gross Domestic Expenditure on R&D as (%) of GDP**



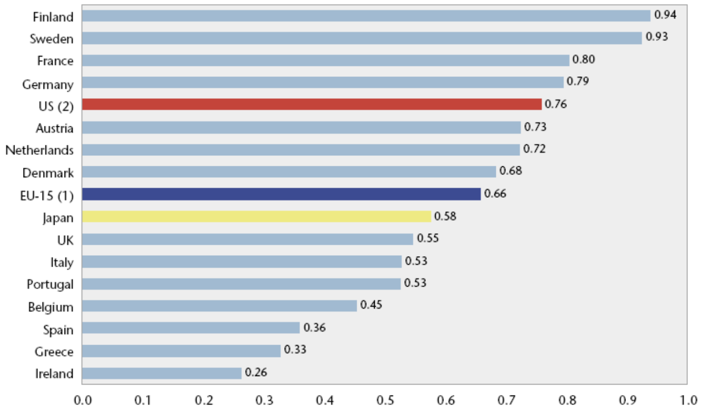
Source: DG Research
Data: OECD – MSTI database (STI, EAS Division) with DG Research provisional estimates
Note: (1) L data are not included in EU-15 average.

Figure 6: **Average annual real growth (%) of R&D intensity (1995-to latest available year)**



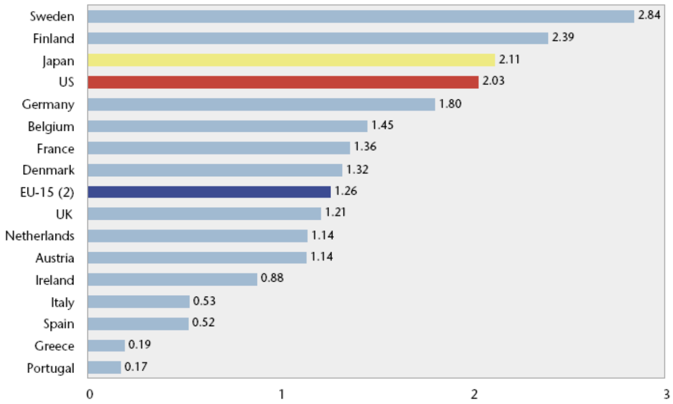
Source: DG Research
Data: OECD – MSTI database (STI, EAS Division) with DG Research provisional estimates
Notes: (1) JP: 1996–2000; FIN, UK, US, EU-15: 1995–2000; D, E, A: 1995–2001; I: 1997–1999; F: 1997–2000; all other countries: 1995–1999. (2) L data are not included in EU-15 average.

Figure 7: **Government financed R&D as a % of GDP, 1999**



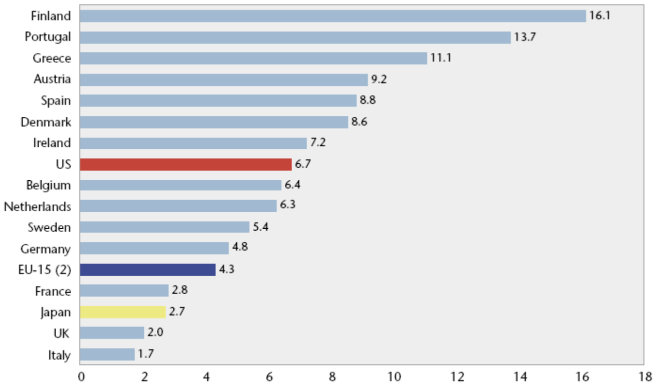
Source: DG Research
Data: OECD; DG Research
Notes: (1) L data are not included in EU-15 average. (2) US: excludes most or all capital expenditure.

Figure 8: **Business enterprise expenditure R&D (BERD) as a % of GDP, 2000 or latest available year**



Source: DG Research
Data: Eurostat / OECD
Notes: (1) A: 1998; DK, EL, IRL, NL, P, S: 1999; D, E, I: 2001. (2) EU-15 calculated by DG Research; L not included.

Figure 9: **Business enterprise expenditure R&D (BERD) - average annual growth since 1995**



Source: DG Research
Data: Eurostat / OECD
Notes: (1) A: 1993-1998; DK, EL IRL, NL, P, S: 1995-1999; B, FIN, UK, US, EU: 1995-2000; D, E, I: 1995-2001; JP: 1996-2000; F: 1997-2000. (2) EU-15 calculated by DG Research; L not included.

Table 2: **R&D Intensities across industries: BERD as % of value added**

	B	DK	GER	SPA	FR	I	A	FIN	SVE	UK	**EU-7**	**US**	**JAP**
Tot. Manufacturing	6.4	5.7	7.5	2.1	7.	2.2	4.6	8.3	11.3	5.4	**5.7**	**7.8**	**8.4**
Food, Bev. & Tob.	1.6	1.4	0.6	0.5	1.0	0.4	na	2.8	1.0	1.2	**0.8**	**na**	**1.9**
Tex., apparel & leather	2.0	0.8	2.1	0.6	0.9	0.1	na	2.2	1.2	0.4	**0.7**	**0.6**	**2.1**
Paper & Print.	0.9	na	0.3	0.4	0.3	0.1	0.5	1.3	na	na	**0.4**	**na**	**na**
Pharmaceutical	25	40	na	10.1	27.6	na	15.1	na	46.5	48	**na**	**23.3**	**19.0**
Non-electrical Mach.	6.6	6.6	5.8	2.9	4.6	1.4	4.4	9.0	11.1	4.8	**4.6**	**4.7**	**5.7**
Comp. & Office Mach.	12.3	18	17	7.5	13.3	7	3.7	na	39.5	3.5	**14.1**	**22**	**na**
Electrical Mach.	7.6	8	3.4	3.3	7.7	na	5.7	na	18.2	7.8	**4.5**	**12**	**17.6**
Electronic Mach.	32.7	13.5	39.6	19.1	34.1	na	28.5	28.1	38.6	12.1	**32.7**	**na**	**23.6**
Instruments	11.3	15.3	11.9	3.7	16.9	2.2	6.8	22.5	18.5	7.3	**11.5**	**32.6**	**23.8**
Motor Vehicles	4.0	na	18.3	2.6	13.1	10.4	10.1	3.6	28.9	9.2	**14.3**	**16**	**13.2**
Aerospace	6.5	na	na	25	40.1	na	na	na	na	24.3	**na**	**30.9**	**0.6**

Notes: EU-7: Belgium, Denmark, Germany, Spain, France, Italy, and Finland. Electrical Machinery does not include data for Italy and Finland. Electrical Equipment does not include data for Italy. Paper and Printing and Aerospace do not include data for Denmark.
Source: DG Research (EC, 2003).

and in others more informal processes of learning-by-doing, learning-by-using and learning-by-interacting with suppliers and customers[9]. It happens that Europe is largely penalized by a composition effect, in that it is relatively strong in technologies (such as mechanical engineering) wherein a good deal of search is not recorded under the "R&D" heading. Moreover, even pairwise sectoral comparisons with the US sometimes reveals a European gap. So, for instance US R&D investments are well above European ones in "Office, Accounting & Computing Machinery", "Electrical Machinery" and "Instruments" industries, while similar levels are observed in "Motor Vehicle" and "Non-Electrical Machinery".

Finally, note that if one considers the world top 500 corporate R&D performers, research investments in a selected number of sectors suggest that the EU gap is prominent precisely in those activities which are the core of the current "tech-

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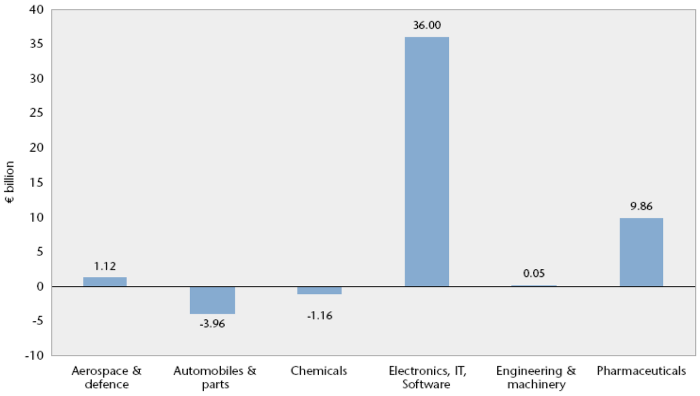
[9] Within an enormous literature, on these points see Dosi (1988); Klevorick et al. (1995); Nelson (1993); Lundvall (1992); Malerba (2004).

Figure 10: R&D investment gap between US and EU-15 by sector



Source: DG Research
Data: R&D Scoreboard (2001), DTI Future & Innovation Unit and Company Reporting Ltd.

nological revolution", namely ICT and Pharmaceuticals (see Figure 10 and EC (2003) (p.143) for details). Of course, this can be due to both sectoral and corporate heterogeneity, but the general message is that Europe invests less in those key sectors.

Consistently with the above evidence, one observes also a lower ratio of "knowledge workers" in the total workforce in Europe as compared with the US: cf. Table 3 depicting the percentage of tertiary level graduates and researchers on the labor force[10].

Complementary to proxies for the intensities of innovative search efforts and for the skills of workforce involved, patent-based indicators are generally used to shed light on the *Technological Output of Nations*. Needless to say, institutional differences, distinct corporate appropriability strategies, and different propensity

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[10] This data should be taken however with some care, given the uneven state of secondary education across different countries.

Table 3: **Shares of knowledge workers on total workforce**

	Tertiary-level graduates %	Researchers per 1000 labor force
EU-15	24	5.36
US	36	8.66

Source: OECD (2003) and EC (2003).

Table 4: **Shares in "triadic" patent families**

	1994	1996	1998	2000
EU-25	34	32	33	32
US	35	37	35	35

Source: OECD (2004a).

to patent across sectors may bias the international comparisons. Moreover, these indicators are generally constructed on the basis of patent applications issued by national patent offices having an "home advantage" bias. However, the OECD has developed "patent families" (i.e. patent filed in different countries to protect the same invention) that try to mitigate this latter bias and generally capture patents of relatively high economic value[11]. In Table 4 we report EU-25 and US shares in "triadic" patent families (i.e. inventions filed with the European Patent Office (EPO), the Japanese Patent Office (JPO), and the US Patent and Trademark Office (USPTO)). Shares are relatively stable with a slight European decline.

Again, EU performance varies significantly in distinct technology fields. The upper part of Table 5 depicts the shares of US and EU patents filed at the European patent office in five main fields. It shows that, having as benchmark the *All*

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[11] See Dernis et al. (2001) for details.

Table 5: **Shares of patents filed with EPO for different fieds**

	Electricity	Instruments	Chemistry	Processes	Mechanics	***All Fields***
EU-15	36.3	36.5	37.5	50	54.1	***42.6***
US	35.2	39.7	39.9	27.1	22.1	***33.1***
	Telecom	IT	Semiconductor	Pharma	Biotech	Materials
EU-15	37.9	26.9	29.2	35.7	28.3	55.1
US	35.7	49.3	36.2	43.5	51.3	19

Source: EC (2003).

Fields column, EU has relative strengths in Processes and Mechanics and, conversely, major weaknesses in Electricity/Electronics, Instruments, and Chemistry. At a more disaggregated level, the lower part of the same table, which focuses on six selected subfield whose technological dynamism has been particularly high, suggests that in Information Technologies, Pharmaceutical and Biotech the US is well ahead, while Europe has comparable shares of patents in Telecommunication and does particularly well in Materials, especially due to the Germany score.

To sum up, R&D expenditures and patent based indicators pinpoint a *European lag in terms of* both *lower search investments and lower innovative output.* This is largely the effect of the weaknesses in technological fields that are considered as the engine of the contemporary ”knowledge economy”. On the other hand, data show a few points of strength in more traditional technologies related to mechanical technologies and new materials.

Structural weaknesses of European corporations and science-industry interaction

The third angle to explore the *paradox conjecture* concerns the limits and weaknesses that European business enterprises display in innovating and competing in the world economy. The evidence, in our view, suggests that a fundamental factor underlying the worsening performance of European firms are their lower commitments to research and international patenting and, in several sectors, their relatively weak participation to the core international oligopolies, quite apart from any immagined weaknesses in the industry-university links.

Let us focus in particular on those industries where the consequences of European lags in science and technological innovation are likely to be more severe.

Figure 11 shows the production shares in several ICT sectors. If the overall rankings of EU-15, US and Japan have remained more or less stable, variations in individual shares shows that EU lost the lead even in the telecommunications industry, where in the nineties it had a big advantage. Europe has also declined relative to the United States in office equipment. On the other hand, in radio communications and radar equipment the United States has somewhat lessened its lead relative to Europe (in turn, this has probably been the outcome of the formation of few European companies especially in the military sector with sizes and capabilities at least comparable with the American counterpart).

A less straightforward, but still rather dismal, picture comes from the data measuring performance in trade in mayor high tech sectors. Table 6 depicts export market shares of large EU countries[12] and the US in 1996, 1999, and 2002.

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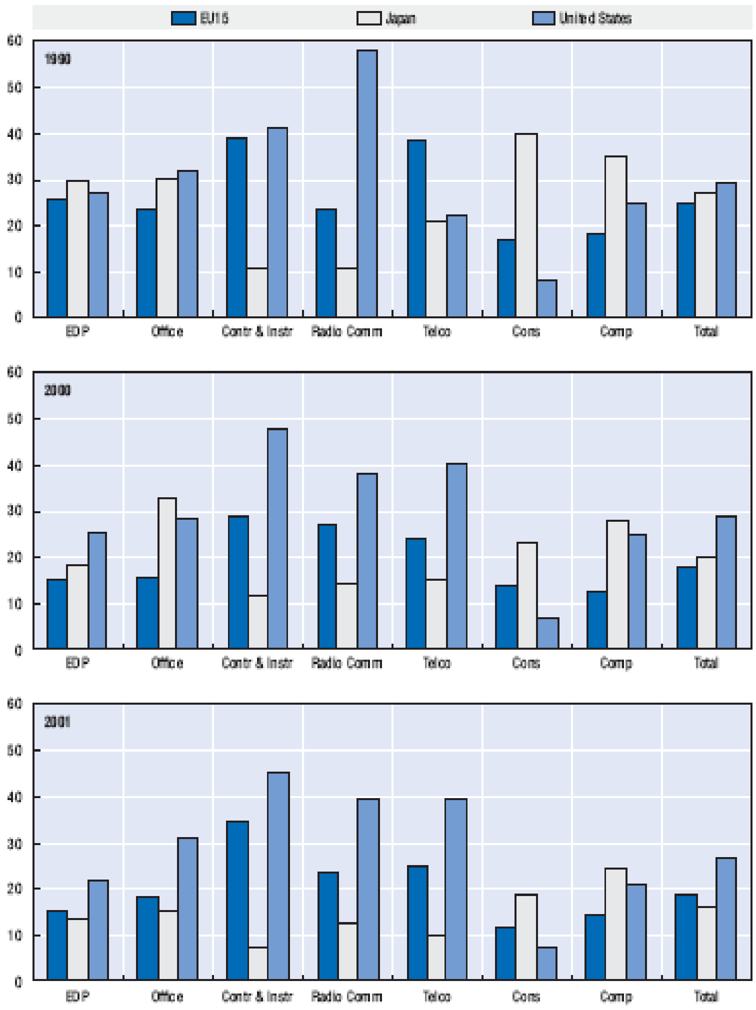
[12] Data on EU total would have required to exclude trade within EU countries.

Figure 11: **Share of World ICT Production**

Percentage of total output in current USD, by sector



Abbreviated sectors stand for: Electronic data processing, Office equipment, Control and instrumentation, Radio communications (including mobiles) and radar, Telecommunications, Consumer audio and video, Components, and Total ICT.
Note: The shares are calculated in current USD, and relative exchange rates (strong USD in 2000-01) will have a large short-term influence on calculations of relative shares of ICT production.
1. No data were available for Greece, Luxembourg and Portugal in 1990. Luxembourg is also not available for the other years.
Source: Reed Electronics Research, various years.

While in aerospace US has lost some ground and EU has grown, the opposite has happened in Instruments (Interestingly the European gains in aerospace, mainly due to Airbus has implied a more even distribution of exports between France, the UK and Germany with a relative loss of France itself). In the remaining sectors shares are relatively stable with the exception of Germany's losses in pharmaceutical.

Combining different sources, the last OECD Information Technology Outlook (OECD, 2004b) explores the performance of the top 250 ICT firms and the top 10 ones in four subsectors (communication equipment and systems, electronics and components, IT equipment and systems, IT services, software and telecommunications). It turns out that 139 of the top 250 firms (56%) are based in the United States and only 33 (13%) in the EU, confirming an overall weak EU amongst the world industrial leaders, notwithstanding subsectoral exceptions. So, six EU firms appear in the top 10 of telecommunication services firms, three in the top 10 of communications equipment and systems firms, two in the top 10 of electronics and components firms, and only one in the top 10 of software ones. Finally, there are no European firms among the 10 larger firms in IT equipment and systems.

These data support indeed the conjecture that, quite independently of the "bridges" between scientific research and industrial applications, potential corporate recipient are smaller weaker and less receptive than transatlantic counterparts.

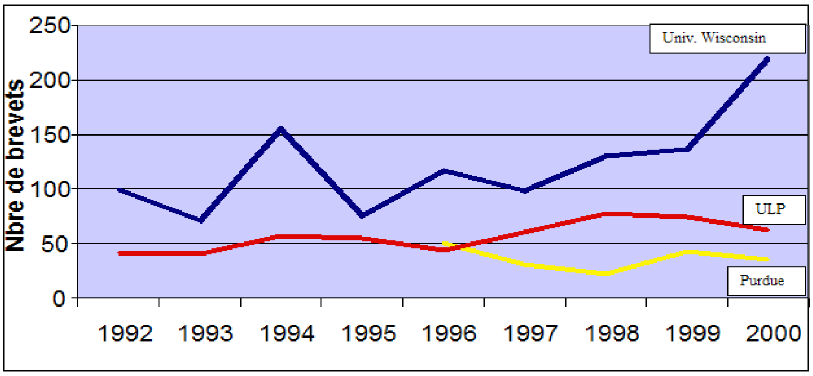
This is well highlighted also by those revealing cases where science is world top class, all the "transfer mechanisms" are in place but hardly any European firm is there to benefit. A striking examples of this are computer science at Cambridge, *England*: an excellent scientific output is most exploited by *non-European* firms (from Fujitsu to Microsoft and many others).

Table 6: **Trade in High Tech Industries: Export Market Shares (Percentages)**

	1996	1999	2002
		Aerospace	
France	16.71	14.26	13.55
Germany	10.71	12.67	13.73
Italy	2.70	2.38	2.95
UK	12.87	11.85	17.09
US	41.02	43.60	36.37
Japan	1.39	1.76	1.35
		Electronic	
France	5.18	5.43	4.77
Germany	7.84	7.34	8.75
Italy	2.42	1.83	1.92
UK	7.72	6.72	8.52
US	19.24	23.69	20.95
Japan	25.33	18.76	17.64
		Office Machinery and Computers	
France	5.68	4.85	3.65
Germany	6.98	6.84	8.09
Italy	2.80	1.64	1.27
UK	10.83	10.29	8.59
US	22.96	27.07	20.22
Japan	20.29	15.69	13.08
		Pharmaceutical	
France	9.89	10.55	9.60
Germany	14.84	15.13	10.84
Italy	6.17	5.73	5.68
UK	11.42	9.98	9.17
US	10.63	11.98	10.52
Japan	3.53	3.03	2.28
		Instruments	
France	5.64	5.15	5.35
Germany	15.05	14.11	14.55
Italy	4.17	3.34	3.44
UK	7.42	6.85	6.60
US	22.87	25.84	25.33
Japan	16.74	14.90	13.54

Notes: Our calculations based on OECD (2004a). ISIC revision 3: Aerospace industry (353); Electronic industry ISIC (32); Office machinery and computer industry (30); pharmaceutical industry (2423); medical, precision and optical instruments, watches and clocks (instruments) industry (33).

Figure 12: **Patent applications by Univ. Wisconsin at Madison, Purdue Univ. and ULP**



Source: Llerena (2004)

Note that the presumed feeble links between science and industry should be one of the most important aspect of the paradox conjecture. Surprisingly, the evidence here is simply non-existent. Curiously the Third Report does not address the issue explicitly, but just discusses the "science content" of EU technology, which is a rather distinct issue (EC, 2003) (p.422). Concerning the latter, the number of citations to scientific journal articles in patents that cite science is indeed higher in the US, but the hypothesis that this reflects the EU weaknesses in Science-Industry interaction is a questionable one. Rather, it might primarily reveal the different composition of European technological output, with patterns of specialization which tend to be less "science based".

Another often cited evidence concerning the "paradox" conjecture is the low revealed productivity of European University and research centers, usually measured by patent propensity. However, a few case studies have shown that the technology outputs of European public research laboratories are higher than usually believed if one considers relevant institutional differences. For instance, once we take into account the whole number of patents filed by European researchers and not just those that are directly owned by the research institutions where they are employed, the inter-atlantic differences across comparable institutions are not so big (Figure 12)[13].

The few indicators available which may be considered more direct measures of the interaction between business and higher education pinpoint to conclusions opposite to the conventional wisdom. As Table 7 shows the share of private investment in higher education R&D, while low everywhere, is marginally higher in EU than in the US and much higher than Japan. Similar results are obtained if one considers the private sectors annual investment in the public research sector (i.e. the sum of higher education and government R&D) and King (2004) (p.314) reports that in the last years a few EU counties experienced larger growth.

6 From the wrong diagnosis to misguided policies

To sum up, certainly the European picture is variegated with respect to the generation of both scientific knowledge and technological innovation. However, no overall "European paradox" with a leading science but weak "downstream" links is there to be seen. On the contrary it seems to us that significant weaknesses

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[13] See Azagra-Caro et al. (2005); Balconi et al. (2002); Llerena (2004); Meyer (2003); Saragossi et al. (2003); Wallmark (1997) for more details on national and European pieces of evidence.

Table 7: **Shares of Higher education Expenditure on R&D (HERD) financed by industry, 1999**

Country	%
Belgium	10.9
Denmark	2.1
Germany	11.3
Greece	5.0
Spain	7.7
France	3.4
Ireland	6.6
Italy	4.8
Nederland	5.1
Austria	2.0
Portugal	1.2
Finland	4.7
Sweden	3.9
UK	7.2
EU - 15	6.8
US	6.3
Japan	2.3

Notes: Austria 1993, Ireland 1998, US 2000. EU-15 calculated by DG research, Luxembourg not included.
Source: EC (2003).

reside precisely at the two extreme with, first, a European system of scientific research lagging behind the US in several areas and, second, a relatively weak European industry. The latter, we have argued, is characterized on average by comparatively lower presence in the sectors based on new technological paradigms — such as ICT and biotechnologies —, a lower propensity to innovate and a relatively weak participation to the international oligopolies in many activities. In turn, such a picture as we shall argue below, calls for strong science policies and industrial policies. However, this is almost the opposite of what have happened. The belief into a purported paradox together with the emphasis on ”usefulness” of research has led to a package of policies where EU support to basic research is basically non-existent. ”Research proposals are expected to identify possible practical as well as scientific benefits; higher priority is being given to user involvement (including partial funding), universities are being invited to extract more revenue from licensing their intellectual properly, and substantial public funds have been spent on ”foresight” exercises designed to create exchange and consensus around future opportunities of applications” (Pavitt, 2001) (p.768).

The ”Frame Programmes” have all being conceived with such a philosophy, which in the most recent one is pushed to the extreme with the ”Networks of Excellence”: not only they do not support research but they explicit prohibit the use of EU money for that purpose!!

Similarly, with regards to industrial R&D, the focus on ”pre-competitive” research has meant the emergence of a sort of limbo wherein firms — often in combination with academics — try to tap community money in areas that are marginal enough to not justify the investment of their own funds. Moreover, the networking frenzy has gone hand in hand with the growth in number and power of research bureaucrats (both at European and National level) whose main competence is precisely in "networking", "steering", writing lengthy reports and demanding researchers to do the same. Here again the extreme is in social sciences. A bit like the old Soviet Union where even papers in mathematics had to begin with "according to the clever intuition of comrade Breznev...", in many areas one has to begin each research proposal by arguing that what follows is crucial in order to foster fashionable keywords such as "cohesion", "enlargement", "citizenship", etc. even if in fact the real scientific interest goes to, say, the econometrics of panel data or the transmissions mechanisms of monetary shocks... And with all this goes yet another type of corruption of the ethos of the researchers who have to develop the skills of camouflage and peddling...

If our diagnosis is correct, this state of affairs is *bad for the research, wasteful for society and also bad for business.*

7 A conclusion with some modest proposals which might help both Science and Business

Some general implications of the analysis above are the following.

First, *increase support to high quality basic science*, through agile institutions much alike the American National Science Foundation (NSF) relying on world-class peer-review and also physically located far away from Brussels — as May (2004) suggests!

In that direction the constitution of a European Science Council is a welcome development[14].

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[14] See also the arguments recently put forward by a communication of the European Commis-

Second, fully acknowledge the difference within the higher education system between (*i*) research-cum-graduate teaching universities, (*ii*) undergraduate teaching universities and liberal art college, and, (*iii*) technical colleges.

The well placed emphasis of the role of the first type of institutions comes often under the heading of "Humbold model" as pioneered by Germany more than a century ago. However, nowadays the practice is most American, while Europe (especially Continental Europe) often offers in most universities a confused bland of the functions which is neither good for research nor for mass-level training.

Third, push back the boundaries between public open research and appropriable one.

One often forget that appropriability is socially justified only in so far it is an incentive to innovation itself. As we have argued above, appropriation of the output of public research does not perform that role. Of course this applies primarily to *basic* research while the picture is much more blurred for practically oriented disciplines such as engineering and a lot of pragmatism is required. However we would stand by the general point that too much of an emphasis on appropriability and IPR is likely to exert a pernicious influence on both the rates and directions of search. Moreover, we suggested above, it might also represent a significant hinderance to business-led innovation.

Our lag in the institutional changes leading to a much more property-based system of research as compared to the US for once might play in our favor in that it might be easier for us to stop and reverse the tendency (for a through discussion of the forgoing appropriability-related points, see Nelson (2004a).

Fourth, build ambitious, technological daring missions justifiable for their in-

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sion, which appears to hint at a promising break with respect to previous policies (EC, 2004).

trinsic social and political value.

As Pavitt (2001) reminds us "Scandinavian countries and Switzerland are able to mobilize considerable resources for high quality basic research without the massive defense and health expenditures of the world's only superpower" (p.276). Hence, he suggests, also the larger European countries and the European Union itself, have more to learn from them than from the USA" (p.776).

Granted that, however, one should not rule out the importance of large scale far-reaching European programs with ambitious and technologically challenging objectives in the fields of e.g. energy conservation, health care, environmental protection (and perhaps also the European re-armament, although there is not much agreement on it even among the authors of this work!).

Fifth, re-discover the use of industrial policies as a device to foster a stronger, more innovative, European industry.

We are fully aware that nowadays "industrial policy" is a bad word which cannot be mentioned in a respectable company without being accused supporting Jurassic-era "national-champions", distorting competition, fostering production patterns which go against "revealed" comparative advantages, etc. We are tempted to answer "why not"?! Certainly the period — until the late seventies / early eighties — characterized by discretionary intervention of policy makers on the very structure of various industries has been characterized by many failures but also several successes. For instance, the European strength in telecommunications, the presence in semiconductors, the growing competitiveness in aircrafts, etc. are also the outcomes of the policy measures of the "interventionist" era. Today, even within the constraints of the new trade arrangements, much more, we think, can be done in order to strengthen the European presence in the most promising technological paradigms, were it not for a self-inflicted market worship (yet another commodity *largely* exported by the US, but consumed there quite parsimoniously and pragmatically!).

We are well aware that these modest proposals might be accused of conservatism. However, for once we do not mind at all be in the camp of those who try to defend and strengthen a system producing top level publicly funded open science — too often under threat by both the "property right" colonization and the "practical usefulness" advocates —, and, together, a pragmatic view of the role that public policies might have in fostering the growth of corporate actors able to efficiently tap an ever-growing pool of innovative opportunities.

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