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The Question of R&D Specialisation: Perspectives and policy implications

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Executive Summary

Evidence suggests that the structural composition of European industry is the reason behind many of the challenges faced by research policy in Europe. The R&D shortfall in Europe relative to key trading partners, for example, is largely due to Europe having a smaller share of its economy composed of high R&D-intensive sectors (compared to the US or Japan).

Similar structurally-dependent arguments have been made about the disciplinary specialisation of research efforts in European universities and public research institutes: efforts seem to be spread out across multiple areas failing to reach critical mass.

As a result, the question of "R&D specialisation" has emerged as an issue of debate on the research policy agenda. But what is this question and why should we bother with it?

To explore this question and examine its implications for policy, the Joint Research Centre (JRC) - Institute for Prospective Technological Studies (IPTS), together with Directorate General for Research (DG RTD), organised a workshop in Barcelona on 30 June 2008. This report is an edited compilation of contributions submitted by participants at this event.

The question boils down to whether, for any given geographical-political entity, there are benefits to having R&D efforts concentrated (or specialised) in a limited number of thematic areas and, if so, whether

(a) public funding of R&D should focus on these areas accordingly and

(b) corporate R&D investment should be steered towards these areas through structural changes to the economy (and how to achieve this).

Examining whether there are benefits to the specialisation of R&D implies looking at the quality (and not just the quantity) of R&D. This is a change in orientation compared to the emphasis, implied or explicit, on reaching a given target of R&D spending.

Good quality R&D is productive R&D: it effectively transforms inputs into output (both measured by whatever means). And, in times of economic crisis where "bang-for-the-buck" is being emphasised, this effectiveness of R&D is as important as ever.

Research on the benefits of specialisation is still in early stages, and robust evidence is scant. However, some points can already be regarded as beyond serious dispute.

For example, it is clear that reaching critical mass is necessary in certain thematic areas. Unless you reach this threshold, the effectiveness of R&D efforts will be suboptimal.

Yet there are limits to the benefits of specialisation, as the law of diminishing returns should kick in at one point or another.

Not all thematic areas are equally "fertile": some (especially novel ones such as Information and Communication Technologies (ICT) and biotechnology) present many more opportunities for making significant discoveries than others.

Enlarging the size of a market (such as the market for knowledge in an integrated European Research Area (ERA)) can lead to increased specialisation provided there is unrestricted exchange of knowledge and there are others who will pick up remaining complementary tasks.

A larger market can also lead to greater competition in an area. The stakes are much larger and more attractive and challengers to any single agent "monopolising" a certain activity can emerge.

Is there a role for policy in this setting?

Without hard evidence, discussion will inevitably be constrained to speculation – though some broad contours can be identified.

Assuming the dissipation of European research efforts is true, specialising in – and reallocating resources to – a limited number of thematic areas would (a) free up funds from sub-optimal areas and (b) give some thematic areas a better chance of becoming globally competitive.

But not all research actors are capable of shifting their thematic focus to the most "productive" areas, due to a number of factors. So specialising in a few thematic areas would benefit some research actors (and by extension places) more than others.

Too little specialisation may spread resources more evenly around Europe but fall short of achieving a strong impact. Too much specialisation might lead to stronger impact, but could have negative implications in terms of anti-competitive outcomes, growth trajectories, etc. For one, policies favouring specialisation would reduce variety – a principal source of scientific novelty and key long-term determinant of scientific and technological leadership.

Also, specialising in a limited number of areas may lead a research system to become locked in a specific trajectory and would affect its long-term resilience, i.e. its ability to respond to exogenous changes.

The challenge for policy, therefore, is to find the right balance between too much and too little specialisation, in the context of the ERA vision and the Lisbon Strategy objectives.

But how such an optimal balance may be attained is the key question – the precise nature of policy interventions, if any, is far from clear.

Different takes on specialisation

The contributions by the participants at the Barcelona workshop address many of the issues raised by the question of specialisation. In doing so, they contribute novel insights to the debate.

Dimitrios Kyriakou (JRC-IPTS) cautions that policy approaches depending overwhelmingly on a few select fields or sectors are particularly vulnerable to systemic risk, which is alive and well as the current economic crisis has shown.

Dominique Foray (Ecole Polytechnique Fédérale de Lausanne) presents the issue of specialisation from a regional perspective. He argues that the free exchange of knowledge in Europe can lead to a situation in which a few "winner" regions specialise in a few topics, leading to "desertification" of R&D activities elsewhere. What can regions do so they don't end up being left behind? "Smart specialisation" in thematic areas that make the most of a region's current knowledge base is the appropriate response, it is argued, as much for Cambridge as it is for Andalucía.

Phil Cooke (University of Cardiff) addresses the trade-off between too much and too little specialisation. Specialise too much and you might end up losing out on benefits that would have been produced by R&D in areas that are being neglected, as you never know where the next bright innovation will come from. So it is necessary to maintain a certain amount of related variety.

But how do we know if the situation in Europe is one of healthy related variety or a situation where R&D is fragmented and duplicated, leading to suboptimal results? Keith Smith (University of Tasmania) argues that to answer this question we need to go beyond traditional statistics and delve further into disaggregated data.

The argument for specialisation hinges on the quality of R&D. But this assumes that there is a quality science base to begin with, and that further specialisation would try to make the most of it. Andrea Bonaccorsi (University of Pisa) argues that there is a strong link between economic competitiveness and a strong science base.

Mark Harrison (University of Warwick) cautions that the evidence on the link between high-quality research and critical mass is weak and, drawing examples from the economic history of Soviet R&D, argues that policy-induced concentration in R&D is unproductive in the long-run. Is the current debate merely part of an institutional cycle?

As has been shown, the question of specialisation has a number of policy implications. It can lead the way towards a more rigorous and evidence-based allocation of research funding. It can also help understand why Europe is lagging behind in R&D investment. Antanas Čenys (Vilnius Gediminas Technical University, Lithuania) presents an overview of factors that account for this deficit viewed from the perspective of specialisation.

But the question of specialisation, while fruitful and potentially insightful, will not make the business of creating an R&D policy mix any easier. If anything, it will make it more complicated. Anastasios Giannitsis (University of Athens) shows policies for strengthening specialisation must be placed in their proper context, and outlines complementary interventions that can support both specialisation and long-term flexibility.

Finally, Dimitrios Pontikakis (JRC-IPTS), George Chorafakis (DG-RTD A3) and Dimitrios Kyriakou (JRC-IPTS) present some stylised expectations attached to specialisation, both positive and negative. How can policy overcome the dilemmas? A case is made for policy approaches that are concerned more with the long-term shifting capacity of research systems and less with micromanaging the direction of research.

Introduction

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Many voices raise concern that European research efforts are spread too thinly. Soete (2005) attributes the alleged lack of excellence in European universities, vis-à-vis their counterparts in the United States, partly to the dissipation of research efforts. Foray and Van Ark (2007) argue that some research specialisation at the level of regions or countries would strengthen the international competitiveness of European research and help make Europe a more attractive destination for R&D investment. Others still, see the policy drive towards specialisation as an opportunity for a shift towards mission-oriented research that could contribute towards tackling the Grand Challenges (Georghiou, 2008) the EU is faced with in the form of climate change, energy and changing demographics.

Between the summer of 2008 when we held a workshop on specialisation in R&D and early 2009, when participants' papers were received for this volume, something very important happened: the financial crisis entered its "no-plausible-deniability" phase and the ongoing profound economic downturn became painful evident. It would be wrong not to take this development into account because in many ways much of the impetus for many arguments in favour of one policy or another came from the apparent systemic reduction of risk in previous years. Such a reduction of risk proved a figment of the imagination –and wishful thinking- of many analysts and market participants.

A systemic reduction of risk would make it defensible for bankers, analysts and policymakers to place many or all eggs in one basket. It would justify concentrating resources where apparently returns were highest and nothing seemed to threaten them. That could be oil technology and exploration, financial engineering, telecoms, software, etc. Monoculture, or near-monoculture economies seemed attractive. One of every ten pounds received in the United Kingdom (UK) in 2006 were in banking; the rate in New York was one of every three. Huge compensation in favoured monoculture industries attracted researchers and new talent. Junior associates' average compensation was around $US240,000 (bottoming out at around $US150000) in 2000 – triple what it would be for Master's, MBA or PhD holders in other sectors (Freeman et al. 2001). Young bright minds paid attention: as mentioned by Ferguson (2008), back in 1970 5% of Harvard's graduating class went into finance, 15% by 1990, and more than 20% by 2007. Yale had Harvard beat – it had higher percentages already in the eighties.

Diversification is the appropriate response when faced with risk. The successive bubbles of the last 20+ years, the nearly-continuous growth in the United States (US) with small blimps in the early 1990s and early 2000s, the apparent superannuation of inflation, etc.

made serious systemic risk seem very small. Portfolio models developed since the seventies were touted to provide financial diversity to substitute for the real diversity that was becoming increasingly out of fashion.

The financial crisis shook this emphasis on concentrating resources where at present you see largest rewards in two ways: it showed that profound, systemic risk is still alive and well; and it showed that when markets collapse financial diversity and hedging cannot provide the cover you hoped they would – largely because your counterparts in these hedging transactions are unable/unwilling to hold their side of the deal.

In the light of the ongoing crisis, one needs particularly heroic assumptions to promote increased concentration for any activity expected to generate economic benefits. The Barcelona workshop and the contributions to this volume provided a rich pre-crisis debate. Thankfully there are important arguments in this debate that escape the irrational exuberance of minimal-risk environments; to these we turn next, keeping always in mind the powerful caveat emptor world markets have delivered in the last few months.

There are quite well-known arguments, in all activities, including research, in favour of concentrating efforts and resources in an area of specialisation, presumably in the area in which an economic agent/group/region/country has the most stellar/excellent record. The idea dates at least to Adam Smith, and was updated by Ricardo in the context of exchanging the fruits of diverse specialisations among agents, and through focusing not on what is best at doing, but on what one is least bad at doing.

The appeal, and the arguments, of focusing on getting the most bang-for-the-buck are straightforward. They require however a certain set of assumptions in order to work, such as free and unfettered exchange, and the absence of powerful stochastic shocks against the activity in which one has specialised, or the ability to use financial instruments as insurance against such shocks. This in turn requires either the absence of multiple individual sovereign states, or the impossibility of any sovereign state exercising its sovereignty in unpredictable ways (e.g. regarding impeding capital flows, expropriations, wars, etc.). Within individual countries specialisation among regions/communities is accompanied by strong central budgets which through tax-and-transfer schemes, targeted development assistance programmes, and infrastructural investment distribute benefits and smooth out the differential gains generated by the different activities in which different regions have specialised.

In the absence of the above the specialisation/concentration approach becomes hard to fathom; indeed most countries do not specialise overwhelmingly in the activity in which they would get the most bang-for-the-buck. The few that have tried it (e.g. mono-cultivation agricultural economies focusing on coffee, cocoa in Africa) paid dearly for it when the first negative shock hit. Their counterparts in terms of regions within countries (e.g. mining areas in industrialised countries) have also suffered downturns when their "mono-product" economy was hit; luckily for them, however, a strong central budget was usually there to help mitigate the extent of their income drop.

One should note that there are also arguments against overspecialisation not simply based on distributional/cohesion issues, and the absence of the necessary accompanying institutions, but even in terms of pure efficiency. Such arguments underscore the importance of flexible responses, shifting capacity, and dynamic assignment of resources. They apply in dealing with a dynamic setting in which what may seem optimal today may not be so tomorrow, as well as when faced with the emergence of monopolies/monopsonies favoured by ever-higher concentration. Note also that hedging strategies developed in and for financial markets in recent decades, to protect one against the risks of concentration have received quite a beating in the current financial crisis, casting shadow on one tool which could be used towards hedged concentration strategies – there is not enough space to do justice to this issue here by exploring it further.

As a starting point made for any policy-relevant analysis one should not generically recommend either more or less centralisation; rather one should take into account the sort of institutions that would be called upon to implement policies. Another point worth stressing is that much of the theorising about making more efficient the production and diffusion of knowledge and innovation is expressed in terms of correcting market failures, while assuming that such markets encompassing all aspects of the production and diffusion process are in operation. Here again the current crisis with the drying up of markets for key transactions it has provoked should give us pause, when we assume markets will exist to smooth out the effect of shocks.

As mentioned above there is a large underlying concern about the existence of effective mechanisms (markets, fiscal schemes, smooth diffusion/absorption, etc) for the distribution of any welfare gains emerging from R&D concentration, beyond the region/state which is the seat of such concentration. Perhaps it would be useful to discuss this more explicitly. Concentrating research where the return on each euro spent is the highest, may make short run sense for a profit-maximising firm (though possibly inefficient in the medium to long run). However, it is quite likely politically infeasible and inefficient, not least because governments focus on welfare in their state first and foremost. Such welfare may depend on the ways welfare gains are distributed, on local externalities from R&D, on the stickiness of knowledge and researcher flows. It also depends on overall human capital levels in a country, and which depend, in turn, on the country's distance from the technological frontier.

The costs and benefits of further concentration of resources should be weighed very carefully, in a context where governments have been repeatedly told by experts that R&D and human capital development are key drivers of economic welfare; where knowledge diffusion/absorption is very slow when R&D and human capital are weak; and where there is no distribution of welfare gains such as exists in a federal state. This is even more so when alternative approaches exist, emphasising flexible assignment of resources and shifting capacity, while avoiding monoculture approaches, which become exceedingly vulnerable in a deep downturn, such as the current one.

It is not as often stressed but, nevertheless, monopsony can be pernicious, just as much as monopoly. Research centres tend to have more autonomy when they do not depend on a single authority (similarly researchers in a research field are more autonomous when they do not depend on one funding source, or one mega-centre of research in that field). Concentration of power regarding funding decisions in an area of science in one centre subjects scientists to the exorbitant power of that single buyer/funder of their ideas/talents.

The US system works – to the extent it does – through the availability of a multitude of funding sources at various different levels, giving proposals many different opportunities to be considered and funded. This is what an earlier meeting of the Knowldege-for-Growth (KfG[1]) group, advising Commissioner Potocnik, vividly termed "the art of creating productive chaos", characterising the US system. On the other hand, in the US the government's role is important not only in terms of spreading the benefits from technical advances concentrated in Silicon Valley, or Route 128, or Route. 1, or Raleigh-Durham, etc. It is coupled by a strong federal role in R&D funding. This, while not straitjacketing local or state funding, provides an important anchor and reference point.

As hinted above, tensions regarding concentration can be partly attributed to the success of R&D and innovation studies, which underscored technology as a key discretionary ingredient of economic success. These arguments identified the role of technical progress as reflected in the residual in growth accounting, linking it with R&D, and through education and technology absorption, linking it with the ability to reap benefits from positive economic shocks, adjust to negative economic shocks, and to forge dynamic comparative advantage (such as Japan, or Finland did).

These insights, coupled with the persistent stickiness in the diffusion/absorption of knowledge, and in light of the advantages enjoyed by those in the vicinity of R&D strongholds (if for no other reason, because they attract dynamic firms near them) have made local policymakers very eager to build the next silicon valley. This eagerness emerges even if their region/state has no important tradition and strength in the specific S&T field (neither did Silicon Valley, nor Finland).

It has also made them very reluctant to forego this goal/dream, in favour of well-established centres elsewhere, with long science and technology (S&T) traditions. It is easy to see why this would be viewed as the equivalent of Silicon Valley foregoing information technology because there was relevant S&T excellence in the northeast of the US, or Finland not pursuing mobile telephony ceding the field to traditional telecoms powerhouses in other countries.

The problems with increasingly concentrating funding on a small number of centres are non-trivial. On the one hand, research support is already heavily concentrated in a limited number of institutions, and history matters in this context: past success propagates concentration of resources.

[1] http://ec.europa.eu/invest-in-research/monitoring/knowledge_en.htm

Moreover, reducing variety is not a desirable goal. Concentration and reductions in variety can undermine the potential for new innovations to emerge (Mollas-Gallart and Salter, 2002). Variety and redundancy open the door for new entrants into the system, and thus new competitors, which can guarantee incumbents will not sleep on their laurels. In science, these new entrants often sit on the margins of traditional disciplines and journals, and do not have stellar records; starving them of a modicum of resources that would allow them to tinker on and with the margins may do science a disservice in the medium to long run.

Software engineers, by way of example were often viewed as low-grade technicians by traditional electrical engineering departments, and they had to conduct their research in second-tier universities. It was only through time and the rapid expansion of the software industry that their work was fully appreciated (Mollas-Gallart and Salter, 2002). This pattern has occurred repeatedly in the history of the sciences. Robert May (1998), the former Chief Scientific Advisor to the UK Government and Head of the UK Office of Science and Technology, suggested that in order to overcome the essential conservatism of institutions of science, it is necessary for research councils to promote diversity and "ambitious" research. Funding only the usual "excellent" recipients is not clever science policy in this regard – not to mention the monopolistic-monopsonistic distortions it can generate.

One limitation of stellar-record-based concentration models is that they tend not to promote the kind of diversity that may be necessary to foster innovation, but rather lead to anti-competitive concentrations of sources of funding as well as of recipients of funds. As mentioned above one of the key characteristics of the US system of research is that there are a number of overlapping and competing funding-sources of research. This competition among funding-sources creates opportunities for new entrants to win resources and enables new areas of research to emerge. In comparison to the US system of multiple and overlapping sources of finding, European researchers have fewer sources to access when they search for funding.

Furthermore, as mentioned in KfG debates and also in the Barcelona workshop, welfare may depend on human capital availability, which in turn depends on research and on a region/state's distance from the technological frontier. Research plays different roles (including training); moreover, research and innovation interact in a variety of ways and the outputs of academic research go well beyond the generation of new knowledge as embodied in scientific papers. A key benefit of publicly funded research to innovation is the development of trained problem-solvers.

Excluding under-performing organisations will reduce possibilities for contact between students and the research process, thus possibly restricting the supply of future researchers as well as problem-solvers.

Given the importance of cumulative advantage in science, left to itself research funding tends to be highly concentrated in a small number of regions. Policy measures have been adopted to mitigate the weight of history in propagating such concentration. In the US, for instance, the National Science Foundation's Office of Experimental Program to Stimulate Competitive Research (EPSCoR)[2] has been set up to support proposals from less favoured US States. The Small Business Innovation Research programme (SBIR) [3] also spreads research funding to many small firms, and has a counter-agglomeration impact.

The problem faced by funding organisations is to determine a priori what will be excellent research. Stellar performance patterns are not necessarily excellent predictors of future research performance, especially in new areas, and especially as "incumbent" research groups become complacent (Mollas-Gallart and Salter, 2002). Under hypothetical conditions of full information and certainty, one could reach an optimal solution applying standard resource allocation algorithms. However, as long as serendipitous discovery is part of science, it is very difficult for peer review panels to know when or where excellence will emerge (Mollas-Gallart and Salter, 2002). The impossibility of identifying a priori successful research, and the monopolistic/monopsonistic distortions that overconcentration can generate may justify pursuing multi-track policies, where by the handsome returns from a few success stories will more than compensate for the cost of those less successful undertakings (Mollas-Gallart and Salter, 2002).

Interestingly, as mentioned in KfG debates and also in the Barcelona workshop, even regions that are currently at the technological frontier may benefit in the long run from an approach which avoids further geographic agglomeration. By not being monopolists of innovation and monopsonists of R&D talent in a research area, regions can gain not only through competition, i.e. by avoiding the complacency associated with not having tough competitors, but also through more complex/diverse specialisation pattern, avoiding the single-crop, all-eggs-in-one-basket mega-specialisation in one area. This point can be seen in conjunction with another one, regarding coordination through central initiatives producing alignment of national and regional programmes in terms of specific priorities, calendars, instruments. These neat and disciplined alignments may be appropriate for scientific activities in "mature" fields/areas, but not necessarily for new path-breaking R&D needs. The latter are marked by fast-paced change, high programme diversity, and unforeseen marriages across disciplines and technologies. In any case better coordination of R&D should be seen in conjunction with higher education structural reforms, and with countries opening up to competition, but at the same time, also locally investing in this process.

This dual approach of opening-up and local investment is worth further analysis, and the resulting researcher flows would also be worth exploring. They should be multi-directional; unidirectional ones lead to brain-drain (with the all-too-common move to the US as the ultimate step in the brain-drain flows). Indeed, there is an analogous concern regarding the emergence/perpetuation of monopolies of S&T (and monopsonists of researcher talent) within smaller enclaves (at the level of region or state). This should not be taken lightly.

[2] http://www.nsf.gov/od/oia/programs/epscor/about.jsp

[3] http://grants.nih.gov/grants/funding/sbirsttr_programs.htm

Avoiding large-area monopolies does not mean condoning local ones. An antidote to local dinosaurs can be found in opening up competition in such local enclaves, while however taking care to have flows of human and other resources be bi-directional, and indeed multidirectional. After all once a researcher has left his home in Bulgaria to go to Germany or the UK, there is little to prevent the next logical step taking him where sirens sing loudest, and scientific/economic returns are portrayed endless, i.e. the US.

Regarding the logical conclusion of concentration, which nurtures monopolies, one may often ask why can't we limit the number to a small manageable number of competing entities, say 5 or 10 or 15? First of all this generates oligopolistic behaviour, which has its own share of problems, but before opening that Pandora's box, the following two crucial questions should be answered? How and who decides on what the magic number should be? And where should those lucky few be located?

Furthermore, shutting to the door to the first runner-up(s) is hard to justify and politically unpalatable. To use a very graphic example of the "dual" of this problem – an example quite in tune with what we are witnessing in the ongoing economic crisis: shutting the door to runner-ups would be like shutting the door to some of the states close to bankruptcy.

Before we move on to brief summaries of the papers that make up this volume it is worth reiterating a key "self-conscious" type of observation – i.e. the kind usually avoided: As long as policymakers are convinced -partly by the innovation-studies community's persuasive arguments over the years- that S&T is one of the very few levers they have to try to turn their country onto a higher standard-of-living path, they will want to be among those striving for and in the most promising S&T fields.

Dominique Foray's report defines and endeavours to operationalise the concept of "*smart specialisation*". It is argued that specialisation can only occur in a large research and innovation area that allows for unrestricted competition. Foray predicts that the realisation of the European Research Area (ERA) will bring Europe closer to such a reality. Regions can then engage in an "entrepreneurial process" of matching local knowledge production to the "pertinent specialisations" of the region. Pertinence in this discovery process, it is argued, will be defined by the (largely exogenous) emergence of General Purpose Technologies (GPTs). Foray argues that while leader regions invest in the invention of a GPT, less advanced regions must invest in the "co-invention of applications". Regions engaging in smart specialisation thus enjoy high returns as they enter a competition arena composed of a small number of players. Government policies have a role in providing appropriate incentives to entrepreneurs who are involved in the discovery of the right specialisation.

Phil Cooke examines existing indicators of national and regional specialisation indicators and finds that contemporary statistical tools offer little by way of resolute explanations. Drawing from a rich body of evidence in regional science, Cooke shows that innovation is more likely to occur in regions that make the best use of various types of proximity – including not only spatial, but also the sectoral type. Specifically, he posits that regional innovation rates and economic growth are positively associated with the presence of *related variety*, understood as the collocation of related industrial sectors, and knowledge spillovers such variety generates.

For **Keith Smith**, understanding the issue of specialisation in Europe requires – first of all – understanding the degree to which Europe exhibits differences in strategy, organisation and outcome of its R&D activities. Do these differences reflect fragmentation and duplication, which lessen the overall impact of national R&D strategies, or rather a healthy diversity? Answering these questions requires looking at *disaggregated data* across Europe. Different, imaginative, classifications of R&D data might be required in order to achieve this in a successful way (some are proposed by Smith), and would yield the added benefit of pointing the way forward for future classification and presentation of R&D data by statistical offices.

Andrea Bonaccorsi argues that *the poor performance of European science* in the last quarter of a century is one of the long-term reasons behind the European *loss of competitiveness*. Bonaccorsi presents evidence indicating that the relative importance of a strong and dynamic science base for manufacturing services production has increased over time. Scientific leadership, it is argued, is important for economic activities that are very far from the technological frontier even if the relationship is indirect and unpredictable. Because of the indirect nature of that relationship, the current policy debate could be severely underestimating the importance of a strong science base. He uses a short case study on the careers of top computer scientists to show that the weak performance of the European IT industry can be associated with weaknesses at the scientific frontier. Bonaccorsi concludes with a discussion of the implications that these observations have for the design of appropriate institutional structures.

Mark Harrison's note, written six years ago in the context of a national debate on the concentration of university research funding in the UK, remains highly relevant. Harrison cautions that the evidence on the link between high-quality research and critical mass is weak and, drawing examples from the *economic history of Soviet R&D*, argues that policy-induced concentration in R&D is unproductive in the long-run. The brunt of his argument is based on the damaging effects brought about by the lack of competition and the associated perverse institutional incentive structures. Harrison takes the view that the ambivalence of policy makers between pluralism and concentration occurs in cycles. He hazards the prediction that his contemporary preoccupation with critical mass would be reversed in the following years. Recent events in the UK (Corbyn, 2008; Gil, 2009) suggest his prediction is well on course to be proven correct.

The paper by **Antanas Čenys** presents an overview of factors which account – in part – for Europe's R&D deficit, viewed from the perspective of R&D specialisation. He proposes that a balance should be struck between having an economy that is *too specialised* (where greater progress in one area will be achieved to the expense of progress in another) or *too diffused* (which will lead to a decrease in activity in each separate area). This balance should take into account that Europe is oriented towards more traditional, low-risk and slow-growing, areas; lacks sufficient academic spending; does not involve businesses enough in R&D (as funders and performers); lags behind in service R&D expenditures and does not have a large enough ICT sector.

Anastasios Giannitsis attempts to delineate the interfaces between research specialisation, the economy and public policy. His report acknowledges that the phenomenon of specialisation is multidimensional and that policies intending to induce specific specialisation patterns carry risks as well as opportunities. On the one hand, opportunities include improvements in productivity, a first-mover's advantage on emerging technologies as well as significant future challenges relating to energy, the environment and climate change. On the other hand, risks include reductions in competition, state failure (including the opportunity cost of not acting) and possible implications for intra-EU convergence. In an attempt to identify viable policy options, Giannitsis distinguishes between proactive and reactive policies and makes a strong case for combining the best elements of both. He sees value in opting for a flexible European Research Area, that combines a *"research friendly ecology*" with a *"cluster specific environment"* for specific research areas of importance. The author cautions that although very often specialisation patterns are path-dependent and therefore change is bound to be gradual, in the case of more radical technical changes path-dependency is not necessarily the case. He concludes that policies for strengthening R&D specialisation must include strategies for enhancing variety creation and selection and supporting "differentiation" elements against competitors, an effective functional coordination of research activities as well as timely adjustments to institutional structures and the provision of large-scale public goods.

Finally, **Dimitrios Pontikakis**, **George Chorafakis** and **Dimitrios Kyriakou** discuss some stylised observations about the potential benefits and pitfalls of specialisation, outline a sketch of the policy approaches currently on offer and make the case for strengthening the capacity of European research systems to shift resources to promising areas. They conclude with suggestions for further research that could enhance the currently lacking evidence base.

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Understanding "Smart Specialisation"[1]

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Preamble

This short report defines and endeavours to operationalise the concept of "smart specialisation" (SS) and, in this sense, is a continuation of the work of the "Knowledge for Growth" Expert Group (Foray and Van Ark, 2007)

First of all, the concept of SS is placed in perspective within the context of European policy on Research, Technology and Development, emphasising the fact that the SS option is in a way unique and essential for regions that wish "to stay in the game", something which will prove increasingly difficult as construction of the ERA (European Research Area) progresses.

Then the basic characteristics of SS are defined:

- firstly, **the creation of a large research and innovation area, allowing unrestricted competition** is an essential condition for specialisation (as stated by Adam Smith : the degree of specialisation is a function of the size of the market) (Marimon and Graça Carvalho, 2008)

- secondly, the search for SS does not involve a bureaucratic process (plan) or an exercise of *foresight*, ordered from a consulting firm. It concerns **an essentially entrepreneurial process** in which the new knowledge produced relates to the « pertinent specialisations » of the region. These « discoveries » have a very high

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social value since they are intended to guide the development of the region's economy.

- thirdly**, the specific properties of General Purpose Technologies or Tools (GPTs) define a framework** to clarify the logics of SS for both regions that are at the technological frontier and those that are less advanced. While the leader regions invest in the invention of a GPT (biotechnology, information technology) or the combination of different GPTs (bioinformatics), followers must invest in the « *co-invention of applications* », that is development of the applications of a GPT in one or several important domains of the regional economy. These regions enter into a realistic and practicable competition logic, by defining a competition arena composed of a small number of players.

- Finally, **there is a role for governmental policies**, which, once again, is not that of bureaucratically selecting specialisations and then picking the winners. The role allotted to governments comprises four parts:

  (i) Supplying incentives to (encourage) entrepreneurs who are involved in the discovery of the right specialisations ; the incentive framework is essential since as already mentioned the social value of the knowledge produced is very high and entrepreneurs who make this kind of discovery are likely to capture only a negligible part of this social value.

  (ii) Assessing the value of the identified specialisations

  (iii) Identifying and supporting the investments that are complementary to the right specialisations (educational and training institutions for example) ; in the case of a region investing in the "co-invention of applications of a GPT", these complementary investments also include the connection with the centres that produce and invent the GPT.

  (iv) Cutting down investments which were supported ex ante as part of promotion of the search for the right specialisations, but turn out to be inappropriate ex post.

European regions, R&D globalisation and ERA as solution

In what way are European regions ill prepared for globalisation ?

The public research system in Europe remains fragmented and nationally based, limiting agglomeration processes and hampering the formation of world-class centres. This fragmentation has prevented the natural development of the hubs whose growth should be unrestrictedly nurtured by the best sources of the knowledge economy. In actual fact, with some rare exceptions, agglomeration processes operate within national systems and resource flows do not cross borders. Without this fragmentation, we could imagine liberated agglomeration dynamics leading to the constitution of truly competitive centres on the global level.

Furthermore, in Europe we observe a definite tendency in Europe for countries and regions to do the same thing and envisage their future in a similar fashion. Every European region prides itself on having its investment plan in information technology, biotechnology and nanotechnology. In most regions, decision-makers define priorities in a very unimaginative way. The problem is not a simple one and technology foresight exercises or critical technologies ordered here or there by administrations tend to produce the same ranking of priorities, without any consideration for the context and specific conditions of the "client" for whom the exercise is carried out. This lack of imagination and vision produces a uniformisation of the European knowledge base and a deterioration of what can constitute the originality and distinction of local knowledge bases. A probable consequence of this lack of originality is that large European companies are going to operate more and more as a global knowledge network and transfer their innovation activities outside their native country because the latter is now doing more or less the same thing as all the others (and certainly does it a little less well than the best of them) (Doz, 2005).

This nationally-based fragmentation and the uniformisation of priorities leave Europe with a collection of subcritical systems, all doing more or less the same thing, systems which are unattractive and thus cannot play in the arena of the world localisation tournament. Such a situation is obviously a source of inefficiency:

- economy of scale and spillover potentials are not fully realised
- economies of agglomeration are dissipated, resulting in a system made up of too many unattractive sites.

In fact, the logic of territorial attractivity is based on the **scarcity of a very specific resource: the economies of agglomeration themselves.** This rare resource is wasted as soon as too many sites are competing to capture the same resources.

How many world centres, in biotechnology for example, can Europe manage to set up? No doubt fewer - far fewer - than 28 or 30 !

European Research Area as solution ?

The European Research Area (ERA) can be analysed in the light of our remarks, that is to say, as an initiative aimed at freeing agglomeration processes (CEC, 2007) The general integration of national systems will allow resources to circulate unhindered and go where they will gain the most benefit from these external effects. Thus centres of excellence will be established to the advantage of some sites while subcritical structures, hitherto protected by national borders, will more or less disappear off the map.

This process can be expected to result in a better exploitation of the principal determinants of research productivity:

Economies of scale

Two sources of economy of scale remain under-exploited : the allocation of fixed research costs (large-scale equipment) over a larger number of programmes and projects and the aptitude to invest in more specialised skills and more sophisticated technologies as the system grows in size. Each « small» national system will manage to employ a few molecular biologists who are sufficiently non-specialised to be able to « do a bit of everything », which, on an aggregated level, leads to the formation of an army of average researchers. On the other hand, a more integrated system would be capable of employing the most highly specialised scientists, who would go where the appropriate equipment and programmes are developed, regardless of national borders.

Economies of variety and internal spillovers

The ERA must moreover facilitate the exploitation of economies of variety and maximisation of the internal spillovers that no longer depend on the size of the system but on the diversity of knowledge bases. The way in which generic knowledge can nurture numerous domains (economics of variety) and a research effort in one domain can generate knowledge that can be applied to other domains (spill-over) is determined by the diversity/complementarity of knowledge bases and their integration into one single area. Are people aware that in the United States the *National Science Foundation* has developed a programme that transfers researchers specialised in clinical trials (university hospitals) to the educational sciences to apply experimental methods used in the medical field to the teaching field? A fine example of economics of variety that can only be exploited in a system sufficiently large and integrated to permit a supply and demand of very specific capacities to coincide and link up.

The necessity for smart specialisation

The mechanisms at work in the ERA can be expected to further increase polarisation phenomena however: scientific densification for some regions, "desertification" for many others. Yet such a result would be politically unacceptable and inefficient from an economic point of view. It is therefore important not to turn the ERA into a mechanism of net transfer of resources to the most advanced regions.

It therefore seems that there is only one means of reconciling unrestricted agglomeration processes aimed constituting these famous knowledge hubs that are competitive on a worldwide scale with a relatively balanced geographical distribution of research capacities throughout Europe : this means lies in the aptitude of regions and countries to "particularise themselves", in other words develop an original strategic vision in terms of science and technology and implement the policies necessary to conform to it.

If all regions do the same thing – we have already stressed the lack of imagination in this domain above – the mechanisms implemented within the ERA framework will result in a "draining" of the greater part of the European territory, or otherwise they will have to be corrupted by the redistributive logics of cohesion policies in order to prevent this from occurring. If, on the other hand, each region succeeds in developing an original and unique knowledge base, the scenario becomes much more interesting. This is the notion of *smart specialisation*.

Specialisation is thus a requirement associated with the construction of the ERA - but it will also be facilitated by the ERA. As stated by Marimon and de Graça Carvalho (2008) "*smart specialisation is not achieved through a clever foresight-political process, but by letting ideas, innovations and researchers compete without barriers, in a large, open and fair field, as the ERA can be*".

Anatomy of the smart specialisation process

The recent report by the Lisbon Expert Group (LEG) clearly shows that even if countries are ready to assume their responsibility to honour the Lisbon objectives, particularly by increasing their research effort, they cruelly lack vision and strategy (Lisbon Expert Group, 2006). In short, they are prepared to make an effort but do not really know why, beyond the general rhetoric on the subject of research as growth factor.

Knowing on which knowledge base any particular region or country must build in order to define its growth strategy is a key question and at the same time a difficult one. It must be emphasized that answering this question should not lead to a bureaucratic logic of industrial planning but indeed to a research process of an entrepreneurial type, that is one in which entrepreneurs must play a central role. The decision-makers will limit their interventions to four aspects of the process : helping these entrepreneurs of a rather special type (see below); evaluating the value of the identified specialisations; identifying complementary investments (human capital) and facilitating the coordination mechanisms allowing a regional system to collectively switch over toward the selected specialisations; and pruning the investments which turn out to be inappropriate ex post but were supported ex ante as part of the search process.

Search for the right specialisations : an entrepreneurial process

Here we are evoking a particular learning process, which has until now not received very much attention from economists. This learning process consists of discovering the research and innovation domains in which a region can hope to excel. This learning process is primarily the responsibility of entrepreneurs who are best placed to discover the right specialisations. This really does involve a process of discovery since the production functions of the different types of innovation and invention are not common knowledge.

This activity poses a public policy problem. The discovery of pertinent specialisation domains has high social value since this knowledge is going to define the direction of company investments and research organisation projects. But the entrepreneur who makes this initial discovery will only be able to capture a very limited part of his investment's social value since, by definition, other entrepreneurs will swiftly move into the identified domain. There is consequently a risk of not seeing enough entrepreneurs « invest » in this particular discovery process (Hausmann and Rodrik, 2002).

Insofar as the process of learning the right specialisations for a given region implies investment and the return on this investment cannot be completely appropriated by the person who makes it, we find ourselves confronted with an incentive problem, which apparently cannot be resolved by resorting to intellectual property. The basic discovery concerns a field of research or type of innovation of which the region could become the leader. This type of discovery is not normally subject to legal protection, whatever its social return. Public policies thus have an essential role to play in encouraging entrepreneurs who invest in this particular discovery process and will not have the possibility of using the usual legal protection mechanisms to enable them to capture a large proportion of the social return on their investments.

Evaluation of knowledge base

The exercise carried out by the author for the Toulouse region and - in another context - for the Lake Geneva region (Lausanne and Geneva) is extremely illuminating (Mowery, 2002).

Confronted with the already existing knowledge base, or one that is under construction, experts and decision-makers must endeavour to answer the following questions :

- What is unique and original about my region's knowledge base ?
- Can it be developed by building on knowledge and know-how accumulated in the past?
- Does this base offer sufficient innovation and spillover potential (in other words, does it hinge on the production of a so-called "general purpose" technology or has it developed in an important application domain of a general purpose technology)?
- Is this base linked to markets with growth potential and/or important economic domains for the region?
- Is it difficult or easy for other countries to reproduce and imitate (particularly emerging countries)?

- Is it sufficiently broad (capable of giving rise to a diversified portfolio of connected activities, mutually strengthening each other thanks to synergies, economies of variety and spillovers) or too narrow, and therefore running a risk of dependency on one single domain and technological monoculture?

A correctly carried out particularisation process will thus reveal the future strategic domains for the region or country.

Complementary investments and coordination policy

Adopting a strategic vision is a very important thing, and then having the capacity to set the system in motion so that the anticipations of the different economic agents coincide and converge towards this vision is another. All the ingredients of an innovation policy must then be mobilised so that public and private agents invest in a coordinated way in the identified domains. We know that in this respect supply policies directed toward the development of the knowledge infrastructure (basic science, high education and training, technology platform, large-scale programmes, technology transfer plan) must be completed by the provision of incentives to the private sector as well as demand policies (public purchasing policy, support of lead markets); public policy to support innovation has proven to be especially effective where funding for R&D was combined with complementary policies supporting the take-up of innovation). This concerted set of actions aims at bringing agents' anticipations into alignment and successfully coordinate investment plans (Mowery, 2006) for the benefit of the development of a particular technology or a particular sector.

A key issue is, therefore, for the regional (or national) economy to be able to shift research and innovation capabilities to more productive use (one or a few number of selected fields) whenever possible. This ability is a critical determinant of success, implying non neutral allocation process with respect to technologies and sectors. But departing from neutrality is always dangerous since it implies guessing future technological and market developments. So a central question is about "program design": how to make these mission-oriented large programs less vulnerable to government failures, wrong choices, picking winners, market distortions.

Complementarities with competition policy is central as well as the presence of more than one funding agency with different but overlapping agenda. Also important is to avoid the pre-definition of technology architectures and design by central planning but rather to let the market discovering the best technologies; even if it is done under the logic of a mission-oriented policy. Such programs have to be designed also in order to foster entry by new firms in emerging industries; not only to help the large firms already in place.

Strategic initiatives are important but the design of the principles of resource allocation is critical as well.

The "joys" of smart specialisation in the ERA

Any region that has managed to do all that is ready for the ERA! It will only be competing with a small number of other territories to attract and capture the specialised knowledge economy resources in its domain ; it will more easily reach the « tipping point » to turn the increasing returns in its favour as the critical size threshold is far lower ; the resources produced by the region, thanks in particular to its higher education, professional training and research programmes, constitute "co-specialised assets" (Teece, 1986) – in other words the regions and their assets have a mutual need of one other – which accordingly reduces the risk of seeing these resources go elsewhere. (Recall the old maxim of the economics of development: "beware of investing in things that can move!"). They will more logically circulate among the small number of regions sharing the same specialisations.

The region around Loeben in Styria, Austria, whose innovation capacity was initially built in the 19th century in the field of mining and metallurgical technologies, is a good example. Constructed around a highly reputed technical university, this capacity has produced certain key inventions in the sector, while renewing technologies and investing in new areas of application, based on sustained entrepreneurial activity.

Thus the particularisation of regional and/or national knowledge bases will prevent the ERA from being turned into a "draining" mechanism of most European territories and will on the contrary encourage the emergence of a geographically distributed system of research capacities, whilst facilitating the emergence of a certain number of globally attractive and competitive knowledge hubs.

Opportunities for everyone: Cambridge and Andalusia

Smart specialisations provide strategies for everybody, not just for Cambridge, Orsay or Louvain! Certain regions are well placed to try their luck in the general purpose technology production domain (Cambridge in biotechnology, Louvain for information technologies, Grenoble for nanotechnologies). Many other regions are in a good position to develop the **applications** of these general purpose technologies in economic domains that are important for the region in question: biotechnology applied to the exploitation of maritime resources in Andalusia ; nanotechnology applied to the wine quality control, fishing, cheese and olive oil industries in Braga (Portugal).

The rare properties of general purpose technologies

Major innovations are of course the result of the invention of a GPT and of the ensuing successive technological generations but myriads of equally economically important innovations result from the "co-invention" of applications. A general purpose technology is in fact distinguished by its characteristics of horizontal propagation throughout the economy and the complementarity between invention and application development

(Bresnahan, 2003). These complementarities are fundamental. Expressed in the words of the economist, the invention of the general technology extends the frontier of invention possibilities for the whole economy, while application development changes the production function of a particular sector. Application co-invention increases the size of the general technology market and improves the economic return on invention activities relating to it. There are therefore dynamic feedback loops in accordance with which inventions give rise to the co-invention of applications, which in their turn increase the return on subsequent inventions. When things evolve favourably, a long-term dynamic develops, consisting of large-scale investments in research and innovation whose social and private marginal rates of return attain high levels. This dynamic may be spatially distributed between regions specialised in the basic inventions and regions investing in specific application domains.

Most productivity gains from information technologies in the most recent period thus result from application innovations in certain domains whereas these gains resulted from generic inventions during the preceding period. This goes to show that there are indeed strategies for everyone: some key regions will play a worldwide role in the production of these technologies, and this role will be all the more prominent since these regions will benefit from more powerful agglomeration effects. A great many other regions must become world leaders by developing their knowledge bases at the intersection between a GPT and an application domain (or several).

These regions must however forge strong links with one or another of those regions in the first category that will supply the generic knowledge, so that the application co-invention processes are permanently revitalised by the generic invention dynamic. These connections are in theory facilitated by the existence of externalities between the two domains, but additional incentives are certainly also necessary.

Road map for regions setting their sights on smart specialisation

Of course, the constraints are many and the journey along the road to smart specialisation is a perilous one for those regions wishing to undertake it and install an application co-invention capacity, liable to act as economic growth engine. These regions must:

- succeed in particularising their knowledge base (see above);
- invest in the production of human capital whose composition and general level will be adapted to the domains of specialisation;
- develop research and innovation capacities and direct them towards the co-invention of applications in the selected domains;
- set up networks of cooperation and knowledge circulation with other regions sharing the same specialisations;
- create and consolidate also - and perhaps especially - knowledge circulation networks with the region that invents the general technology;
- and finally make sure that most of the benefits from innovations are captured by regional actors. The « innovate here, benefit elsewhere » syndrome particularly applies to the least well-placed regions. Consider for instance start-ups that are

bought and relocated. It is thus advisable to scale down this syndrome by adopting an active policy for financing company growth for example.

The connection between the two categories of region is important; it imposes investments in knowledge circulation networks in order that generic knowledge plays a nurturing role for application co-invention while the latter has a retroactive effect on the main invention dynamic.

Finally, it should be pointed out that the « smart specialisation » strategy does not necessarily offer any protection against the risks of collective inertia and inability to respond to the challenges of a radical innovation that threatens to render the capacities of a particular region obsolescent. We know that resource agglomeration and geographical co-localisation have many virtues, particularly when a new technological paradigm emerges (these are the external effects that we have already reviewed). However these collections of resources can also turn into "communities of inertia", in other words communities in which the persistence of behaviours, values and beliefs that had previously worked well predominates (Sull, 2001). Firms may even tend to respond to the new challenge by placing even more confidence in the organisation routines of the past, a phenomenon that Sull designated "active inertias" (Sull, 2001). As this author clearly demonstrates, tyre companies in the Akron region of the United States responded to the technological challenge posed by Michelin by striving to incrementally improve their own technology that had become obsolete and heavily investing in new production capacities without making any radical technological changes to them. Akron was wiped off the map. So smart specialisation does not necessarily provide any protection against obsolescence and inertia. Even *Silicon Valley* is probably not immune (The Economist, 2003)! However three mechanisms – i) emphasis placed on application domains, essential for the local economy (for example the exploitation of maritime resources), ii) a continuing investment policy in higher education aimed at an appropriate composition and level of human capital for innovation, creativity and entrepreneurial activity and iii) a strong connection with the regions that invent generic technologies – must allow us to protect ourselves against too much inertia and, in the course of time, manage the inevitable moments of creative destruction and renewal.

By way of conclusion

At the dawn of the ERA, most European regions do not seem ready to become part of a European area that is open and competitive in the areas of research and innovation. Too many regions in Europe opt to compete in the *same* worldwide or European tournament in the field of biotechnologies or information technologies. This sheep-like behaviour inevitably leads to a collection of subcritical systems and results in an unhealthy uniformisation of the European knowledge base.

The ERA is obviously one step ahead however since regions will no longer be able to take refuge behind their national borders in order to somehow or other maintain an uncompetitive or even mediocre research system. The ERA is aiming to liberate agglomeration processes and facilitate the emergence of world centres that will be able to draw from the best sources, without obstacle or limit. This development must not however be synonymous with a "draining" of the greater part of the continent in the science and technology domain.

"Smart specialisation" is the only concept that provides an answer to the problem of how to reconcile polarisation and distribution. If correctly carried out by a large number of regions (see above), "smart specialisation" will gear down the ERA in a way, by creating numerous sub-areas of competition and regional polarisation. But these will no longer correspond to state borders; they will be based on the existence of separate areas of specialisation, selected by these regions.

The smart specialisation process has already begun in a great many regions and territories. The few examples given in this article certainly do not do justice to all the efforts made at regional or country level to identify what is original and unique about their respective knowledge bases. Innovation systems associated with these knowledge bases are being developed in liaison with the application domains essential to the economy of the region or country. They must also maintain close relationships with the central regions that invent the generic technologies.

What still remains to be done however is to provide this smart specialisation process with a solid theoretical interpretation to perhaps give it an even greater political impetus. What is essentially required to achieve this are a good understanding of the entrepreneurial dimension of smart specialisation and an appreciation of the importance of the complementarities between the invention of a generic technology and the co-invention of applications that sustain it. We hope that this volume will help to contribute to this understanding.

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The Knowledge Economy, Spillovers, Proximity and Specialisation

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Introduction

The complexities of where and why economic growth occurs nowadays are difficult to pin down, especially if using growth models that are not accomplished at dealing with the exigencies of the knowledge economy. Hence a first task is to seek to show how "knowledge economy" conventions create different and distinctive demands of people and places than the prominent, century-long and more, effects of industrialisation and what came to be called the "Industrial Age." It is one of the surprises to many observers of the rise of globalised web-based communication technologies, that work and communities have not spread out ubiquitously as a result of information society and its attendant "footloose" locational potential for people and jobs. Rather, as globalisation has proceeded, regions have become more prominent economic governance actors than they were, because many have evolved science and technology-based (and creative) clusters requiring elements of localised policy support.

Thus in a knowledge economy, greater economic force exists than hitherto in innovation deriving from creative, scientific and technological knowledge, often generated in university rather than corporate laboratories. It is thus important to understand, for economic purposes, the varieties of knowledge-based clustering, most notably in ICT, biotechnology, and newer ones even more focused on addressing climate change, like "cleantech", to pin down the rationale behind it (Burtis et al., 2004). There are very strong indications for biotechnology worldwide that clusters in geographical proximity to university labs rather than large firms' intra-mural R&D, are the source of knowledge-based growth. In ICT there are cases of comparable lab-focused location for R&D but also of location near customers and suppliers, or even airports, (so-called Marshallian "localisation" externalities) for more routine interactions. Of central importance in the analysis of this kind of clustering compared to say, the remarkably successful clustering that generates so many employment opportunities in traditional Italian luxury design industries or those that pioneered textile manufacturing in the Great Britain of Alfred Marshall (1916) is the role of innovation and the science and research base.

Reinforcing proximity are opportunities to gain from "knowledge spillovers" from the talent available, the novelty and quality of the "research industry" in specific knowledge "hotspots" and the opportunities for "open science" and even "open innovation"

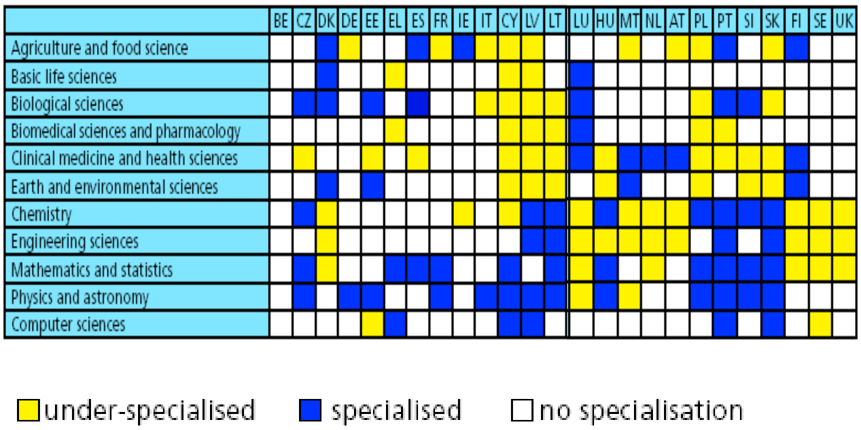
(Chesbrough, 2003). These are often found in proximity in the form of clusters, many warranting a post-cluster "megacentre" or "platform" designation since they contain "related variety" sub-clusters that may have high *lateral* absorptive capacity, major public or non-profit facilities like universities, hospitals, research laboratories, and government research institutes as anchors as well as firms, the more common element in business clusters according to Porter (1998). Within them are numerous intermediaries that are masters of many kinds of knowledge from exploration to exploitation and in-between (March, 1991); analytic, synthetic and symbolic knowledge categories distinguish science, engineering and creative production; and at the cognitive level, tacit, codified and, as proposed elsewhere, something that frequently *intermediates* in-between that we term "complicit" knowledge (Cooke, 2005). In what follows we examine national and regional R&D and S&T specialisation. This is followed by a section on theoretical implications for contemporary regional specialisation and "related variety."

Evidence on EU S&T Specialisation at National Level

A region/country's level of specialisation in a given field of science or technology is measured by comparing the world share of the region/country in the particular field to the world share of the region/country for all fields combined (we refer to the "share of scientific publications" for scientific specialisation patterns, and to the "share of patents" for technological specialisation). The EU's scientific and technological output appears to be more diversified than that of the US. Although this is a potentially rich resource in the medium and long term, additional efforts are required to ensure that activities are not too fragmented.

The EU countries show diversity with regard to their scientific capabilities. Among the most active publishing EU countries, Germany is strong in physics and astronomy but is less involved in agriculture and food science; the UK is not overly specialized in any field according to statistics in Figure 1 and is relatively under-specialised in chemistry, engineering sciences, and mathematics and statistics; France is specialised in mathematics and statistics as well as in physics and astronomy but is weak in agriculture and food science; finally, Italy shows under-specialisation in agriculture and food science and in biological sciences. With regard to the smaller (in terms of publications) EU countries such as Portugal and Slovakia, concerns may arise about the broad scope of their scientific efforts given the constraints imposed by their limited financial and human resources.

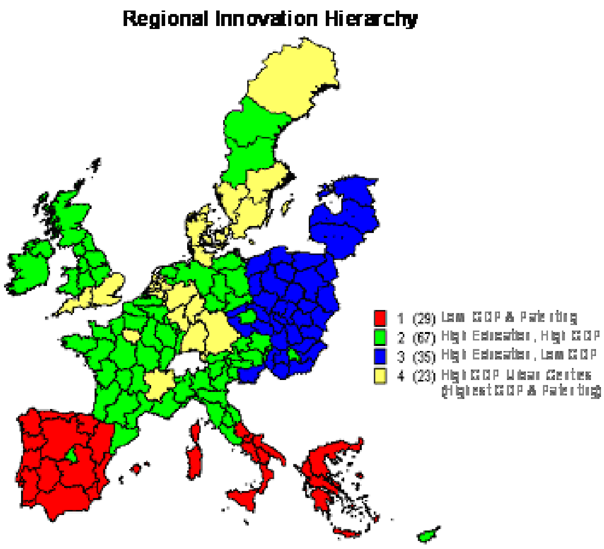
Figure 1: EU S&T Specialisation, 2005



Regional Specialisation in EU

In Figure 2 we see the EU structured according to its S&T "meta-regions" normalised in relation to regional Gross Domestic Product (GDP). Methodologically the map is derived from factor and cluster analyses of numerous S&T indicators drawn from Eurostat databases.

Figure 2: EU Regional S&T over GDP variations

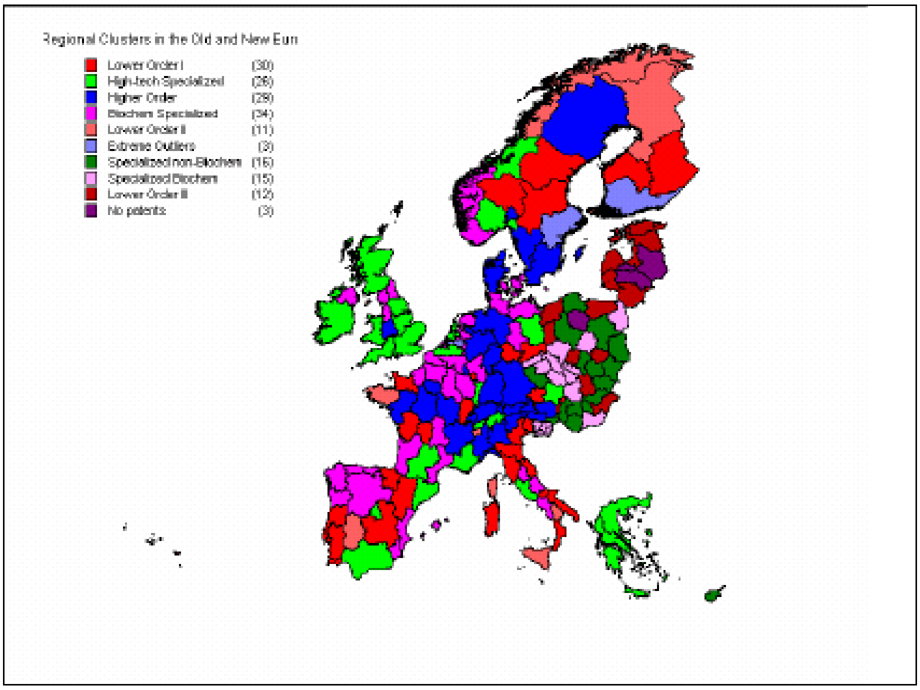


Source: Verspagen (2007)

Examples of the indicators selected are shown in Figure 2 but others include Tertiary Education, Business R&D and Share of Innovation Strategies. Of especial interest are, first, the presence of islands of relatively high performing regions in the Accession Countries. While these generally form a S&T meta-region of high tertiary education but low GDP, the Prague, Budapest and Gyor regions score relatively high on both. Second, (Finland data not available) the Nordic countries are the highest performing meta-region, especially (Sweden) in its peripheral regions where a "knowledgeable cities" factor is the most likely explanation. Finally, southern Europe performs weakly on these S&T indicators.

Figure 3 presents some macro-sectoral manufacturing breakdown of S&T indicators. Thus categories including high technology specialised, specialised biochemistry, higher and lower order functions, absence of patenting activity, and so on. Frankly-speaking this analysis produces some counter-intuitive results. First Greece (and Cyprus) are not normally considered high technology specialised countries. This can be explained partly methodologically where, amongst the S&T industry sectors analysed in Verspagen (2007) the high-tech ones are more pronounced than any others. However this does not mean Greece is a high-tech economy, rather the reverse. Regions specialised in biochemical S&T are less counter-intuitive (e.g. Northern England, west Norway, and Rhine valley). Also "no patents" occur, predictably in a few rural, east European regions.

Figure 3: Regional Clusters in the Old and New Europe



Source: Verspagen (2007)

Lineaments of Proximity in the Knowledge Economy

In recent years, a focus on sub-national (regional) analysis has emerged as there has been a spotlight upon science-based clusters, interactive innovation, and creative, tolerant and talented concentrations of politically desirable economic growth. This is associated with a corresponding eclipse of the notions of ubiquity (Maskell, et al., 1998) as conditions of digital connectivity and the death of distance (Cairncross, 1997) as its main effect, in favour of the idea of proximity as a powerful economic force. In well-rooted research on even traditional industrial districts in Italy, one senses a revitalised recognition and analysis of social capital, trust and interactivity – and a notion of economic community as key contributors to continued small firm economic buoyancy (Becattini, 2001). Indeed, such is the dynamism of these globalising agglomerations that many now host in their interstices, communities within communities, as thousands of Chinese entrepreneurs and workers alongside fewer but still substantial numbers of Islamics migrated into cities like Carpi, near Bologna and Prato, near Florence, in the early 2000s (Becattini and Dei Ottati, 2006). Foremost are agglomerative opportunities for tacit, complicit, codified, face-to-face and tactile contact, knowledge exchange and of course business. Such socio-economic "communities of practice" are also the *ne plus ultra* of, especially, modern science-based economic development (Brown and Duguid, 2001).

Thus the death of distance and the end of geography were rumours much exaggerated upon the advent of innovative, knowledge-based clusters (Morgan, 2004). However, interestingly, proximity, the literal meaning of which includes nearness, closeness, contiguity, and propinquity, all with traditionally geographical connotations, has evolved elaborated and geographically unconfined meanings, involving nearness in context, domain and even opinion. Thus digital chat-rooms are quite neighbourly places in virtual space. A multinational company displays characteristics of organisational proximity in all its global operations because of its common rules, conventions and resources, from job-titles to the commonalities of its intranet. Zeller (2004) in an interesting article tracing the dependence of Swiss "big pharma" on innovative biotechnology clusters elsewhere, lists, as well as geographical proximity, the following "virtual" proximities: institutional (e.g. national laws); cultural (e.g. communities of practice); relational (e.g. social capital); technological (e.g. Linux software users); virtual (e.g. a multinational); internal and external (e.g. firm supply chain management). Actually few feature prominently in empirical analyses such as the one he conducts and those that do are usually less important in explaining locational behaviour these days than the core idea of geographical proximity. Thus pharmaceuticals firms open R&D "listening posts" or acquire incumbent firms capable of quarrying American biotechnology clusters. This is a strategy to re-balance the knowledge asymmetries that have arisen as university centres of excellence and DBFs have outperformed "big pharma," resulting in some re-establishing domestic R&D headquarters abroad in the San Diego and Cambridge, Massachusetts biotechnology "megacentres" (Cooke, 2005). Nevertheless, the contemporary elaboration of the notion of proximity, unlike propinquity, is no longer restricted to expressly spatial "nearness in place" meaning. Thus Zeller (2004) performed a useful service in this sense1.

[1] A further theoretical analysis of the relations between innovation capability and varieties of proximity is presented in Boschma, R. (2005) Proximity and innovation: a critical assessment, *Regional Studies*, 39, 61-74

Nevertheless, it is hard to escape the conclusion that much contemporary knowledge economy development tends to become increasingly city-focused. There is little yet that engages rurality with innovative clustering, though the rise of "cleantech" such as biofuels is beginning to change that (Cooke, 2008). The city, and even more so, metropolitan context has traditionally been the most powerful spatial determinant of growth, by and large. Now in the knowledge economy, its force is geared up, reinforcing geographical proximity as a vehicle for achieving economic success worldwide. While the "death of distance" was wrong, especially in its presumption of global "flattening", nevertheless "knowledge economies" exist and evolve as nodes in global knowledge connected by globally networked information flows. This rests on the observation that globalisation actually proceeds through varieties of networks linking nodes of economic power, mainly cities, their knowledge institutions, governance mechanisms and firms. What the economist's "spaceless playground" perspective misunderstood until Krugman (1995) was that such nodes would be the result of increasing returns to urban agglomeration (Sternberg and Litzenberger, 2004).

By and large this has meant increasing returns derived from varieties of spillovers, especially knowledge spillovers, that tend to concentrate in cities, and elsewhere in other "knowledgeable cities" such as university or research towns. This is true for North American, Asian and European cities for which the required analysis has been performed. Clearly, such a wide array of city settings means the growth process is by no means identical in all cases. Moreover, the competitiveness of cities often accompanies social polarisation. However, this is also a by-product of growth where in-migrants are attracted because of perceived economic opportunities absent in their location of origin.

Spillovers, Innovation & Growth

An emergent pattern in the contemporary variety of proximities is that proximity to knowledge spillovers is nowadays crucial to city growth from the exploitation through innovation of research knowledge. This harks back to the initial contention of Glaeser et al. (1992) that human capital and scarce skills are significant factors in a city's capability to retain and augment its economic growth. This is thus something of a progenitor of Florida's (2002) talent-led analysis of US city growth in the contemporary era. However, much of the finer detail of variations within growth trajectories is lost in these analyses, not least because of definitional, and even unit of data analysis complexities. One interesting differentiation first hypothesised from a static analysis of major concentrations of knowledge economy sectoral activities, derived from EU and other city and region level data on high technology manufacturing and knowledge-intensive business services (KIBS), was that major cities, sometimes also capital cities, accreted much of the KIBS employment. Contrariwise, more specialist satellite cities concentrated high technology manufacturing employment to a greater extent. Live instances of that modern urbanisation process would include, for example, Cambridge and numerous lesser high-tech satellites of Boston such as Waltham, Worcester, Woburn and Andover; San Francisco *vis à vis* many such places in Silicon Valley, London in relation to Cambridge, Oxford and the Thames Valley; Stockholm and Uppsala; Helsinki and Espoo; and Copenhagen in crossborder relationship to Lund, the so-called Medicon Valley, traversed by the Øresund bridge. These "cumulative causation" and "spatial backwash" effects were predicted long ago by Myrdal (1957) and Hirschman (1958)

This suggests that in countries where the main financial centre is not the capital city the former will exert the stronger proximity effect but that where, as in the UK and, for example, Austria, the capital is also the leading financial services centre, a strong spatial monopoly (or more accurately quasi-monopoly) proximity effect is exerted (Cooke et al, 2007). This is the classic result modelled by Krugman (1995) in applying increasing returns to scale theory, under conditions of imperfect knowledge, to two hypothetically competing candidate cities with the consequence that one always ended up monopolising space. Contemporary city growth theory places knowledge spillovers from (geographical) proximity at the forefront of the explanation for these observed tendencies.

To repeat, this is not to say that geographical proximity determines economic activity to an overwhelming degree. If anything, the implications of what has been concluded here is that the defining feature of knowledge spillovers from geographical proximity is qualitative and quantitative in equal measure. That is, a firm, let us say, located proximately and actively in relation to multiple and varied sources of high grade intelligence, creativity and connectivity is in principle at an advantage compared to a competitor who is not. However, connectivity to other appropriate knowledge nodes elsewhere in the relevant global knowledge networks is likely to be quantitatively less intensive albeit of qualitative equivalence or even superiority. In their discussion of precisely this geographically proximate as against virtually proximate relationship Owen-Smith and Powell (2004) argued for the superiority of geographical proximity along the following lines. Key processes by which dynamic proximity capabilities are expressed interactively in research or exploration knowledge transfer, and commercialisation or exploitation knowledge transfer include the following:

- There is a difference between "channels" (open) and "pipelines" (closed). The former offer more opportunity for knowledge capability enhancement since they are more "leaky" and "irrigate" more geographically proximately. Pipelines offer more confidential, contractual means of proprietary knowledge transfer. This may occur locally or over great geographical distances based on contractual agreements. These are less "leaky" because they are closed rather than open.
- In high-tech fields, research centres may be a magnet for firms because they operate an "open science" policy, promising spillover innovation opportunities. These are possible sources of productivity improvement, greater firm competitiveness, accordingly proximate, localised economic growth.
- Such open science conventions influence inter-firm innovation network interactions. Although researchers may not remain the main intermediaries for long as successful firms grow through patenting and commercialisation, they experience greater gains through the combination of proximity and conventions, than through either proximity alone or conventions alone.

These propositions each receive strong support from statistical analyses of research and patenting practices in the Boston regional biotechnology cluster. Thus:

"Transparent modes of information transfer will trump more opaque or sealed mechanisms when a significant proportion of participants exhibit limited concern with policing the accessibility of network pipelines closed conduits offer reliable and excludable information transfer at the cost of fixity, and thus are more appropriate to a stable environment. In contrast, permeable channels rich in spillovers are responsive and may be more suitable for variable environments. In a stable world, or one where change is largely incremental, such channels represent excess capacity" (Owen-Smith and Powell, 2004)

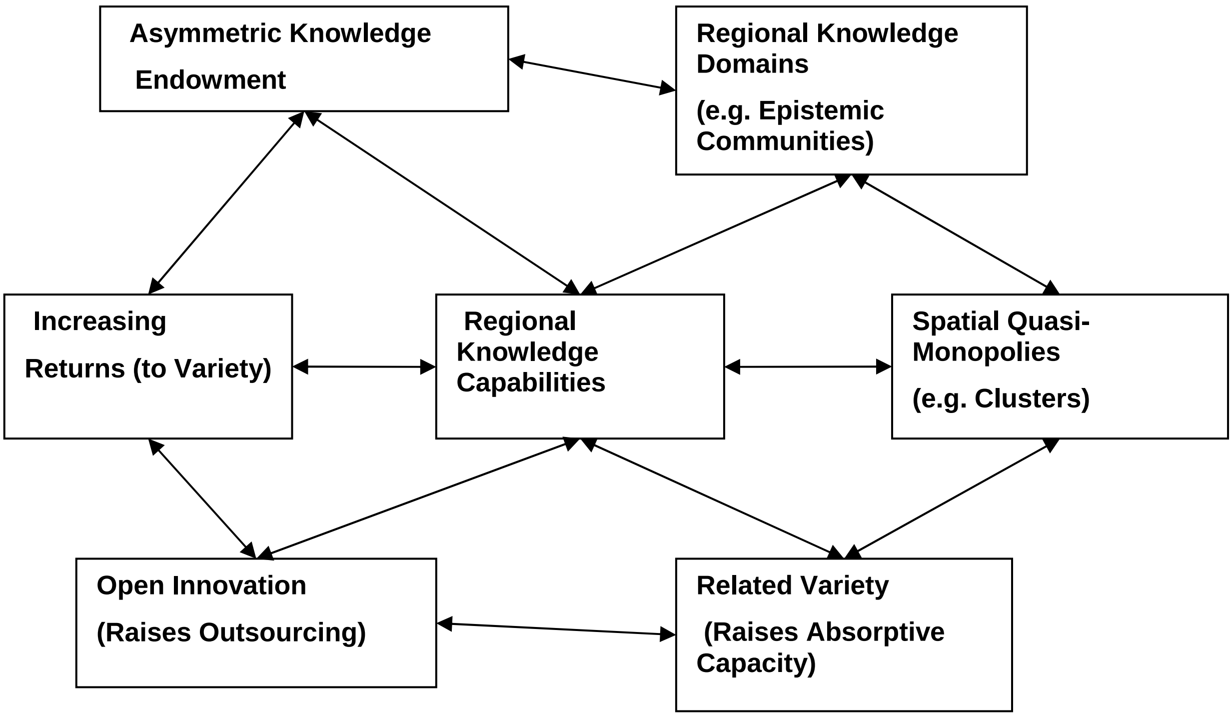
Finally, though, leaky channels rather than closed pipelines also represent an opportunity for unscrupulous convention-breakers to sow misinformation among competitors. However, the strength of the "open science" convention means that so long as research institutes remain a presence, as in science-driven contexts they often do, such "negative social capital" practices are punishable by exclusion from interaction, reputational degrading or even, at the extreme, convention shift, in rare occurrences, towards more confidentiality agreements and spillover-limiting "pipeline" legal contracts. We noted in the introduction how open science conventions attract, in further evolutionary rounds, "open innovation" to such knowledgeable clusters when it might otherwise be assumed openness should mean knowledge advantage erosion. But likely gains are perceived to outweigh losses by customers taking the plunge. This is a major factor in proximity-based economic growth since knowledge supplier firms garner a substantial share of their income from, especially, R&D outsourcing by larger customer firms.

A Generalised Theoretical Framework: Economic Growth and Related Variety

In this section, it is underlined how knowledge hegemony has shifted to universities and the cohorts of science-based firms that often co-locate with those that are "ahead of the curve" in industries like ICT, cleantech, nanotech and biosciences. In the course of this account, a possibly new theoretical framework for explaining spatial industry organisational shifts has to be essayed. It is evolutionary in origin, interested in the economics of search and selection practices of firms in contexts where variety acts as "evolutionary fuel" in Hodgson's vivid phraseology (Hodgson, 1993). By evolutionary fuel is meant iterative, trial-and-error interactive feedback from experimentation by actors to survive and prosper economically. The greater the variety, the greater the opportunity for innovation arising from interactions with other actors.

It has been shown empirically that opportunities for the swiftest innovation occur in conditions of proximate and related variety because of knowledge spillovers and high lateral absorptive capacity (Boschma, 2005). Cities are one variant of this, but because their variety can be fragmentary and only partly related, they are less fruitful than settings with only related variety (e.g. clusters or groups of related clusters, a good example being KU Leuven's (catholic university Leuven) six ICT, bioscience and agro-food clusters, employing 20,000; Hinoul, 2005). Hence this new perspective settles at the apex of a conceptual triangle between Jacobs (1969) who advocated sectoral diversification and Glaeser et al. (1992) specialisation as key wellsprings of innovative growth through spillovers of various kinds. It is post-sectoral, recognising innovative growth to be facilitated through knowledge or technology platforms characterised by openness of knowledge flows. For example, a location specialising in leading edge research in sensors finds numerous applications of such technology in many related yet extensive fields where absorptive capacity is high.

Figure 4: Knowledge Capabilities and Economic Geography: A Theoretical Framework



Understanding of technological efficacy is transferable with greater facility among "communities of practice" with low internal "cognitive dissonance" between industries. *A priori* biotechnology is the exemplar of this mode of industry organisation, but more as pioneer than offshoot now that the model of "open innovation" building on "open science" norms is emulated widely, from "open systems architectures" of various kinds to "open source" software (Owen-Smith and Powell, 2004). The point here is that "open science" norms among scientists operate informally through normal "channels" even if "formally" confidentiality agreements exist with clients. This rather under mines Zucker et al.'s (1998) over-legalised interpretation of contracts that cross the academic and entrepreneurial interface. As Chesbrough (2003) notes clients know this – complicitly - in the knowledge also that they will themselves receive returns from localised knowledge spillovers in the cluster. Not all of this *openness* is geographically proximate, distant networks play a strategic part, and *cognitive* and *relational* proximities come into play as Boschma (2005) stresses.

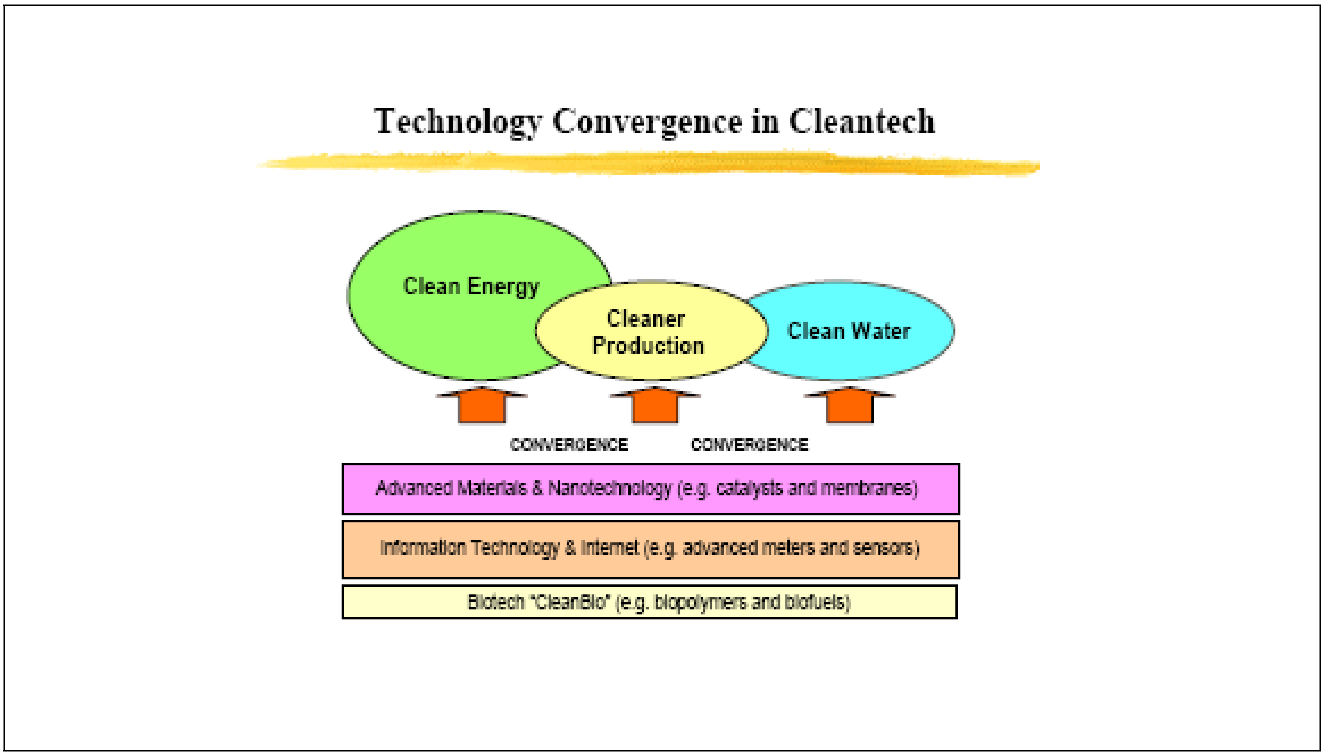
Nevertheless, the implications of related variety as witnessed in the demise of the *generic* corporate R&D model compared to the *varietal* choice model found in the rich mix of research centres and niche firms in, for example a major biotechnology cluster, is testimony to the attractions to customers of the latter over the former model. These may be measured in terms of *capabilities* ranging from those relevant to exploration, examination or exploitation knowledge (Cooke, 2007). Hence, there are grounds for advancing a theoretical framework that links together these new elements and highlights the role of varieties of *knowledge* in contributing a testable explanation of regional developmental asymmetries. The key elements are presented in Figure 4 above, and discussed subsequently. We start from the centre of the diagram, denoting a region in which a mix of widely in-demand knowledge capabilities evolves. Connecting to north-west in the diagram, and compared to other regions, this expresses its *asymmetric* knowledge endowment from a variety of knowledge organisations and institutions (Akerlof, 1970). *Exploration* knowledge organisations, such as research institutes, knowledge networks among individuals (e.g. "lunar societies"; Uglow, 2003) and knowledge leadership figures (e.g. possible future Nobel laureates) co-exist with *examination* knowledge equivalents for standard-setting, trialling, testing and patenting, and *exploitation* knowledge bodies such as entrepreneurs, investors and related professional talent. The evolutionary fuel is supplied (linking westward in Figure 4) by the attraction of a variety of imitative and innovative talent to the region, a Schumpeterian "swarming" realising increasing returns to related variety (south-eastward diagrammatic connection) where innovation may move swiftly through various parts of the innovation "platform". Related variety nourishes absorptive capacity because cognitive distance between platform sub-fields is low (think of "general purpose innovations", after Helpman, 1998).

Moving north-east in Figure 4, these processes result in the presence of regional "knowledge domains." The dictionary definition of "knowledge domain" is a region or realm with a distinctive knowledge base, common principles, rules and procedures, and a specific semantic discourse. This naturally fits well with the concept of the epistemic community with its own professional discourse and interests. Such monopolistic features are frequently characteristic of, for example, *clusters* that in regional terms may display related variety (e.g. varieties of engineering expertise in the industrial districts of Emilia-Romagna in Italy in a spectrum from *Ferrari* cars and *Ducati* motor cycles (both Modena) to *Sasib* in packaging machinery (Bologna) and *drgSystems* machine tools in Piacenza; Harrison, 1994). These and other clusters have spatial quasi-monopolistic or "club" characteristics, exerting exclusion and inclusion mechanisms to aspirant "members" consequent upon their knowledge value to the club. If such industries operated as markets rather than knowledge quasi-monopolies it is difficult to see why spatial "swarming" would occur. But high technology firms at least are willing to pay super-rents of 100% to locate in clusters – even when they are professed non-collaborators, to access anticipated localised knowledge spillovers (Cooke, 2007). Finally, to the south-west of Figure 4, it is precisely such localised knowledge spillovers that induce what Chesbrough (2003) calls "open innovation" whereby large firms outsource their R&D to purchase "pipeline" knowledge, and access via "channels" regional knowledge capabilities (Owen-Smith and Powell, 2004). These processes interact in complex, non-linear ways displayed graphically in Figure 4, to explain regional knowledge asymmetries. Variations in the market value of regional knowledge combinations also contribute significantly to associated regional income disparities (Boschma and Frenken, 2003). Being an evolutionary growth process, successive increasing returns may be triggered from any point within or, of course, beyond the confines of Figure 4.

Conclusions

With respect to other sectors, perhaps less work has been conducted than in the economics of biosciences though "open innovation" and varieties of "outsourcing" research seldom focus on biotechnology as such. ICT, aerospace, even "consumer products" as studied by Chesbrough (2003) point to the knowledge quest having brought major reductions in large corporate intra-mural R&D. There is of course a large question over the validity, reliability and even meaning of such an antediluvian notion as "sector". Here is unfortunately not the place to delve into the lethal critique of the notion due to space limitations. However three criticisms can briefly be offered. First, the sector notion is a statistician's artefact that is an increasingly misleading representation of reality. Second, sector classifications are little changed since their nineteenth century origins to enable identification of such activities as biotechnology, nanotechnology or "cleantech".

Figure 5: Technology Convergence in Cleantech



Third, as we have seen technological innovation increasingly progresses by means of the evolution of "platforms" that take spillover advantages, combine many technologies that are, in increasing numbers of cases, adaptable across first, related variety, later even more diverse industrial and technological applications, as a moment's reflection upon the technology platform built around "cleantech" (Figure 5), let alone software or genetics makes clear.

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Specialisation and Europe's R&D performance: A note

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Introduction

Although Research and Technology Development (RTD) is only one part of the overall investments that are necessary for innovation, it is nevertheless a central element of any innovation strategy. Moreover it is an element in which government policy plays an important role: public investment in RTD is a significant component of overall RTD and knowledge creation in the European economies. A big question is the extent to which RTD policies should focus on existing and potential specialisations at the national level, and what this implies for EU policy.

Convergence and diversity

One of the primary objectives of the European Union is the promotion of a process of convergence in real incomes and living standards across the countries and regions of the Union. To a large extent, policies for achieving this have been seen in terms of establishing common frameworks for economic behaviour. These include most importantly the completion of the internal market, common regulatory and procurement frameworks, and the common currency. In some cases convergence is not only an intended outcome of these actions, it is seen as a precondition: entry into the monetary union, for example, involved convergence in some key macroeconomic ratios, such as debt to GDP, deficits to GDP, inflation rates and so on.

How does innovation and technological capability fit into this picture? If countries and regions in Europe are to converge as a result of integration, then they must do so on the basis of economic growth paths which have quite different starting points, if only in terms of initial differences in productivity, real incomes and so on. What is involved in growing towards convergence? It is widely recognised that economic growth rests - in complex ways - on capabilities with respect to organisational and technological innovation: all theories of economic growth, from whatever conceptual starting point, assign an overwhelming importance to technological change in particular in the growth process. It seems reasonable to suggest, therefore, that improving the growth performance of lower-income countries and less favoured regions involves upgrading the technological capabilities and innovation performance of the areas in question.

But does this mean that convergence and integration are likely to rest on common technological capabilities? Does convergence - meaning similarities in terms of economic outcomes - imply similarity in terms of areas of technological knowledge, skill and competence, and in the investment processes which are necessary to develop such competence? From a policy perspective, to what extent does the process of European integration lead to convergence in policies with respect to RTD and innovation, and hence to the possible emergence of a "European system" of innovation based on commonalities in policy objectives and practices? There are important questions to be asked concerning whether Europe is involved in a coherent and diversified pattern of RTD. Most of the questions depend for their answers on an understanding of specialisation.

RTD specialisation

Central to the development of the Lisbon Agenda, in many of the relevant policy documents, is the idea that the overall publicly-supported European RTD effort is fragmented and incoherent. This claim suggests replication and duplication of effort in some areas, but it also implies that there are problems of scale: because the national efforts are divided, there are difficulties in reaching critical mass, and therefore sub-optimal scale at the level of particular technological areas of fields of science.

The broad issue concerns the interpretation of differences in RTD efforts across Europe. Do these reflect fragmentation and duplication, or do they on the contrary represent a healthy diversity? From an evolutionary point of view, diversity – which in this case means different compositions of RTD, different organisational forms, and different research trajectories - is a key attribute of adaptability to change. In research generally, it is often fruitful to have multiple paths of investigation. Is this how European differences should be interpreted, or do we by contrast in fact have overlapping efforts, without genuine diversity?

Clarifying such questions is important to the discussion of scale issues in European RTD. Here the issues concern not just the level of RTD in Europe, but rather its composition and organisation both at the aggregate level and within the Member States. The latter are of course responsible for most of Europe's publicly funded RTD. Improving coherence is therefore very much a matter of enhancing coordination mechanisms across the diverse RTD systems of Europe, which in turn can only rest on a far more detailed knowledge of what is actually occurring in European RTD. Some broad issues for the implementation of ERA include:

- To what extent are there real differences or similarities in strategy, organisation and outcome (in term of actual performance of RTD) across Member States and regions?

- To what extent do such differences represent diverse paths (perhaps appropriate to differing regional or national conditions) or, by contrast, replication or duplication of priorities which lessen the overall European impact of national strategies?

To get a useful picture of evolution and trends in European RTD which might answer such questions, we need to go beyond general statements of strategy or statements of priorities into the detail of programme objectives, fields of research, and application areas, as well as into the details of research performance across large firms, government organisations and universities in Europe.

This area is so closely related to the broad objectives of the Lisbon strategy, that it is a central challenge for the ERAWATCH project[1]. In line with this, evolution and trends in RTD are already being taken into account within ERAWATCH[2].

Measuring specialisation: methods and indicators

The background to any analysis of specialisation is the claim (made in several of the Lisbon/ERA documents) that the EU has too much duplication of effort, with everyone doing the same thing but a below critical mass. Behind this is the implicit idea that EU countries are all engaged in R&D replication/duplication. Is this true? Do we have duplication in the EU, or is there some kind of diversity? If there is diversity, then we would expect to see greater specialisation.

Now we know that there is sectoral specialisation, and technological specialisation as measured with patents, bibliometrics etc. But what about R&D? The big problem is that we have not explored data classified by socio-economic objectives, and fields of research, at levels of disaggregation that enable us to say with any confidence that there is or is not any real specialisation (or conversely duplication) of R&D efforts across the EU.

This suggests that it is important to focus on the issue of looking at R&D data in the most disaggregated way across the member states. We usually look at R&D in terms of sources of funding and sectors of performance. But it is also classified according to fields of research, socio-economic objectives (SEOs), types of research etc.

What can be said about specialisation using existing Eurostat or OECD data on SEOs and Fields of Research? Not much is the answer, because the data is available at best at 2-digit level. This general problem could the theme of research on specialisation for the ERAWATCH project. Part of the project could focus on existing results and methods for looking at specialisation. A big part could discuss how we might get a better picture of R&D specialisation by using the different classifications of R&D data in a more imaginative way. This could include looking across countries with existing R&D data, then asking which countries have better data than others, and then doing specific country studies where the data is good. Where data is classified by all fields at 4 to 6 digit level, then it is

[1] http://cordis.europa.eu/erawatch/

[2] Editors' note: See for instance the national specialisation profiles provided by the ERAWATCH Intelligence Service: http://cordis.europa.eu/erawatch/index.cfm?fuseaction=intService.rdSpecialisation

possible to get a good picture of specialisation. Then case studies can follow up on the data part of the exercise by trying to say what is actually happening in R&D efforts at country level. A related objective could be about the statistical problems involved in trying to get a picture of R&D specialisation, making recommendations for statistical offices about classification and presentation of the data they collect.

R&D Data characteristics

What are the specific characteristics of the R&D data that need to be explored? R&D is normally financed by four broad "sources of funding", and is carried out across four broad "sectors of performance". The primary funding sources are:

- The business sector
- Government
- Private non-profit sources (such as charities or foundations)
- Overseas funding

Each of these funding sources provides a flow of finance which is usually spent across four sectors of performance, which are:

- The business sector
- Government (including organisations such as ministries, R&D labs and research institutes
- The higher education sector
- Private non-profit foundations (including a wide range of non-profit research institutes)

The basic sources of potential data are national R&D surveys. Among the advanced economies, some countries have more or less unique features in their R&D surveys that permit a detailed understanding of the structure of R&D performance. This is because, as well as collecting data on sources of funding and sectors of performance, they also provide four other types of breakdown of R&D expenditure. In the first place, the business sector data is broken down by performance by the industry which is performing research. This can, in principle, be done at fine levels of details.

For all sectors, there are three further ways of classifying R&D expenditure and personnel resources. These are:

- by socio-economic objective (such as economic development, defence, health, environment etc)

- by type of research (that is, pure basic research, strategic basic research, applied research or experimental development)

- by field of research (meaning the specific area in which new knowledge is sought, such as molecular biology, applied mathematics, electronic engineering and so on)

It is possible to explore these categories down to very fine levels of detail, thus generating an understanding of the real priorities and specialisations of the European system. The problem for the future is to focus on total flows of funding and the specific uses to which financial resources are directed, and the objectives and scientific fields that are involved, rather than just looking at total amounts of funding and aggregate R&D intensities. This can potentially be done for all major R&D performing sectors.

Policy Priorities

Specialisation does not necessarily have to be mapped in statistical terms. The qualitative evidence from ERAWATCH is also highly relevant. Turning to priorities, do EU Member States show commonalities in terms of explicit research priorities or do the efforts reflect specialisation? The ERAWATCH database suggests that at a general level there is a set of core science-technology priorities that are common across many countries: ICT, biotechnology (especially biopharmaceuticals), and nano-sciences all feature strongly as priority fields across the EU. However at the level of detail currently available it is not possible to identify the extent to which there are overlaps or commonalities in the specific research programmes undertaken in these fields. There are some signs of emerging scepticism about the priority fields (that are of course common across a much wider spectrum of countries than simply the EU). In Finland, "present RTDI policies have to be seen against the background of dissipating ICT euphoria … and commercial difficulties of biotechnology companies". However Finnish nanotechnology investment is increasing, with about 40 research groups active. Both Germany and the UK have strong medically oriented biotech programmes, with priorities in cardiovascular diseases, cancer, neural problems and (in Germany) genetic factors in environmentally-caused disease. Some smaller countries have strong biotech programmes – Cyprus, for example, has a large biotech priority area, as does Portugal (with links to health objectives).

Behind these broad commonalities there is apparent diversity across countries in a wide range of country-specific research fields. Germany, for example, has major programmes on transport and mobility, focusing on sustainability, low emissions traffic, railways, and traffic management in urban areas. The transport emphasis is shared in Austria. These programmes clearly relate to, and to some extent underpin, strong German industrial specialisation in vehicles, but also in high speed rail. German "lead projects" that relate to prospective technology fields include nutrition, food processes, and mobility, as well as more apparently science-based project. In terms of more country-specific objectives, Finland has programmes in food RTD and innovation, construction materials, and wood products, as well as social research specialisations learning, social capital, environment and law, and developments in Russia. Portugal has a strong emphasis on marine sciences and technologies. These diversities suggest that strong specialisations in public RTD efforts are already present across the EU Member States, and that further mapping derived from ERAWATCH will be fruitful.

Linking industrial competitiveness, R&D specialisation and the dynamics of knowledge in science: A look at remote influences

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Introduction

The debate about the reasons behind the weakening of relative advantages, or competitiveness, of European countries in international competition has examined a large number of factors.

This short informal paper argues that one of the long term reasons for loss of competitiveness is to be found in the poor performance of European science in the last quarter of century, which largely depends on the structure of European academic and research systems. In order to build this argument, we will follow several steps.

First, we suggest that a larger part of manufacturing and services production depends on, or take large benefit from, a large and dynamic scientific base.

Second, we suggest that the inability to lead science has negative influences in sectors that are technologically very far from the frontier, but nevertheless benefit from the scientific environment in indirect and unpredictable, but highly effective ways.

Third, we will offer a short case study in the field of computer science and the related IT and telecommunications industries, based on original data.

Finally, we will show how staying ahead of the scientific frontier places new demands on the institutions of science and higher education, for which European countries have not offered adequate responses in the last few decades. Consequently, the specialisation of European R&D has been focused on fields that have a negative composition effects in dynamic terms. Some policy conclusions follow.

Science and industry: the neglected remote influence

There has been a large research work on the relations between science and technology, and between technological innovation and industrial competitiveness and leadership. The literature on sectoral systems of innovation, particularly on high technology industries, has reconstructed the links between basic research and innovation. The studies on non-patent references, patent trails, citation flows, and author-inventors have done a great job in documenting the increase of importance of scientific inputs to manufacturing and service innovations. This literature suggests that the links between science and innovation are never direct and linear, but rather indirect, non-linear, and largely unpredictable. Nevertheless there is sufficient evidence to claim that several new industries have been created from scratch from the inputs from scientific research (mainly in the biotechnology, scientific instrumentation, and IT sectors), and that high technology industries make increasingly use of scientific knowledge for their activity.

See Table 1 for recent detailed evidence on the pattern of citations in scientific papers written by industrial researchers. The analysis covers approximately 230.000 papers published by scientists affiliated to top 200 firms (ranking by total expenditure in R&D) in more than 7.000 scientific journals in the period 1981-1999. What is impressive from this analysis is that top 200 firms make approximately 1 million citations to publications of top 110 universities and only 600.000 citations to industrial publications. Moreover, in advanced IT industries (Software and business services, Communications services, Computers) between 40% and 50% of citations made by scientists in companies point to publications in Physics.

In our own research on nano-science and nanotechnology we have been able to demonstrate that patents applications by groups of inventors that include both individuals with a track record of publications in the field and individuals that never published (hence most likely industrial researchers) are of better quality than patents from inventors that share the same pattern of activity (i.e. they all publish in nano S&T, or none of them publish).

Table 1: Number of citations to papers authored by academic scientists in papers published by industrial scientists in several industries, by scientific discipline

	Knowledge flows (citations)				
	Number	Chemistry (%)	Computer science (%)	Engineering (%)	Physics (%)
Communications services	26,292	12.1	10.8	22.2	51.4
Software and Business services	25,272	15.1	17.7	17.1	46.3
Electrical equipment	22,896	8.2	9.1	50.3	27.9
Computers	9,210	15.3	13.6	26.5	40.5
Total Industrial sector	217,623	17.7	5.5	22.4	22.4

Source: Adams and Clemmons (2006)

This work has tried to identify *indirect* effects of science on technology, innovation and growth, overcoming the limitations of the simple linear model associated to the early neoclassical conceptualisation.

The emphasis has been mainly on the distinction between direct impact (i.e. technology uses science as an input) and indirect impact (i.e. technologists benefits from good training in science, or other indirect benefits). This is correct, but rather limited.

We suggest there are impacts that are not only largely indirect, but also remote in time and space, and still extremely influential.

First, there are important effects that are *remote in time*. There may be very remote flows of knowledge from pioneering intellectual work, early discoveries, initial conceptualisations, down to ideas that eventually find their ways into technological solutions and then the market. The relevant time scale is in the order of several decades in most cases. Tracing these flows is generally extremely difficult from external observers. Documenting flows of ideas on the basis of direct citations from papers and patents may capture a very limited portion of the real impact. Detailed case studies and contributions from the history of technology are needed. This creates a methodological barrier for economists interested in science and technology, that work mainly with cross-section data or relatively short time series.

Second, there are important effects that are *remote in space* and/or *sector*. The impact may take place in totally different sectors of the economy, ones that transform the knowledge for their own purposes to a point that reconstructing the original roots may be difficult for external observers.

Because of remoteness, it is likely that the actual importance of scientific background for competitiveness is severely underestimated in the current economic debate. Although a general validation for this claim would require new methodologies (for which some work is underway), we offer here two illustrative yet impressive evidence.

The first example comes from the Information Technology industry, in particular the hardware and software industries. We asked a small judgmental sample of scientific authorities in computer science, in both European and US universities, to mention the most important technological innovations in the industry after Second World War and to identify the origins of the idea.

Table 2 shows the list of top 10 innovations. All of them can be traced back to genuine new ideas originally conceived in the academic world. Although there may be a bias in this reconstruction, due to the professional background of our respondents, still what is mentioned is not pure academic outcome but technological breakthroughs, eventually transformed into huge worldwide market opportunities. Incidentally, with the (partial) exceptions of early pioneering ideas of John Von Neumann and of the invention of Internet at CERN, all major breakthroughs were originated from academic research carried out by American scientists and/or in American universities.

Table 2: Origins of most important ideas in computer science technology

Top ten ideas in computer science

1. Turing machine (Goldstine and von Neumann; Turing)
2. Programming languages; formal description of syntax and semantics; LISP (Mc Carthy)
3. Memory hierarchy; cache memory
4. User interface; Graphic User Interface (GUI); concept of window (Xerox Palo Alto Research Center; Apple)
5. Internet (UCLA/DARPA); packet switched multinetworks; http and html protocols; WWW (Berners-Lee)
6. Computational complexity; computational intractability; pseudocausality
7. Relational database
8. Fourier Fast Transform (FFT) (Cooley and Tuckey)
9. Efficient algorythms; data structure (Knuth and Tarjan)
10. Artificial intelligence

Source: our elaboration from expert opinion, in Bonaccorsi (2000)

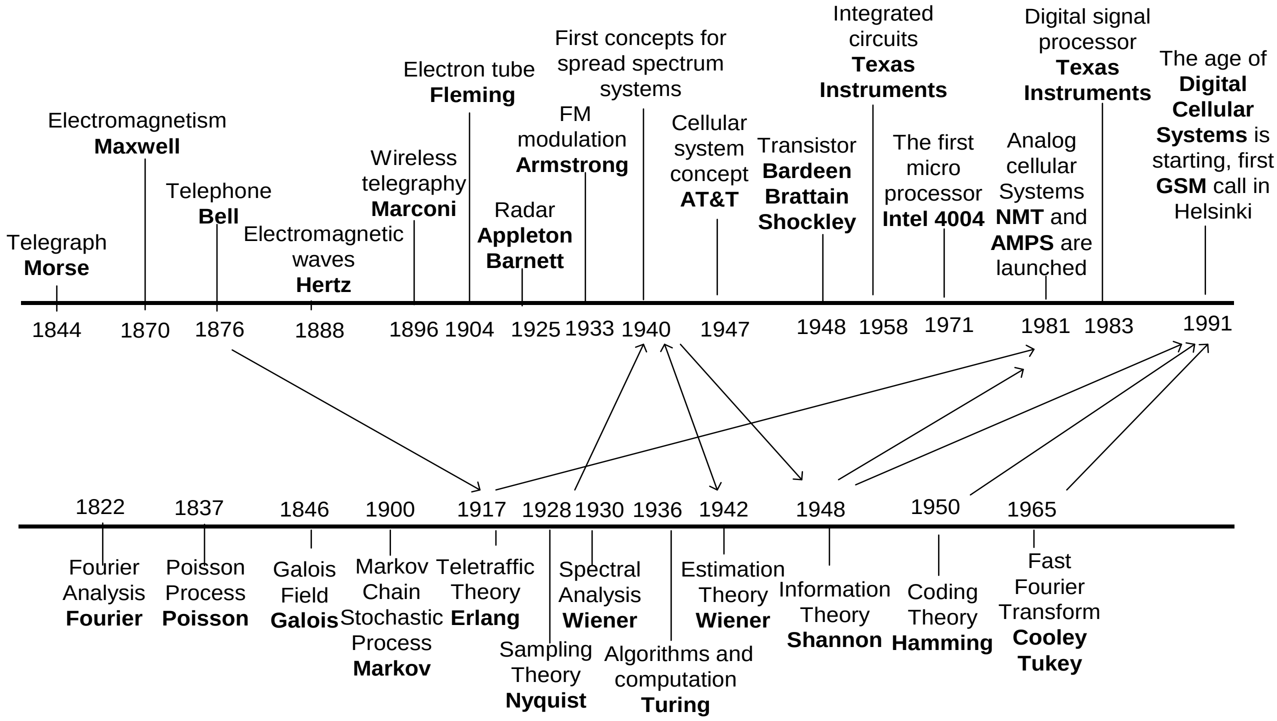
This situation is continuing over time. According to some observers, almost all research carried out by Microsoft Research in the last 10 years had its antecedents in academic research in the "70s and "80s. The cycle of incubation of truly innovative ideas may be very long.

The second example comes from the Telecommunications industry, in particular the mobile telecommunication. Here European industry has performed well, developing a continental standard that facilitated the creation of a large market (GSM) and taking the leadership with Nokia and Ericsson. EU policy has facilitated strong research on pre-standardisation issues and appropriate coordination around a standard (GSM). However, if we trace back the origins of cellular technology, it is interesting to see how deep are the intellectual roots.

Figure 1 offers an ex-post reconstruction that goes back to early Post-War research. Again, remoteness is evident in both time and sector.

The two examples below are ex-post reconstructions, that look backward at the history of technology. While remoteness in time can be identified with historical approaches or expert reconstructions, it is more difficult to identify sectoral remoteness. Usual input-output based measures of inter-sectoral spillovers fail to identify these effects.

Figure 1: Historical milestones of technology and mathematics leading to cellular telecommunication systems.



Source: Nokia

A case in point is given by service industries. It is now recognized that innovation in the tertiary sector follows different paths than the manufacturing industry. Two well recognized sources of innovation and increase in productivity are Information Technology and the quality of human resources.

Although we do not have systematic evidence, we put forward the conjecture that many innovations in the service sector depend on ideas originally developed in the scientific sector, and then transformed, adapted and assimilated through the action of knowledge producers such as software firms and management consultants.

Many innovations in the service sectors take origin from new information technologies such as relational databases, workflow systems, allocation procedures, route optimisation, process engineering and others. These technologies were developed to address operational problems, but none of them could be developed without the rich intellectual background offered by computer science starting from the "70s.

The case of Information Technology

It is generally acknowledged that the competitive performance of IT industries in Europe has been disappointing. As Dalum et al. (1999) show on the basis of US patents in the period 1969-1994, the Revealed Technological Advantage (RTA) of Europe in ICT steadily decreases vis-à-vis competitors, from 0.86 in 1969-74 to 0.84 in 1979-84 to 0.73 in 1989-94. The European IT industry is currently almost completely absent in packaged software (with the exception of SAP) and innovative services, while a flourishing software industry can be found only in customized software and services. A good competitive position is found only in semiconductors (ST Microelecronics). Since the beginning, most of national and EU policies were oriented to support national champions in IT, such as Bull (France), Siemens Nixdorf (Germany), Olivetti (Italy), ICL (UK). These companies almost disappeared from international competition. Another large part of industrial and innovation policies were aimed at supporting IT developments in user industries, such as automotive and aerospace, with a strong captive orientation.

We suggest that one of the long term causes for the poor performance of the European IT industry has been the inability to stay at the frontier of science.

Supporting evidence for this claim can be found in unpublished research based on the analysis of the curriculum vitae (CVs) of approximately top 1000 scientists in Computer Science (n= 1010). The list of top scientists by number of citations received was derived from the CiteSeer citation ranking, a universally accepted system for automatic updating of citations to authors in a large list of both academic and technical journals. The list of top scientists includes authors of all ages, for which we do not control in the following results. We have used these data in Bonaccorsi (2006) and Bonaccorsi (2008) in order to discuss the poor performance of European science. In this paper we use other slices of data in order to examine the permanent mobility of top scientists, that is, the sequence of organisational affiliations over the career. The pattern of observed mobility is highly revealing, because it is the result of two forces. On one hand, universities may want to compete for good or promising scientists, offering positions. On the other hand, good scientists will receive several offers and will make a decision contingent on many factors. Among these factors, along with personal and family considerations, including the salary, the scientific reputation of the university and/or the prospects for future investments are paramount. Good scientists move to a new affiliation if they believe they can find good students, exciting colleagues and a stimulating research environment. Therefore is we see top scientists moving to an affiliation, it ultimately means that an equilibrium has been found between demand and supply of talent.

Top 1010 computer scientists moved, on average, 4,36 times in their career, for a total number of affiliation moves of 4418, of which 3117 academic. Table 3 offers a breakdown of affiliation moves in academic places.

Two elements are striking. First, the top list involves only US universities. Top scientists, whatever their country origin and nationality, move principally within the American academic system. Universities of other countries attract top scientists only marginally.

They are unable to attract them, or simply do not compete to attract top scientists. The mobility pattern is clearly hierarchically organized.

Second, mobility in the top 4 universities account for 544 moves, or 17% of the total. More than one sixth of the overall career of a global and immensely influential community of scientists, whose ideas generate large opportunities for the world IT industry and beyond, are concentrated in just four universities, namely MIT, Stanford, Berkeley and Carnegie Mellon.

We derive strong implications from this evidence. Top scientists, as we have seen from Table 1, the main origin of radically innovative ideas. Their brilliant PhD students further develop these ideas and create start ups, or are recruited by large IT companies. In working in the IT industry, they still maintain strong linkages with the intellectual environment of the academy. This system is open to any newcomer, but is also highly structured. Competition is fierce. The system is multi-layered: universities that do not have a track record of excellent quality and exciting scientific environment cannot compete for these scientists, whatever the resources they have. Data tell us that few European universities compete in upper echelons. This is one (perhaps one of the most important) reasons behind the decline in competitiveness of the European IT industry.

Table 3: Most important affiliations involved in mobility paths of top 1000 Computer scientists

Institution	Count
Massachusetts Institute of Technology	174
Stanford University	166
University of California at Berkeley	102
Carnegie-Mellon University	102
University of Illinois	59
University of Maryland	58
Cornell University	52
University of Washington	45
University of Pennsylvania	44
Harvard University	44
Princeton University	44
University of Texas	44
University of Massachusetts	42
Brown University	41
University of Toronto	34

Source: Bonaccorsi (2006) and Bonaccorsi (2008)

Implications for institutional design

Why has European science been weak in playing the big game of frontier science in Information Technology?

We suggest that this is just a case of a more general problem, namely the inability of European institutions of science to adapt to fast moving scientific fields, or search regimes.

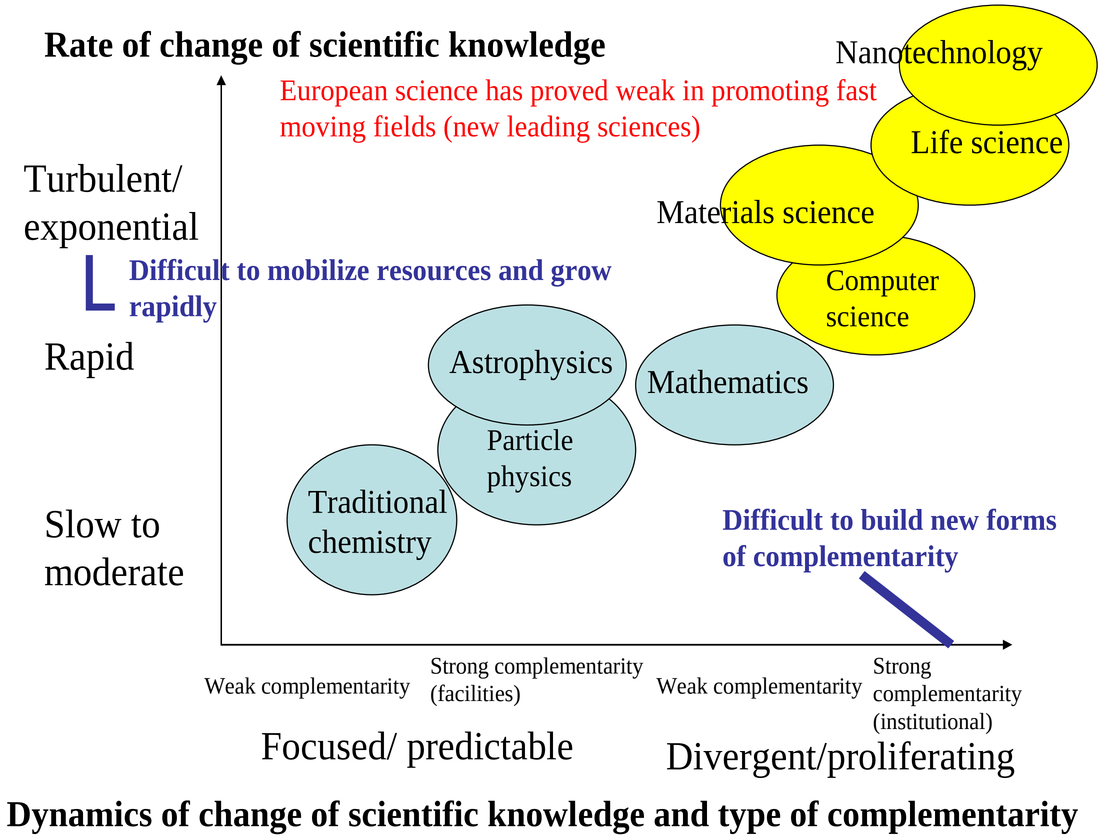
Figure 2 places scientific fields in a space in which the vertical axis describes the rate of growth (rapid or turbulent vs slow growth) and the horizontal axis describes both the pattern of diversity (convergence vs proliferation) and the type of complementarity (physical complementarity vs institutional complementarity). European science has historically been strong in two types of search regimes: scientific fields characterized by slow growth or high growth, but limited degrees of complementarity, such as mathematics or conventional chemistry, and scientific fields characterized by strong complementarity of physical type, but convergent pattern of search, such as particle physics and astrophysics.

European science has developed separate institutions at national, intergovernmental and European level, for dealing with search regimes with strong physical infrastructure complementarities (e.g. high energy physics, astronomy, space research, oceanography, nuclear technology).

In the field of technology, the case of aeronautics and space is interesting: there have been separate institutions in research (the European Space Agency (ESA)) and industry (Airbus), relatively independent from other fields, while the coordination around a focal artefact facilitated complementarity.

It is much more difficult to provide rapidly emerging fields the required complementarities in terms of human capital within the common institutional framework. There are few rapid growth mechanisms in European science.

Figure 2: The link between dynamic characteristics of search regimes and the institutions of science in Europe



Our propositions therefore are as follows.

1. The relationships between science and technology have changed deeply in the last part of the 20th century,
2. There is an indirect but strong relation between long term industrial (and service) productivity and competitiveness and the underlying dynamics of scientific knowledge production,
3. Europe is relatively de-specialised in leading scientific fields that form the knowledge base for large industrial/tertiary sectors. In particular IT and life sciences, whose search regime is characterized by fast rate of growth, proliferation dynamics and new forms of complementarity.

In this short paper, we have suggested, quite radically, that the poor performance of European high technology industries is rooted in the weakness of European science.

Contrary to the common wisdom (the so called "European paradox"), European science in several fields, including IT, lags behind the US and Asia. Almost all technological breakthroughs in IT have their origin (although indirect and lagged) into radically new ideas created in the scientific environment.

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Does High-Quality Research Require "Critical Mass"?

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Charles Clarke, the UK's education secretary from 2002 to 2004, once asked: "Should we enable more of the best researchers to focus on research, and develop a more professional teaching force for universities specialising in teaching?" The drift of research funding decisions in British universities since then has been to concentrate resources on a few key institutions that already command the bulk of research finance. We have been told that world-class research requires "critical mass", and this is to be found in the "golden triangle" formed by Oxford, Cambridge, and London; those institutions elsewhere that do not have critical mass would be better left without any research funding at all than encouraged to continue to waste national resources on the small-scale, low-value projects that are the only kind of work they are capable of.

Is there critical mass in research? How big is it? These are essentially factual questions; no doubt the truth varies, depending on whether we are talking about art history or particle accelerators. In any case I do not claim to know the answer. But I am thoroughly familiar with the question, which has been asked before. In my own research I have studied how government officials in the USSR allocated scarce funding among competing research and development projects in Soviet aero engineering in the 1930s and 1940s[2]. What we find is that, in the secret military core of a command system dominated by a harsh dictatorship, nobody was able to make a lasting decision about the best way to organise research. On one side were proponents of competition. They believed that the right framework within which good ideas for the future of aerospace could best emerge and be most easily spotted and selected for further development was to spread the limited funding available over many projects. Many would fail but a few would succeed and that would be enough. On the other side were the advocates of concentration. They found the waste and duplication of competitive funding unacceptable. An advantage of the planned economy, they argued, was its potential for bigger projects that could be controlled more tightly from the centre: in short, a potential for "critical mass".

[1] *Editors' note*: Professor Mark Harrison was not present at the workshop. However, his short note, written in July 2003 in the context of a national debate on university funding in the UK, remains topical. We thank him for granting us permission to include it in this compilation.

[2] For results see Harrison (2003), “The Political Economy of a Soviet Military R&D Failure: Steam Power for Aviation, 1932 to 1939”, *Journal of Economic History*, Vol. 63, No. 1, pp. 178-212; Harrison (2005), "A Soviet Quasi-Market for Inventions: Jet Propulsion, 1932 to 1946", *Research in Economic History*, Vol. 23, pp. 1-59.

The result was an institutional cycle. In the first phase of the cycle, competition ruled. Soviet funding officials would announce a new mission, for example, to build a new type of engine. Many hopeful designers would set out their research proposals. Behind closed doors they lobbied and negotiated for funding; sometimes they even diverted funding from an existing project to a new one to get a head start and win some credibility. It was hard for officials to decide who had the best chance of success so the cash was shared out among many. As the work got under way the projects already funded tended to attract further financing more or less regardless of results; after all, by now money had already been committed and it became hard for funding officials to cut off projects they had authorised previously without looking bad because they had nothing to show for it. At the same time new technological possibilities began to emerge from the work already done so still more projects were designated and authorised. Funding obligations multiplied. At a certain point the higher Soviet authorities lost patience with rising expenses and lack of results, and announced a turn to "critical mass". The problem, they declared, was that money had been scattered over too many small-scale, low-value efforts; there was a need to concentrate efforts and focus them more narrowly. The second phase began. Who would lose funding? Some designers fought back: they lobbied defensively to protect their funding, or they acted aggressively to try to gobble up the organisations of other designers in a weaker position. In the outcome, however, judgements had to be made and funding removed from those projects judged less successful, which were terminated; the money saved could then be concentrated on a smaller number of bigger projects that reflected a narrower mission and more sharply defined priorities.

In the process research monopolies were created that went on to behave like monopolies: they consumed resources, increased costs, and restricted output. Moreover, in the rush to rationalise, the officials in charge of funding generally made some mistakes. They would have liked to curtail only bad projects and save the good ones, but they often made bad decisions, sometimes out of ignorance or myopia, sometimes because they were swayed by the influence of designers who were better at lobbying and persuading than at organising research. And yes, such people do exist, even among high-minded academics at top universities. Once it was realised that the concentration drive had gone wrong the arguments in favour of competition and pluralism tended to be rediscovered. The cycle began again.

Of course there are some differences between the cycle that we find at work in the Soviet command system under Stalin and the working of our own research councils and department of education under Charles Clarke. In Britain today no one is shot or imprisoned for a mistaken funding decision or a faulty design. Personal consequences aside, however, the parallels are remarkably similar. The underlying reason is that in both cases we are dealing with research for the value of which there is no good market test, but there is no good bureaucratic test either.

I predict, therefore, that five or ten years from now another education secretary will discover that today's policy of concentrating research funding in pursuit of "critical mass" was mistaken, or at least was taken too far. The monopolistic research giants of the golden triangle will receive stinging criticisms for their lethargy, bureaucracy, and capacity to absorb funding without giving results. There will be much wisdom after the event. We will hear speeches full of regret for the blight that the theory of "critical mass" spread through Britain's higher educational periphery in the first years of the new millennium: the emerging research groups in second-rank universities that lost their funding, the small but promising centres closed, the individual careers curtailed. Ministers and research council chiefs will announce a new era of competition and pluralism, in which funding will be spread in small, rationed instalments right through to the periphery of the higher education system.

But the new era will again turn out to be shorter than anticipated. Ten or fifteen years from now yet another education secretary will be making a speech on – yes: the importance of "critical mass"!

R&D Specialisation and the Lisbon Strategy

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Introduction

The EU's 2010 goals for R&D expenditure were set out in the Lisbon Summit Strategy and endorsed by European Heads of State and Government in Brussels in 2002. The two main targets were:

- To increase EU R&D intensity (R&D expenditure divided by GDP) from 1.8% in late 1990s to about 3% by 2010,

- One third of this spending was to be funded by government, with the rest coming from the business sector.

The above targets have been motivated by the fact that the EU remained behind the US and Japan in R&D intensity. Current annual R&D expenditure will have to skyrocket over the next two years if the goals settled in Lisbon Agenda are to be fulfilled.

For the time being the situation is the following: Total EU R&D activities have stayed stable over the last 3 years with R&D intensity hovering at the level of 1.84%, according to the latest figures released from EUROSTAT, the Statistical Office of the European Communities. Although such EU members as Sweden and Finland have reached quite high R&D intensity (in Sweden several years ago it exceeded 3%), the majority of EU countries are significantly below the level of 2%. By contrast, some American States have R&D intensity of 4%, whereas no EU country shows as highly. The following reasons can be put forward for such a situation:

- The stagnation of EU R&D intensity can be partly explained by the decrease in government funded R&D in several large European countries.

- In different countries different industries are important. More than 60% of EU R&D spending is contributed by the three top countries – France, Germany and the UK. If we take a look only on these three countries, we see that pharmaceutical industries are important in overall R&D expenditure in the UK, but in France and Germany they are less significant. In Germany, engineering and chemical sectors are important, but these sectors spend a lower ratio of revenues on R&D. This fact explains the slower growth of R&D expenditure in Germany in comparison with the UK.

- Another possible reason for the stable level of Europe's R&D intensity is the EU research specialisation in traditional and slow growing areas. In many countries, members of the EU, there is a fear of investment in new, fast growing spheres, such as lasers or nanotechnology. Such fields are considered to be risky and these fields require more R&D activities than the traditional disciplines.

- There are still barriers to the mobility of researchers that have to be removed. Larger markets are linked with larger returns from R&D activities. An example is the US market, a huge market with one language and one regulation regime. The EU is not a federation of states; it is a community of 27 countries, with different languages and regulation regimes. The European market for technology is still quite fragmented, mostly due to the patent system. If a patent is granted by the European Patent Office (EPO) it has to be translated and enforced by other patent offices. This makes the process of acknowledgment of the patent granted in one EU member by others long and expensive. This problem is one of the hardest to solve, but also having a huge influence to R&D expenditure efficiency. The research systems have to be connected for more efficient and effective work.

- The success of Sweden is conditioned not by the size of the market, but by the level of academic research expenditures in the country. The high spending on academic R&D stimulates business R&D. Activities geared towards academic research facilitate the generation of new ideas by universities. University-produced ideas are then used by the business sector and stimulate its development. So the inefficient distribution of R&D activities in the academic area can result in unsatisfactory results in terms of business R&D and R&D in general. Additionally, successful academic research can attract more funding from the business sector.

To cope with the problems mentioned above the EU has to improve its R&D specialisation policy.

The issue of specialisation

R&D specialisation is the concentration of R&D activities within some thematic area. The problem of R&D specialisation, in general and in the EU in particular, is related to the distribution of activities. We can image two extreme options in this distribution:

- When all activities are concentrated in the margins of some specific and narrow area.

- When activities are spread among many thematic spheres, trying to support more scientific, technological or industrial fields.

Both options have their advantages and disadvantages. In the first case the selected thematic area will receive enough activities, but specialisation in one area implies less progress in another. For its turn the diffusion of activities between several fields will cause the decrease in amount of activities for every sphere separately. So there should be balance, returns from the concentration in one area have to compensate the damage in other areas. There are fields that need less activity, but the output from such spheres is usually not big. On the other hand, there are areas which give big outputs and which are going to develop in future, but such areas are typically risky and they need a lot of work. Most EU countries are more orientated to less risky, but slowly growing, more traditional research areas, which need less R&D spending. This is one of the reasons why the EU is staying behind the US in R&D expenditure and is the thing that have to be improved. But due to fragmentation of the EU this is hard to change.

The importance of a strong higher education sector

The lack of R&D spending in the higher education sector is part of the problem. The complexity of connection between European universities is harming the competitiveness and quality of education in the EU. It is also pushing EU business to make R&D investments outside the margins of the EU. The second thing that is harming the quality of education in the EU is the lack of autonomy and diversity of the universities. The European higher education system is in need of rapid diversification to enable its universities to cooperate and make them more attractive for private R&D investments. On the other hand the lack of competition between European universities has a negative impact on the quality of education and other activities in universities, resulting in fewer R&D investments. Though the EU produces more higher education graduates and doctorates in science and technology than the US and Japan, the percentage of them at work as researchers is much higher there. If the Lisbon Strategy objectives are to be met, the EU has to have 700,000 researchers by 2010 – a figure that now seems difficult to reach. Europe is viewed as a union in an economic and political respect, but not in terms of higher education.

When it comes to higher education, the perception focuses on the continent's individual countries, and mostly on the larger ones. In such a setting, Europe's higher education institutions receive good marks. But on a number of issues, such as prestige of institutions, labour-market acceptance of qualifications, and dynamism and innovation force, it came out second to the US. The concepts that are associated with European universities are culture, tradition and history, whereas in US they are progress, reputation and innovation. A solution to the problems of higher education in Europe will help improve the efficiency of R&D expenditure and increase the private R&D investments in the higher education sector.

A sectoral view of Europe's low R&D intensity

Europe's R&D intensity remains at a lower level than those of other main economic players in the world and has not improved over the last decade. It is stagnating, in spite of the goals set by the Lisbon Strategy. The main reason for such a situation is the lack of business funding of R&D in Europe. Two thirds of all R&D expenditure worldwide is carried out by the business sector, which is why one of the objectives of the Lisbon Strategy was to increase the private sector contribution to R&D to two thirds by 2010. In spite of this the business funding of R&D did not increase over the last 10 years and stayed unchanged in the same way like the EU R&D intensity in general. In 2004 the private sector financed 64% of total R&D in US, 67% in China and 75% in Japan and South Korea comparing with only 55% in the EU. The deficit of private R&D explains the 87% of the gap between the EU and the US R&D intensity. Privately-funded R&D is clearly increasing in the US over the past ten years, as is also in China and Japan. In all these countries the financing of R&D by the private sector has increased in a much faster pace than in the EU. As a result the gap between the EU and the US and Japan has widened significantly over the past decade. It has to be taken into consideration, that the level of business-funded R&D is slightly underestimated due to the impossibility of breakdown in the category "funded from abroad" between public and private sources. But in view of the fact that the level of the "funding from abroad" in the EU-27 is only 0.16% of GDP (2005), this margin of error does not explain the gap in the EU R&D intensity. The major reason is still the lack of the private contribution to R&D funding.

The business sector is not only the principal financing sector of R&D, it is also the main performer of R&D. The business sector is the closest to consumers, so it is the best positioned in terms of generating new ideas with economic applications, using existing knowledge in new fields and making use of new ideas commercially. To involve the business sector in research and development is therefore crucial for Europe to ensure future growth and competitiveness. As the overall R&D investment position in the EU remains on the lower levels then in the most of the other main world regions. Due to the universal process of globalisation, the R&D investment is becoming more and more internationalized. According to the OECD, there has been a significant improvement in the level of the international controlled business R&D. the share of domestic business R&D controlled by foreign affiliates increased from 12% in 1993 to 16.5% in 2001 in the OECD area. One of the reasons of the low R&D intensity in the EU is the decision of some EU companies to carry out the R&D activities in the US rather than in the EU in order to benefit from American expertise or market openings. One would have expected that there will be the opposite phenomenon of the American companies carrying they research in the EU in order to benefit from local expertise. However this is not the case. There is evidence that EU companies tend to invest more in R&D in the US, then US companies in the EU. Moreover there are emerging world economies that are attracting investors and becoming important locations for the international R&D expenditure. A survey carried by the Economist Intelligence Unit (2004) has shown that the favourite location for future R&D investments for many large EU companies are China, followed by US and India. This fact explains the diminution of the EU share in US outward R&D spending and this trend is going to continue as the new marker players are emerging and opening their markets to foreign investors.

Compared to the US, the EU has a very low level of R&D expenditure in the services sector. One may think that the reason behind the gap between US and EU R&D intensity can be found in the services sector. However recent surveys have determined that there are comparability problems with industry-level data on R&D spending. The conclusion is that the R&D expenditure in services is overestimated in the US in comparison with the EU. The main thing that prevents the comparability across countries is the differences in the methods they use to classify the R&D by industrial activities. While in the US all firms are classified by the principal activity only, in the EU the majority of countries are using product field information to re-allocate R&D expenditure (among the 13 EU-27 member states covered in OECD's ANBERD (Analytical Business Enterprise Research and Development) statistics, eight use product field information to re-allocate R&D expenditure, and only five use the principal activity criterion). This may explain the part of the difference between the US and the EU share in R&D expenditure.

At least three quarters of business R&D expenditure is located in manufacturing industries as in the US, as in the EU. The comparison of the diffusion of manufacturing R&D across industrial sectors according to their technology intensity shows that in the US manufacturing R&D is more concentrated in high-tech industries than in the EU. In the EU, manufacturing R&D is more concentrated in medium-high-tech and in medium-low-tech industries. Therefore the larger concentration in high-tech manufacturing in the US can be explained by the differences in industrial structure between the US and the EU.

EU companies considered sector by sector appear to be as R&D intensive as their US counterparts. The deficit in the private R&D sector is mostly due to differences in industry structure and the smaller size of the high-tech sectors. 67% of US corporate R&D investment is made up by companies belonging to high R&D intensity sectors compared with only 36% in the EU.

Taking into consideration that the EU R&D deficit with the US appears to be located in the high-tech sector, it is necessary to examine EU-US differences in the high-tech industry and the relative importance of the each sector in the R&D funding gap. The fact that EU R&D is more focused on the medium-high-tech level reflects the deeper concentration of attention on this sector. Examining the high-tech sector, one can see that:

- The chemical industries sector is equally large in the EU and the US, somewhat bigger in the EU, and it is equally R&D intensive in both economies. So it does not explain the differences between the EU and the US.

- Aircraft and spacecraft industries have same R&D intensities as in the US as in the EU, but in the US this sector is twice as big as in the EU. It contributes to the higher concentration of the R&D expenditure in the high-tech industries, but only due to the sector's size.

- The ICT manufacturing industries largely explain the higher concentration of the high-tech sectors in the US, due both to the size of this sector and the R&D intensity of it.

- Office, accounting and computing machinery sector is much more R&D intensive in the US than in the EU, but it is very small in the both economies.

- Radio, television and communication equipment is slightly less R&D intensive in the US, but it is 60% bigger there than in the EU.

- Medical precision and optical instruments sector is twice as R&D intensive and almost 50% bigger in the US.

A conclusion that one can make is that ICT manufacturing conditions the differences in R&D expenditures between the EU and the US, not only because it tends to be more R&D intensive but also due to its large size.

Taking a look at the medium-high-tech sector one can see that:

- The Railroad and transport equipment-manufacturing sector is more R&D intensive in the US, but this sector is very small in both economies, so it could not play a significant role in explaining the appearance of the funding gap between US and EU R&D expenditure.

- "Motor vehicles" also plays a rather limited role: it is only slightly bigger and more R&D intensive in the EU.

- The major difference comes from the machinery and equipment sector and the electrical machinery sector. These sectors are twice as large and more R&D intensive in the EU than in the US.

Here again, the differences between the EU and the US depend on the structural differences and the larger size of sectors.

The Lisbon goals in the context of increasing internationalisation

According to the 2007 edition of the Key Figures by the European Commission (Duchêne et al., 2007), EU member states can be divided into three groups:

1. Sweden, Finland, Denmark, Germany and Austria. These countries have the R&D intensity above 2.4% and are also on the top of the ranking of R&D intensive Member States.
2. France, Belgium, the UK, the Netherlands and Luxembourg. These countries are close to the EU average and have the R&D intensity varying from 1.5% to 2.2%

from GDP. From these countries only France has R&D expenditure over the average.
3. The third group includes the Southern European countries and the new members of the EU. These countries show the R&D intensity below 1.5%. The fluctuation inside this group is still very big with the countries like Czech Republic and Slovenia having the R&D intensity at a level higher than 1%, and the countries like Romania spending less than 0.4% of GDP to R&D.

The first group's countries, except Sweden, have increased their R&D expenditure during the period between 2000-2005. The spending of GDP to R&D in the Member States belonging to the second group has declined in the period from 2000 to 2005. The countries of the third group are improving their R&D intensity, though in the different speed. But the six Member States with the R&D expenditure at a level lower than 0.67% (Greece, Poland, Latvia, Slovakia, Bulgaria, Cyprus, Romania) have been falling further behind since 2000.

26 Member States have set the targets for their R&D intensities by 2010. If all these goals will be reached, the EU R&D intensity will be at about 2.6% by 2010. The counties that are already reached very high showing in their R&D expenditures will be able to advance towards their targets. The large group of EU members has experienced the positive average of growth since 200, but they will still need to improve their R&D intensity significantly to reach their goals by 2010. However an equally large group has experienced decreasing of the part of GDP spend on R&D.

In 2005 54.5% of R&D expenditure in the EU were financed by private sector, 34.5% (that is nearly one third of total R&D expenditure)- by government, and 8.5% - "from abroad", as by private as by public sources. The countries of southern Europe and new members of the EU are characterized by the high level of government involvement into R&D financing. In 2005 more than 60% of R&D expenditure were financed by government is such countries like Poland, Bulgaria, Lithuania and Cyprus. In Member States with high R&D intensity like Sweden, Finland, Germany and Denmark the private sector is financing the larger part of R&D spending.

In view of the impossibility of the breakdown between private and public sources in the category from abroad and bearing in mind that large part of 8.5% of R&D expenditure financed from abroad is financed by private sector, it is clear that the share of private sector in the financing of domestic R&D is higher than 54.5%. This factor could be very important for such countries like the UK and Greece, where nearly one fifth of total R&D expenditure is financed "from abroad".

The role of the government involvement in R&D financing should not be underestimated. In the high R&D intensive Member States like Sweden and Austria where the share in the domestic R&D financing is large, the contribution from the government to R&D expenditure is plays a very important role. High levels of private sector financing of R&D go hand-in-hand with high levels of public sector funding. In low R&D-intensive countries the involvement of the government in the R&D funding is much more important than the involvement of the private sector. The government funding is significant in the creating science and technology capabilities and in financing research projects with high expectations of social benefits, which would not attract the attention of the private sector investors.

The globalisation of R&D has definitely intensified over the last few years. In 2004, about 20 to 50% of domestic business R&D funding was financed by foreign affiliates (20% in Poland, Greece and Finland, 50% in Ireland and Hungary). The share of foreign affiliates in total R&D expenditure has expanded considerably in a number of new Member States – the Czech Republic, Slovakia, Poland, and Hungary – as well as in Sweden. In Germany, Ireland, Greece, the Netherlands, France, Spain, Portugal and Finland the increase was less marked, but still substantial. It can be clearly seen that business R&D in Member States relies strongly on the foreign financing.

R&D intensity of foreign companies however remains below the R&D intensity of national companies in most countries. The R&D intensity of domestic companies in the EU varies from 0.01% in Greece to 2.59% in Sweden and 3.06% in Finland. The R&D intensity of national firms in Finland is twice as high as in France and Germany and tree times as high as that of national firms in the United Kingdom. In other countries it is lower than 1%.

In most countries national companies carry out more R&D than foreign affiliates. It is the case in Finland, Germany, France, Greece, Spain, Poland, Portugal and Slovakia. However for Belgium, Hungary and Ireland the contrary holds true. In these tree countries the R&D of foreign companies outpaces that of domestic firms (Duchêne et al., 2007). Therefore in these countries business R&D is extremely dependent on foreign sources of funding. It has to be noted that some firms are known to transfer their technologies directly to their affiliates: while this activity is not captured by R&D spending, nevertheless foreign affiliates do bring new technologies into the country.

The level of the attractiveness of the country for R&D can be appreciated by comparing the share of R&D expenditure of foreign affiliates to their share of the turnover in the country. A country where foreign companies contribute more to total R&D expenditure than to total turnover is considered to be relatively attractive for the R&D activities.

Countries where the share of foreign companies in total manufacturing R&D expenditure is significantly higher than the share of these companies in total manufacturing turnover may be more attractive for R&D than for production activities. This is the case for Portugal and, to a lesser extent for the Czech Republic, Spain, Italy, Hungary and Sweden. But for some of these countries this observation can be explained by the limited R&D efforts of the national companies. It could also depend on the location of foreign affiliates in R&D-intensive sectors. In Germany, Ireland and the United Kingdom the share of the foreign affiliates in total R&D is very similar to their share in the total manufacturing turnover. That means that these countries are equally attractive for R&D as for production activities. Poland and for much lesser extent France, the Netherlands and Finland are the countries in which the contribution of foreign firms to turnover significantly exceeds their contribution to total R&D, so these countries are less attractive for R&D activities than for production activities. Foreign companies may prefer to transfer technology to these countries directly rather than to set up there local R&D activities.

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Towards an appropriate policy mix for specialisation

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Introduction

The issue of R&D specialisation has to take into account the relations between specialisation and a number of other issues such as:

a) the choice of specialisations (the substance of specialisation) to be enhanced,

b) the right balance between pro-active and more neutral or reactive policies on technological and research specialisation,

c) the fragmentation issue seen under the perspective of economies of scale, of scope and of excellence,

d) the concentration issue and the disadvantages of restricted competition,

e) the concepts of externalities and public goods, combined with the concept of state failures,

f) the probability of divergent growth rates, standards of living and employment opportunities, and the trade-offs to be made (the issue of intra-EU convergence).

On the R&D specialisation in the EU five dimensions are to be underlined in the present context:

- The EU in world terms is lagging behind the pioneers in core technologies, especially in ICT technologies. This produces adverse consequences in terms of productivity, productivity growth, market positions and business strengths.
- The capability of the EU to be an early comer concerning the development of a number of emerging technologies will influence the competitiveness and the capability of the European Union in the years to come to succeed in achieving the benefits of technological leadership in crucial research and productive fields.

- Any initial lagging position, as today in the case of ICT technologies, makes necessary the implementation of policies aiming at closing the gap either by enhanced research, or by technology diffusion, transfer and application.
- Significant visible future challenges have to be faced at a world scale during the next few decades, especially with regard to energy, environment and climate change and their much broader implications (health, alternative social organisational schemes, transports etc).
- R&D specialisation focuses on structural issues concerning the productive system of the EU. However, macroeconomic and other policies are much more influential in determining performance in any term (economic or social). Hence, the relation between R&D, R&D specialisation and (at least) macroeconomic policies has to be examined in a more detailed way. The present trends show very clearly how growth, employment, stability and standards of living are determined by the complex interplay of many factors, among which the impact of a performing R&D specialisation depends on the whole interplay of these factors.

Three types of policy

R&D and technological specialisation can be achieved through various policies, according to the policy objective, such as:

a) Preservation of existing specialisations
b) Enhancement of successful specialisations
c) Prolonging product cycles
d) Diffusion of technologies and innovations into new areas
e) Enhancement of new more radical technological changes

In turn these strategies can be classified under three main headings:

- Strategies of technological leadership (case e)
- Upgrading strategies (cases a, b and c)
- Strategies of late followers leading eventually to strategies of fast followers (case d and b).

Pro-active R&D specialisation policies (especially in the framework of the ERA policies) raise the question of the relevant specialisation areas to be targeted. The ERA as a primary EU objective is in fact an instrument supposed to contribute to the achievement of the Lisbon goals, in particular competitiveness, growth, employment, standards of living. ERA in itself has not an explicit and specifically predefined focus on research specialisation, or on areas of gravity and research objectives. The lack of an explicit delineation of such priorities is not to confuse with a vacuum. The areas of gravity are implicitly outlined. Since the objective is to make of the EU "the most dynamic and competitive knowledge-based economy in the world capable of sustainable economic growth with more and better jobs and greater social cohesion..", this by definition implies the need for the EU to develop capabilities on those (existing and/or emerging) scientific and technological trajectories, the dynamics of which drives forward economic growth and welfare in world competition in the present phase. In this sense, the various high tech (and, selectively, even medium to high tech) areas occupy a central place. This underlines how important is to recognize at an early stage the dynamics of new technical change and innovations within sectors and/or clusters.

In other words, in order to meet the ERA and the revised Lisbon goals, research, technology and innovation policies have to target both the strengthening of existing industrial structures and the preparation for more radical technical changes. Experience has showed that being a latecomer in core technologies has serious implications which last for long, are difficult to reverse and affect economic and social performance. In the example of ICT technologies it becomes apparent, that followers do not succeed in avoiding productivity and competitiveness gaps as against leaders. Foremost, technological leaders are facilitated to expand into new science and technology fields and create conditions for reiterating such processes in further emerging science and technology areas.

Pro-active R&D and technological specialisation policies are seen with some skepticism because of two major policy drawbacks: a) the failures of past interventionist industrial policies, and b) the high risks associated with pro-active policies in general and even more so with research and technology policies. As against these experiences, there are other elements which allow a reconsideration of the issue under a new angle:

- The risks of the no-policy (or reactive or neutral) choice,
- The risk of retrogression and
- The shaping of a more flexible fine-tuning of policies, which is prevailing in many other policy areas.

The risk of no-policy (reactive and/or neutral policies)

Specialisation policies either for strengthening existing industrial structures or for catching-up technological leaders, but in particular for promoting emerging technological fields, involve risks. In principle, the most known and visible risks are the risks of failure. This is half of the reality. The other half is that in absence of any action, risks are equally present. Inertia is not deprived from risks and costs. The difference to pro-active policies is of political nature. It cannot be directly associated with the option of no-policy. It has no direct visible political cost. However, the risk to neglect or to delay technological advancement and to lose ground at the international level can be significant in terms of growth, income, employment, competitiveness, market positions and environmental degradation. To the extent also that the speed with which the big social issues on energy, environment, health etc. will be tackled appears today to be of paramount importance, the rapidity of policy implementation becomes a significant factor. Not only because it is important to avoid duplicating the adverse experience with ICT technologies, but also because the needs to be covered make timely research results extremely important.

As a result, it could be argued that in the present conditions both pro-active and reactive (or passive or neutral) R&D and technology specialisation policies might have risks and costs. The difference between passive and more active policies is that in the case of the former (and of wrong policy decisions), cost rather than being a probability becomes a certainty.

The risk of failure in meeting significant social challenges

In the next future our societies are faced with qualitatively different challenges than in the past. What is at stake in this phase is not just the issue of national or continental convergence to the USA or the enhancement of capabilities for growth in comparison to third competitors or the creation of knowledge for achieving higher standards of living. In the past, the leaders in each new core technology could achieve higher standards of living, create conditions of a more dynamic evolution, draw benefits in terms of political power, influence and welfare, and, according to policy values, enhance the social state. In the present phase we are faced with numerous gloomy predictions concerning the climatic change, environment and energy, and their broader implications on health, food, water and other aspects (massive migration, conflicts) at a global scale.

In all these cases what is at stake is not simply to obtain at a later stage the necessary scientific and technological tools to face the new challenges and to have lose the gains from a success at an earlier stage. The risks associated with slow progress on some critical technologies are of a more generic nature, implying the deterioration of economic and social situations worldwide. Some particular technological fields are today of such an important priority that a failure has high social costs at all levels (EU, national, regional eventually also global). Inversely, a success could result in significant benefits in economic, social and even political terms (e.g. stability). Briefly, because of the high social priorities associated with some knowledge areas, pro-active R&D specialisation policies in a range of areas are not simply an economic priority but also a significant social priority. Focusing on these top necessities and not on particular players (firms, organisations) is a quite different approach than the past strategies of picking winners. Hence, what is at stake is how to avoid potential major retrogressions on crucial areas, how to prepare early enough the tools for meeting big challenges and how to adapt efficiently to an emerging new world landscape. Obviously, the successful management of these policy issues will ensure success in conventional economic terms as well.

The diversified technological base of the future

Basically, the future phase seems not anymore to be dominated by one basic technology and/or one "key factor" a la Freeman. Many sets of frontier technologies are continuously developed in an ongoing race process. Depending on the size and the capabilities, it is rationale to try to strengthen positions in broader areas of frontier research. Who will gain early enough strong positions in the evolving technological trajectories will be also capable to draw significant benefits both of economic nature and in the form of achieving economic and social structures compatible to the new global challenges. Obviously, the case of emerging technologies is more controversial. Market signals are not yet strong and risks of failure are higher. On the other hand, core technologies take many decades to be developed and the history of technological evolutions shows that:

- Rarely, if ever, core technologies have been developed without strong public supportive mechanisms,
- During these long periods one can observe an interaction between technological change and public policies, which cannot be classified within one discernible pattern,
- Often public policies alternate between pro-active and reactive forms according to the specific evolutions and needs,
- In this interaction, reactive policies can under certain conditions have also a pro-active nature.

Externalities and the issue of efficient policy making

If correct, the above considerations mean that in some cases we are faced with a kind of public goods which require more active policies in the aim to capture externalities and to provide a collective service which the market alone is not able to offer. If the principle of active policies is to be answered positively, then the "how" becomes the open and significant question. The legitimate prioritisation of some objectives does not ensure the success of policy intervention. It does not eliminate the difficulty of answering how to deal with governance failures and inefficiencies. Hence, the question is how to minimize risks of all kind (risks of failure, of high cost and of delays of technical advancements) while ensuring performance.

A policy option: Flexibility coupled with minimizing risks

The effective implementation of pro-active policies depends largely on the articulation of the policy mix and the definition of clear and efficient policy objectives. Experience shows that voluntarism and a top-down approach have limited chances to succeed. Bureaucratic inefficiencies, political considerations, embedded interests make such approaches inflexible and inefficient. On the other side, neutral policies are associated with inertia and short-termism. However, options are not restricted within these two extreme choices. It is conceivable to focus selectively on key technological areas and organize a flexible and diversified policy framework for facilitating the evolution of specialisations. Pro-active policies at the EU (and national) level can aim at a "research friendly ecology" (Georghiou, 2007) but combined with a "cluster-specific environment". They have to be based on the co-evolution of the following elements:

- To define priorities on selected areas and design a package of policies to support the research activities of firms, and research organisations and, in particular, innovative ideas and research proposals.
- To alter the concept and the criteria to judge the success of R&D and technology policies, especially the coherence, the efficiency, the long-term commitment and the time framework within which policies have to be implemented.
- Strengthening of R&D specialisation foremost implies policies enhancing variety creation and selection, and supporting "differentiation" elements against competitors.
- To achieve a good functional coordination of research activities, social needs, new knowledge, learning activities, public demand, inter-country cooperation schemes.
- To cooperate closely with the business sector and the scientific community in detecting needs, capabilities, technological trends, key discoveries, possible advancements.
- To be flexible enough to adopt timely institutional arrangements, incentives, types of financing, priorities and/or complementary and supportive policies to the changing conditions.
- To the extent that the transformation of the specialisation patterns is associated with path-dependent and evolutionary processes, R&D specialisation policies have to follow also an evolutionary and gradual approach and hence reduce the risk of serious failures.
- To provide timely new infrastructures encouraging the absorption and application of new knowledge.
- To focus on the creation of a favourable general framework which can target specific knowledge areas, is facilitating new entrants, is favouring competition, is not associated to specific agents and, in general, makes the preservation of a competitive ecology a key ingredient of policy making.
- To learn from policies and practices of third countries.

The above elements imply also that in the framework of the ERA the support of high tech clusters is a necessary but not sufficient condition for successful policies. What is essential is to shape governance structures in ways that can implement timely and effectively R&D and technological policies. Success is codetermined by a range of additional elements:

- an appropriate coordination at European level of public organisations, business firms and research communities, each of which has different interests, priorities, or strategies (e.g. on the appropriation of new knowledge) and functions,
- policies promoting existing or emerging technologies, instead to proceed on a voluntaristic base have to rely on the signals of the (research, innovation, product) market, and
- the capability to design and implement effectively appropriate policies and governance of these policies (i.e. the national innovative capacity) in a long-term period, since the effectiveness of policies often depends on:

  a) the way they can meet successfully the above conditions,
  b) the complementarities with other policies,
  c) the broader economic environment,
  d) the supportive activities, and
  e) the social capabilities to adjust and to exploit opportunities.

The ERA can facilitate the development of a range of high-tech milieus with internal and external interactions, linkages with business partners and public research organisations, with specific and costly infrastructures. It can enhance the creation of high-tech clusters and communities of joint research and technology targets. Such poles of excellence could be engaged in the promotion of emerging new technologies with crucial economic and/or social implications. The development of such high tech milieus is justified from the critical mass of resources (financial and human, physical and soft infrastructures) which are needed but cannot be provided in the framework of existing policies at lower levels of governance. Frontier research is not a question of percentage spending to GDP but of absolute amounts of available resources. In such a perspective the ERA can enhance research and technological change enabling both the leveraging of continuous change, adaptation, and competitive strengthening of industrial structures as well as the unfolding of emerging new techno-economic paradigms.

It should be added that R&D and technology specialisation policies should not limit their scope on knowledge production. The diffusion aspect is of equal importance and this has often been neglected at the policy level. It is well known that one of the weaknesses of Europe is precisely the diffusion of new technologies throughout its industrial system, with the consequence of lagging behind technological leaders in terms of productivity and growth rates. Hence, in case of not sufficient trickle-down, the creation of new knowledge will not succeed in leveraging competitiveness, growth and standards of living.

The element of cumulativeness with regard to scientific knowledge influences positively also the capabilities to enter new areas of knowledge, even if this knowledge is discontinuous and revolutionary in some respects (Zucker, Darby, et al., Furman, Porter, Stern). Often, new elements in new science fields are interconnected with old elements, which are transformed, incorporated and combined with the new elements leading to new mixes of knowledge. From the point of view of policy this implies that accumulated knowledge facilitates the transition to new research and technology areas. Societies with weaker capabilities will not be able to achieve such transitions. Gaps of such a kind cannot be closed without active policies, in particular RTD policies. In the present era of technological race as a source of competitive specialisation advantages, RTD coupled with appropriate structural policies should have a distinguished place also in cohesion strategies. Consequently, technological specialisation in the ERA has to be considered in the framework of a balanced approach, conciliating technological advancement and cohesion.

The issues of cohesion and intra-EU convergence are a different but crucial aspect of R&D and technology specialisation strategies. Regarding specialisation in the framework of the ERA and from the cohesion point of view the issue has not yet been answered sufficiently. R&D and technological specialisation, if successful, to a large extent drives industrial specialisation and industrial specialisation drives competitiveness, growth, incomes and standards of living. Even if reality often differs from such a linearity, differential growth capabilities lead to divergences and raise the question of possible trade-offs. The Lisbon goals and the closing of the gap between the EU and the US in the crucial areas of research and technology performance explicitly or implicitly constitute a major objective for the EU. The same logic however, cannot but prevail also within the EU.

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R&D Specialisation in the EU: From stylised observations to evidence-based policy[1]

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Introduction

The topic of R&D specialisation is attracting growing attention[2] in the context of the discussion on the future development of the European Research Area (ERA) (CEC, 2000; CEC, 2007). *Appropriate* specialisation policies hold potential for improving:

- R&D productivity[3], decomposed in terms of the *volume of research output produced for a given level of inputs*[4] and the *value*[5] of individual research outputs;
- Cohesion in the European research system, viewed in terms of its ability to act as a well *connected and co-ordinated*[6] whole;
- Flexibility in the European research system and, in particular, its ability to shift resources in response to the *emergence of novel* scientific and technological fields.

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[2] See Bonaccorsi (2005), Foray and Van Ark (2007), Georghiou et al. (2007), Marimón and de Graça Carvalho (2008a), Giannitsis (forthcoming)

[3] One of the key recommendations of the Aho Report (Aho, 2006: VII) and also relating to the following features of the ERA outlined in CEC (2007: 2): world-class research infrastructures, excellent research institutions.

[4] e.g. the number of patents/scientific publications "produced" for a given level of R&D expenditure or a given number of R&D personnel.

[5] e.g. as reflected in the number of citations received by individual scientific works.

[6] Relating to the following features of the ERA outlined in CEC (2007: 2): an adequate flow of competent researchers, effective knowledge sharing, well-coordinated research programmes and priorities, a wide opening of the ERA to the world.

These are worthy policy objectives. However, as we discuss here, some evolving specialisation patterns (whether natural or policy-induced) might be difficult to reconcile with progress in all three areas. The success of policies on specialisation rests on an informed understanding of possible trade-offs.

We attempt to delineate the place of policy by discussing the expectations attached to specialisation. To that end, we present a sketch of the policy options currently on offer and propose an alternative approach that overcomes many of the underlying dilemmas, before concluding with some suggestions for the construction of a robust evidence base.

By way of a definition

Research actors, at all conceivable levels of aggregation - from the EU as a whole, its constituent member states and their regions, down to individual organisations, project teams and researchers - focus their efforts in particular directions. In other words, they *specialise* within specific scientific disciplines and domains of technology.

At its simplest, R&D specialisation can be understood as the relative *concentration* of activity in a specific thematic area, be it scientific, technological or even industrial, within a given "division of labour" in knowledge production. For a given level of aggregation, specialisation therefore refers to a *distribution* of R&D activity. Thus conceptualised, one may imagine two opposite extremes of this distribution; one in which activity is evenly spread among thematic areas and another in which activity is concentrated in one major thematic area, with various intermediate stages in-between. By definition, more specialisation in one thematic area implies less in another. Naturally then, the specific shape of the distribution, and the justification for changing it, will depend on whether the benefits from concentration in one area outweigh the costs of foregone research in others.

Specialisation makes economic sense when there are sufficient exchange mechanisms in place to enable the sourcing of essential inputs that are not produced with own efforts. By this analogy, efficient research specialisation at the level of the EU implies an elaborate division of labour among connected and inter-complementary research systems, or a "system of research systems".

Stylised relationships

The most obvious opportunities afforded by policy-induced specialisation concern the productivity of research systems, an economic measure, closely linked with effectiveness – which is often the implicit or explicit concern of policy discussions on research *"quality"* and "*excellence*". In *theory*, these opportunities can be considerable:

- **Free-up resources from sub-critical areas & permit economies of scale.**

The thematic concentration implied by specialisation frees up resources that would be otherwise dissipating in numerous sub-critical areas and thus facilitates economies of scale (Foray and Van Ark, 2007; Georghiou et al. 2007). These are even more pronounced at the context of research, given the "indivisibilities[7]" associated with the production of knowledge (Arrow, 1962).

- **Benefits from cumulative learning & spatial agglomeration.**

When a particular thematic specialisation is systematically pursued and built-upon over time, cumulative learning enables increases in R&D productivity and entrenches the comparative advantage of specialised research actors. As highlighted by Foray and Van Ark (2007), when increases in scale are focused within a particular geographic space and sustained over time, other forms of cumulative advantage kick-in; top researchers attract other talented scientists and gain further research funding in a positive-feedback loop that facilitates excellence – a so-called "agglomeration process".

- **Permit focus on thematic areas with the most low-hanging fruit.**

Moreover, the orientation *itself* is important. Some thematic areas are, by nature, more productive; the rapid pace of change in microprocessor design (popularised in the proverbial – if only partially accurate[8] - Moore's "law") and ICT in general, make this point abundantly clear. While Computer Science and ICT are the most widely known examples in science and technology respectively, they are by no means special. Other, less visible thematic areas including biotechnologies, the life sciences and perhaps nanotechnology also yield more than average "bang per buck". These generally novel thematic areas are commonly thought to hold more technological opportunities (Dosi, 1988), be more fertile (Schmookler, 1954; 1966) or characterised by divergent search regimes (Bonaccorsi, 2005) and have, as it were, more *low-hanging fruit* for R&D to harvest.

- **Exposure to international competition.**

By focusing on thematic areas at the scientific or technological frontier, specialisation fosters international connectedness, which in turn has a *"raising the bar[9]"* effect, exposing hitherto protected enclaves to the effects of international competition. More focused specialisation at the EU level, would imply that R&D resources which hold little relevance to international concerns are no longer sheltered by national systems and policies (Foray and Van Ark, 2007).

[7] As highlighted by Arrow (1962), scientific discoveries and technological inventions are "indivisible" in the sense that they are intricately linked with an accumulated stock of past knowledge (i.e. a "standing on the shoulder of giants" effect) and are only purposeful when they are achieved in their entirety (scale effect) –For example, the practical benefits emanating from decoding say 10, 20 or even 99 per cent of the human genome pale by comparison to the benefits stemming from an integral unravelling of its properties.

[8] See Tuomi (2002).

[9] The use of the term in this context (although in a different line of reasoning) is due to Porter and Stern (2000).

However, the well-known economic arguments, suggesting that there are gains to be had from specialisation, in general, are accompanied by caveats regarding their *applicability to specific contexts*:

- **The level of inputs and the spectre of diminishing returns.**

All other things being equal, the output of research systems does not increase linearly with the scale of inputs (e.g. R&D expenditures); that is the relationship follows a sigmoid pattern, with low (but increasing) returns for low levels of inputs, highest returns for medium levels of input and low (but diminishing) returns again for high levels of input. It is clear though that different research systems find themselves at different points along this curve, and by extension, also differ with respect to their receptiveness to increases in inputs; for systems positioned on the diminishing returns stage, the increases in inputs implied by specialisation would have a *negative* effect on R&D productivity.

- **Scale diseconomies.**

Excessive specialisation could also have long run implications for R&D productivity. As scale increases more broadly, (i.e. not just increases in expenditures, but also a more numerous workforce, better infrastructures etc.) the efficient organisation, control and administration of research projects becomes more difficult and above certain thresholds, diseconomies of scale can be expected. Within a specific thematic area (e.g. discipline / technological domain) scale diseconomies may be due to demand saturation or the exhaustion of technological opportunities (Schmookler, 1954; 1966; Dosi, 1988).

- **The bluntness of change.**

In their natural state most research systems exhibit constant returns to scale *over time* (see Madsen, 2007), despite the fact that inputs also tend to gradually increase from one year to the next. The key word in the previous sentence is *gradually*. Gradual increases in inputs can happen hand-in-hand with gradual adjustments in institutional structures that, together with cumulative learning, allow for the productive deployment of the newly available resources and maintaining the input/output ratio. In the absence of proportional adjustments in these proximate areas, there is no guarantee that a windfall increase in resources will result in a concomitant increase in outputs[10].

- **The need for experience and critical mass in a proximate area.**

Not all research agents can specialise in areas which hold the greatest promise for further technological change. Their willingness and ability to re-align their thematic orientation, and do so successfully, will partly depend on their historical experience with proximate areas of research and the accumulated set of skills, research infrastructures, inter-institutional linkages and financial networks that go with this experience.

[10] This observation is partly based on research suggesting that, all other things equal, the productivity of R&D is sensitive to sudden increases in inputs (Pontikakis, 2008).

In addition to the above, "qualified" implications, artificial increases in specialisation may have the following, more broadly applicable negative consequences:

- **Spatial implications and EU cohesion**

Related to the previous point, precisely because of the cumulative advantage of some regions over others, thematic specialisation will have important spatial implications; regions with a prior stock of experience and resources will be more likely to benefit from agglomeration processes[11], leaving regions whose profile does not happen to match the emerging trend lagging behind. A trade-off between concentration and cohesion, is implied if only because more concentration to a particular discipline and/or spatial unit, means that there remain fewer potential nodes to connect to, effectively leaving large parts of the EU disconnected from the ERA. "Too much" specialisation may lock research agents (or groups thereof) into mutually incompatible skill-sets, paradigmatic *modi operandi* and infrastructures, thus narrowing the potential pool of talent and resources that each one can individually draw from; in such a situation, the restricted sampling of human resources and funding calls may have an adverse effect on the quality of research (Bonaccorsi, 2005).

Insofar as increased specialisation has spatial implications, it will also have direct consequences for the absorptive capacity of regions. Depriving regions from a minimum threshold of research activity could diminish their ability to learn and reap productive benefits. Crucially, insofar as policy-induced specialisation is concerned, visionary regional and national policy makers may have little sympathy for the suggestion that each region possesses inalterable comparative advantages and should therefore be content with "finding its place" in a knowledge production hierarchy.

- **Effects on competition.**

Perhaps the gravest threat associated with increases in concentration, has to do with its effects in terms of limiting competition. Though one may think of research agents conducting research in similar areas as engaging in wasteful duplication, it is worth remembering that duplication is an inevitable side-effect of *competing* in the same area. As long as selection mechanisms based on merit and adequate communication channels are in place, a measure of duplication will need to be welcomed (for many member states (MS) even at the sub-national level, and almost certainly at the EU level) in order to develop the competitive qualities that permit shifting the global STI frontier[12]. A multiplicity of funders will also be needed (Marimón and de Graça Carvalho, 2008b).

[11] This is supported by the findings of Clarysse and Muldur (2001).

[12] An analogous argument is made by Marimón and de Graça Carvalho (2008b: 2): "*A "fair competitive field" means that there are institutions and rules that guarantee fair R&D competition, but it also means that each region within the ERA has its own fair chance to compete and to become competitive. In an Integrated Research Area this goal can be achieved since the emergence of strong R&D agglomerations can, and must, go together with the development of a decentralized R&D and Higher Education base of excellence across all European regions.*"

- **Reductions in variety.**

Reductions in variety are another corollary of "too much" specialisation. These can constrain opportunities for new entrants and undermine the potential for new innovations to emerge. In science, these new entrants often sit on the margins of traditional disciplines and journals, and do not have stellar records that would be rewarded through a focus on "excellence" (Molas-Gallart and Salter, 2002). Importantly reductions in variety also imply;

- **Loss of flexibility.**

Moreover, in any production process faced with uncertainty, some redundancy is needed in order to deal with rapidly evolving needs. Insofar as increased concentration reduces variety in thematic specialisations (including those which fall below the visible threshold of existing thematic classifications) and constrains redundancy to a minimum, it may have adverse effects on the flexibility of the research system.

More importantly though, loss of flexibility constrains opportunities for developing capacities in *emerging fields of science and technology* and, importantly, doing so first. Excessive specialisation may narrow the system's ability to disengage from old techno-economic paradigms and associated search regimes, discourage research outside disciplinary bounds and place obstacles to the branching of scientific disciplines. Loss of variety implies loss of flexibility not only in cognitive aspects, but, crucially, in other aspects of the research system, such as the private financial markets that support it and the preferences of lead markets that use its products. An unfortunate confluence of the above elements could reduce the EU's chances of "riding the wave" generated by the next technological "irruption" (Perez, 2002) and being the first to benefit from it.

Rationale for specialisation-minded policies

Specialisation is an autonomous process. In an unfettered market individuals specialise motivated by the relative returns to specialisation apparent to them. Observed specialisation patterns represent aggregates of individual choices made by (boundedly-) rational economic agents. These choices are not taken at random but are the reflections of persistent economic fundamentals contingent on history and geography. What can be the purpose of policy in this context?

Specialisation-minded policies can be advocated when there are benefits to the joint, co-ordinated determination of specialisations which are, however, not apparent to individual research agents. At the EU level this implies coordination of the thematic orientation of regional and national research systems. However, all other things being equal, the concentration of resources could have different ramifications for different facets of the ERA. EU policy will have to perform a careful balancing act, which will become more difficult the more specific the thematic area and the more granulated the intended level of aggregation.

At this stage two important pre-conditions for successful specialisation policies, whatever their exact shape, can be identified:

- Achieving an optimal balance – aiming for neither too much nor too little specialisation – with a definition of optimality that takes into account the ERA vision as a whole and its economic welfare implications as outlined in the Lisbon Strategy.

- Harnessing the benefits from specialisation within a research system partly depends on the degree to which its component parts are *connected* and function in a *coordinated* fashion.

Policy also has a role in shaping efficient institutional frameworks – what is often termed among some economists as "the rules of the game" (North, 1990). For instance as highlighted by Bonaccorsi (2005), many of the institutional structures that characterise European science are better suited to the past. Policy can mould institutions with key changes in legislation, employment, education and welfare rules, the functioning of financial markets and the regulation of competition, among other things There are of course limits to what policy can do with regards to institutions; many institutions are socially-embedded and for all practical purposes cannot be considered policy variables (Williamson, 2000: 597).

Implementation: first, do no harm

The policy challenge lies not only in deciding what to change but also in what to leave intact. The EU possesses carefully crafted policies and instruments for research that have served their current purpose well (Peterson and Sharp, 1998). Drastic interventions in the form of a top-down directed drive towards specialisation run the danger of disrupting otherwise efficient policy instruments. The bottom-up principles governing the allocation of grants in the Framework Programme for Research and Technological Development (FP) have been exemplary in allowing the funding of new initiatives and the emergence of new ideas (Luukkonen, 2001: 215). That is not to say that changes in existing instruments will not be needed, but that their scope will need to be mapped carefully.

Moreover, policy takes time to elicit the intended outcomes. A string of recent policy interventions have set in motion processes that could contribute substantively to the realisation of the ERA vision. These include interventions that address the issues of R&D productivity[13] /sub-criticalities[14], connectedness[15] and coordination[16], even though they were conceived before the current debate on specialisation.

[13] e.g. Networks of Excellence in FP6, the recent founding of the European Research Council (ERC) and the European Institute of Innovation and Technology (EIT) were in part borne out of a desire to foster quality in European research.

[14] The EIT has an explicit mission to address areas lacking the "critical mass" necessary for innovation (CEC, 2008). Recent initiatives on European infrastructures such as Trans European Networks, the launch of the European Strategy Forum on Research Infrastructures (ESFRI) and the exploitation of Risk Sharing Finance Facilities, European Investment Bank (EIB) finance, the FPs and Structural Funds to that end.

Caution is called for though, particularly where the evidence is still tentative and the specific target elusive: rush actions risk exchanging short-term and uncertain benefits for long-term and certain costs.

New policies: a menu for choice

Various types of policies fostering specialisation can be envisaged. Policies of different types bring forth important governance issues; who decides in which thematic area to specialise and how? What types of instruments might be called to put into action such policies and what are the minimum conditions for success in each case? The following table summarises some hypothetical policies. These policies differ primarily with respect to the degree of centralisation in decision making they would require in order to make their own shade of specialisation work.

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[15] The collaborative character of FP-funded research has been the hallmark of EU research policy for over two decades - with increasingly more resources devoted to it over time. More recent initiatives aiming at stimulating researcher mobility (e.g. the EURAXESS database, the EU scientific "visa" directive etc.) also serve this aim.

[16] e.g. Open Method of Coordination (OMC), OMC-Net initiatives and the very well received ERANets.

Table: Hypothetical policies and their implications

Type of policy / Aims	Relevant spatial level	Who decides?	How are decisions taken?	Criteria for resource distribution	How are decisions implemented?	Minimum conditions for implementation
Centrally-administered specialisation	Transnational, National	EU, MS	Foresight, Benchmarking	Past-performance, evidence of sub-criticalities, sectoral / disciplinary dynamism	R&D budget priorities, S&T skills micromanagement	Sovereign state / Distributional offsets / absence of stochastic stocks / full info. on emerging fields
Smart specialisation (Foray and Van Ark, 2007)	Regional & transnational, national, supranational	EU, MS regional authorities	Benchmarking, Priority setting	Past-performance, evidence of sub-criticalities, comparative advantage	R&D budget priorities, fiscal incentives, S&T skills micromanagement	Distributional offsets, absence of stochastic stocks, full info. on emerging fields
Networked specialisation (Georghiou et al, 2007)	Supranational, national, regional	EU, national and regional authorities, research performing org., individual. research agents (teams/ researchers)	Case studies/ Foresight, Statistical identification of related variety,	Social goals ("Grand Challenges"), related variety, needs of a "research-friendly ecology"	R&D budget priorities, fiscal incentives, institutional interventions	Mechanisms for connectedness and coordination, full info. on emerging fields
Enhancing shifting capacity	Supranational, national, regional	Research funders, research performing org., individual research agents (teams/ researchers)	Case studies, scenario modelling of component flexibility	Not applicable	Institutional interventions	Mechanisms for connectedness and coordination

- **Centrally administered specialisation**

The first option, "*centrally administered specialisation"*, involving a Soviet-style handing down of specialisations, has of course not been on the offering. It is also an obviously irrelevant mode of governance. Nevertheless its presence here is illustratory of an extreme variety of a top-down type of policy and evocative of the well-known economically inefficient and politically unpalatable consequences of extreme centralisation.

- **Smart specialisation**

Foray and Van Ark (2007), in a Policy Brief of the KfG Expert Group argue that *"smart specialisation*" in research, at the level of countries or regions, holds considerable opportunities for facilitating agglomeration and excellence which in themselves may make the EU a more attractive destination for R&D investment. What is implicitly proposed here is a shift from the traditional (almost) thematically/regionally neutral and "generic" orientation of R&D funding instruments to a thematically/regionally focused one. The rationale behind "smart specialisation" has to do with avoiding duplication in thematic orientations between geographic areas. To counter duplication, they argue, regions with similar thematic aspirations may engage in "smart specialisation".

However, Foray and Van Ark (2007) do not discuss how such an ambitious policy might be put into action. A policy implying that some research actors or administrative units will be on the unlucky end of the concentration distribution inevitably raises the important issue of governance. How are they to be made to give up their research aspirations? Responding to Foray and Van Ark (2007), the Director of Directorate General for Regional Policy, Natalija Kazlauskienė (2007: 5) argues that top-down interventions would be both undesirable and impracticable. With his contribution to the present volume, Dominique Foray attempts to clarify and operationalise the approach.

- **Networked Specialisation**

Georghiou et al. (2007) in their report on "ERA Rationales" are enthusiastic about the potential of policies for specialisation and argue for a model of *"networked specialisation"*. Georghiou et al. (2007) recognise the narrow scope for policy manoeuvring at the level of the EU and offer clear guidance regarding the role of specialisation policies in a multi-layered governance setting. They also emphasise the importance of communication and exchange mechanisms for the long-term sustainability of R&D specialisations and hence talk of *networks*, where the nodes are many and flows are bi-directional.

As Georghiou (2008) argues elsewhere, some scope for top-down policy would remain in particular with regards to aligning European research with broad[26] societal issues (the so-called "Grand-Challenges"), e.g. related to energy and the environment.

[26] A broad sectoral focus of EU research and innovation policy was outlined in the Aho Report (Aho, 2006): e-health, pharmaceuticals, transport and logistics, environment, digital content industry.

On the question of an "optimal" level of specialisation, Georghiou et al. (2007) refer to the promising concept of related variety, a statistical measure that attempts to single out useful shades of variety from irrelevant ones on the basis of thematic proximity (Cantwell and Iammarino, 2001; Boschma and Iammarino, 2007). However, its usefulness as an indicator on which to base policy decisions is limited: Many thematic classifications group together subfields that could belong to multiple and sizeable interdisciplinary strands of research. Moreover, inasmuch as operationalisations of related variety are based on existing (and one may add, slowly changing) thematic classifications[27], these are *ex post* assessments of relatedness. Simply put, measurements of related variety may underrepresent (or miss altogether) the opportunities afforded by *emerging* fields and fields that have yet-to-emerge that, by nature cannot be given a heading before they do so, and as a result often "fall through the cracks" of existing thematic classifications. If the concept is taken at face value, emerging fields could be missed altogether.

In our view the "networked specialisation" concept, as has been put forward, would demand a multiple role of policy. This would almost certainly involve ensuring the provision of relevant and timely information, facilitate co-ordination and cooperation and cater, along with MS, for long-term institutional interventions.

The flow of information between those who take specialisation decisions will be a key aspect, requiring diverse instruments. At the level of individual researchers and project teams this is arguably already happening through conferences/research publications etc. The hard part which the approach needs to address is the role of funders (regional/national – research councils, ministries etc) as well as research organisations managers and university administrators.

- **Enhancing shifting capacity**

The success of a directed policy towards specialisation rests on a delicate and costly to maintain and implement balance of considerations. An opportunity to tread around such costly acrobatics presents itself in the form of proactive policies aiming to cultivate pre-existing tendencies and thus foster the organic emergence of socially desirable outcomes – as opposed to reactive policies that arise in response to market failures. These involve fostering desired systemic qualities by way of key *institutional* interventions. These are interventions that would not favour any one particular thematic distribution, but would rather nurture the ability of the system to change rapidly in response to exogenous stimuli (such as e.g. the emergence of a new discipline / area of technology) and assume whatever distribution approximates optimality: in other words what we term its "shifting capacity"[28].

[27] e.g. ISIC/NACE sectoral classifications, THOMSON ISI's classifications of scientific disciplines, international patent classes (WIPO IPC), ISCO-88 professions, ISCED fields of education to mention but a few elaborate thematic classifications of relevance.

[28] The contrast between, on the one hand, the ability of countries to promote "*shifting"* from old to new uses and, on the other hand, "*deepening"* or improving their productivity in existing uses (loosely analogous to specialisation) can be traced back to Ergas (1987: 223). Crescenzi et al. (2007: 676) are the first to refer to the "shifting" quality of national systems as a "capacity".

Promoting shifting capacity would take more than a distributional mechanism to channel resources in the most promising thematic areas or the most efficient research agents (though improvements in shifting capacity would by definition induce improvements there too). It would entail a much wider ability to *systematically*, *rapidly*, and *efficiently* deploy resources, both old, and importantly, *new*, towards continuously changing needs in scale-dependent emerging areas, where the window of opportunity is small and the cost of not acting enormous.

The need for institutional change

Of course, let's not forget the elephant in the room: the emergence of ICT in the US and its successful economic exploitation there is purported to be the major culprit behind the gap in total factor productivity between Europe and the US (Aho, 2006). The prospect of managing to specialise in those emerging fields that give rise to new industries and contribute to the development of a comparative advantage dwarfs other issues in importance. The trouble is we do not know what these emerging fields will be before they emerge, and the scope for action is limited once they do so. In that respect, shifting capacity, in terms of increasing preparedness and allowing nimble, rapid-deployment would be *the* key quality.

Flexibility is also called for in the design of institutions themselves. Institutional interventions will have to vary both in the cross section dimension (i.e. across disciplines, technological fields and geographically across states and regions) and over time. Introspective efforts to improve the ability of policy making systems to change their-own-selves will be necessary.

In a classic essay, Nelson (1994) describes the institutional conditions that favour the emergence of new industrial sectors and the co-evolution of institutions and industrial structure over time. He posits that one set of institutional qualities is needed in preparing for the arrival of the next "dominant design" (a term loosely analogous to a techno-economic paradigm) and another one once it has emerged. According to Nelson (1994), before a dominant design is established, the chances of benefiting from it depend on the ease of getting funding, the degree to which markets are open to new sources of supply, the speed with which universities adapt to new sciences, how adaptable legal structures are to changing demands put on them by new technologies and how supportive public sector programs are of novelty. By the time a new dominant design is apparent, the ability to finance large scale investment and train labour with specific skills comes into the spotlight. A rich ecosystem of institutions is likely to emerge afterwards, including industry associations, professional societies and technological standards, that co-evolve and add to the dynamism of the nascent industrial sectors.

Strengthening the evidence base

ERA-specific evidence is still rather anecdotal, particularly with regards to the implications of specialisation for different research systems at various levels of aggregation, as well as to its broader economic welfare consequences. A revisit of the important work of Archibugi and Pianta (1992) on the determinants of national R&D specialisation patterns is now long overdue. A renewal and extension of this analysis at the regional level would go some way towards identifying important policy levers and informing the design of appropriate instruments, whatever policy approach is taken.

Obtaining a more complete picture of the so-called "untraded flows of knowledge"[29] (Smith, 2000: 100), including a better understanding of their consequences will be essential. Establishing for instance the extent to which increased networking and collaboration in European research activity (as promoted by the FPs and proposed by the "networked specialisation" concept) can substitute geographic agglomeration and help build "virtual critical mass" would illuminate a key question on the debate.

A stronger evidence base will hinge on the timely availability of appropriate specialisation indicators. As Phil Cooke and Keith Smith argue in this volume, current indicators are unable to provide answers to some of the most pressing questions. Novel indicators that measure not only variation in the *concentration/diversity*[30]axis (whether relative or absolute) but also convey the internal *composition* of R&D and of the degree of its *structural change*[31]over time seem necessary. The systematic collection of data in and compilation of indicators on *relatedness*[32] (horizontal similarity, vertical position) seems also profitable. Such novel measures could, with the application of an appropriate modelling framework that combines them with other variables of significance, help gauge the effects of different specialisation patterns on R&D productivity, EU cohesion and the flexibility of research systems. Follow up studies that seek to identify the determinants of variation in specialisation could also be of direct interest to policy – particularly with respect to shifting capacity.

Useful insights for policy will not come from any one analytical tool alone. As summary measures, statistics inevitably imply a loss of information; even if the remaining information were otherwise perfect, this loss, combined with the inevitable lag in obtaining such, drastically limit its usefulness to the policy planner. Research from multiple angles will be needed, complementing quantitative work with topical case studies and foresight analysis.

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[29] These include personal interactions (through e.g. human resource mobility), codified knowledge flows (as they register in scientific and technical literature) as well as other flows that currently remain below the visible threshold (e.g. flows emanating from public domain sources, marketing relationships, co-operative knowledge exchange, trade literature etc) (mostly Smith, 2000: 100).

[30] E.g. Herfindahl (concentration), variations of Balassa, Ellison and Glaeser (relative concentration), Shannon (diversity) etc.

[31] E.g. indicators of proximity to dominant design / major technoeconomic paradigms, and of shifting capacity (degree of responsiveness)

[32] E.g. related variety (Theil's entropy), but also those that establish relatedness empirically, including e.g. technological proximity (thematic shares correlations), vertical linkages derived from input-output tables etc.

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List of Acronyms

ANBERD -Analytical Business Enterprise Research and Development

CEC – Commission of the European Communities

CV – curriculum vitae

EPO – European Patent Office

EPSCoR – Office of Experimental Program to Stimulate Competitive Research

ERA – European Research Area

ESA – European Space Agency

EU – European Union

FP – Framework Programme for Research and Technological Development

GDP – Gross Domestic Product

GPTs – General Purpose Technologies

ICT - Information and Communication Technologies

IPC – International Patent Class

IPTS – Institute for Prospective Technological Studies

ISCED – International Standard Classification of Education

ISCO - International Standard Classification of Occupation

ISIC – International Standard Industrial Classification

IT – Information Technology

JRC – Joint Research Centre

KfG Expert Group – Knowledge for Growth Expert Group

KfG Unit – JRC-IPTS' Knowledge for Growth Unit

LEG – Lisbon Expert Group

MIT – Massachusetts Institute of Technology

MS – Member State (EU)

NACE – Nomenclature of Economic Activities

OECD – Organisation for Economic Cooperation and Development

R&D – Research and Development

RTA – Revealed Technological Advantage

RTDI – Research, Technological Development and Innovation

SBIR - Small Business Innovation Research

SEOs – Socio-Economic Objectives

S&T – Science and Technology

SS – Smart Specialisation

UK – United Kingdom

US – United States

WIPO - World Intellectual Property Organization

Annex – List of participants to the Barcelona workshop

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George Chorafakis – DG Research

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Abstract

The question of 'R&D specialisation' has emerged as an issue of debate on the research policy agenda. But what is this question and why should we bother with it? The question boils down to whether, for any given geographical-political entity, there are benefits to having R&D efforts concentrated (or specialised) in a limited number of thematic areas and, if so, whether (a) public funding of R&D should focus on these areas accordingly and (b) corporate R&D investment should be steered towards these areas through structural changes to the economy (and how to achieve this). To explore this question and examine its implications for policy, the Institute for Prospective Technological Studies, together with DG Research, organised a workshop in Barcelona on 30 June 2008. This report is an edited compilation of contributions submitted by participants at this event.

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