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EDITORIAL

We are witnessing a return to industrial policies aimed at supporting innovative activities in an increasingly competitive and complex world where relationships between science and industry have undergone profound changes. In the article which follows, Philippe Larédo sketches out the main lines of these transformations in order to explore the notion of the 'research regime' and its institutional forms. In his view, Europe is becoming the relevant if not essential authority for efficient support of research and development. But this means that EU players will have to take concrete steps along those lines instead of begging the issue.

THEORETICAL NOTE

The transformation of 'search regimes': implications for government interventions

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1- Introduction

The notions of 'knowledge society' or 'knowledge economy' highlight a vision of growth based on intangible investments. They give knowledge production activities a central role in the transformation of our economic systems. For many authors, however, what is involved is no more than an intensification of the integration of technological progress into analyses of economic development. Such a view presumes (and this is the hypothesis we are challenging) that the conditions for the production of new knowledge do not require in-depth institutional changes and that we can thus ignore the contents specific to each 'technological revolution'.

It is our view that the forms of knowledge production, which Bonaccorsi (2005) terms 'search regimes', have a decisive influence on the organisation of markets and government intervention. In the remarks which follow, we shall draw on evolutionist theories analysing the emergence of new technological 'paradigms' as well as management studies dealing with breakthrough innovations.

2- 'Search regimes'

Bonaccorsi (2005) sets out the notion of 'search regime' to describe the varied conditions of knowledge production. A search regime, for him, is characterised by three dimensions: a rate of growth, a degree of diversity and a level of complementarity.

The first feature of the new research fields which are emerging (for purposes of simplification, we shall speak of the leading new sciences) is a very sharp increase in publications over a period which is often long: an annual growth rate of 8 percent over a decade for human genetics, for example (according to the French Observatory of Sciences and Technologies, OST), and nearly 14 percent over a five-year period for the nanotechnologies (according to our estimates), compared to an overall publications growth rate which is less than 2 percent.[1] As management studies have shown, the growth of a market facilitates new entries and is at the same time a strong means of marginalising established organisations which cannot follow this pace.

According to the literature on the emergence of dominant designs (from Abernathy to Metcalfe), both the opening up of the market and the marginalisation of established players result from the fact that this growth is based on existing competences (competence enhancing) or calls for completely restructuring them (competence destroying). Bonaccorsi proposes to analyse this phenomenon in terms of the two dimensions of convergence and complementarity required by these 'new sciences'.

The *degree of diversity* refers to the way research activities carried out in different places fit together and link up. A common theoretical framework (such as standard theory in physics) is a powerful instrument of convergence. But such convergence can also be imposed by the way the studies are carried out. The major nuclear programmes, for example, can thus be taken as a tool for ex ante selection of a trajectory (cf. Brian Arthur's 'historical small events' and irreversibilities). And the committees for access to scarce facilities may also be considered a means of aligning scientific research (we might think, for example, of the beginnings of HIV sequencing and the role of the Erfurt Laboratory). Conversely, the convergence can take place following a confrontation between different approaches and paradigms (cf. the different precursors of digital TV and what the European players invented with the D2Mac standard in order to get around the Japanese MUSE, or the battle of the video standards). At an intermediate stage, this confrontation is often organised as an element of the transition from exploration to exploitation which leads the players (labs and firms in competition) to define a shared standard. The successful examples of Digital Audio Broadcasting (via the intergovernmental Eureka initiative) or the GSM platform (via the European programmes) bring out the importance of this kind of government intervention in the construction of markets. In a certain way, it is what the world of microelectronics organises around the international road map

[1] . OST = Observatoire des Sciences et techniques, www.obs-ost.fr. On the nanotechnologies, see the work of the 'nanodistricts' project developed within the framework of the PRIME excellence network, www.prime-noe.org and www.nanodistrict.org

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defining the standards for the next five generations, which amounts to practically a decade.[2]

Our hypothesis is that we have gone from leading sciences which were highly convergent to those which function through mechanisms of 'ex-post' selection (or divergence, in Bonaccorsi's terms). In the examples cited, these convergences are largely the fruit of pro-active policies. Ex ante alignments on targeted products (via large programmes) have been replaced by alignments 'along the way' through the use of the classical means of creating market infrastructures. Examples of this include the mobile telephony standards, the special rules on competition for wind power, internet for the 'information society' and the extension of intellectual property to genomics applications. To which must also be added the public debates (such as those on GMOs or stem cells) which, by supervising scientific activities from the exploratory stage on, help to shape tomorrow's markets.

The *degree of complementarity* refers to the nature of the competences which must be brought together. These complementarities may be institutional (e.g., the growing role of clinical scientists and teaching hospital faculty in the human biotechnologies), technical (the role of the large facilities and more broadly, instrument platforms) or cognitive (inter- or multi-disciplinarity). Two phenomena are decisive in the developments we are analysing, and particularly with regard to nanoelectronics. The first is the scope of the platforms necessary and the local forms which their realisation assumes, as seen with Grenoble's MINATEC, the centre for innovation in micro- and nanotechnology. The second is the growing recourse to competences which are quite distant in disciplinary terms. It took more than a year for a group of researchers who already knew each other to set up a chemistry programme for nanoelectronics. This programme, far different from those of nanochemistry, drove to replace a network approach (where members remain in their own institutions) with the construction of shared spaces around general objectives for the middle term.

3- An interpretation of recent transformations

How are we to go from a conceptual analysis to a description of the transformations underway? The table below reflects our attempt to transpose different studies in the history and sociology of science which bring out the emergence phases of the decisive new leading sciences. These phases lead to the establishment of a paradigm, which provides the basis for cumulative processes of learning, consolidation of routines and incremental innovations, with their two key dimensions: optimisation (of functionalities and costs) and differentiation (the familiar market segmentation).

Leading science	Physics	Information technologies	Molecular biology	Nano-convergenc
Cristallisation dynamics	Large objects, technical systems	Distributed intellectual property (patent pools), strong ties between public/private research	Science based/individual intellectual property and licence transfer	Hybridisation remote discipl
Development	Rapid selection of a dominant design, cumulative improvements	Adoption of standards and design tools	Competition between paradigms	Initial path m fied by the orig disciplines
Critical infrastructures	Very large specific facilities	Generic infrastructures, prototyping centres	No entry barrier	Technology platforms, i disciplinary groupings
Modes of co-ordination	Product-oriented major national programme	Complementary forms around technologies - technology programme - centre of competences	Networks and clusters (bottom-up)	Multi-player centres at gional l 'Nanodistricts'
Main industrial players	Large national firms (specialised in public infrastructure)	Multinational firms (mass-market oriented) Specialised New Technology Based Firms (Business-to-Business)	Start-ups and venture capital in the initial phase, concentration by established firms in the extension phase	Central role incumbents (global Busin to-Business Business-to-Customer fi the ex-start-up the earlier wav
Archetypes	Nuclear energy, space, civil aeronautics, fixed digital telecommunications	Information technologies, mobile communications (GSM)	Biotechnologies	Nanotechnolo

Source: P. Larédo and V. Mangematin (Nanodistrict project)

In this table, we have stylised the main features of knowledge dynamics and the forms of organisation accompanying them. It should be read both as a sequence, to the extent that the sharp growth patterns are concentrated in the new sciences, and as an accumulation, because the successors do not make the predecessors disappear, thus complicating the picture even more. What are the implications of such a table in terms of government interventions? We shall propose an initial reading over time.

The *point of departure* is the Second World War and the immense advances generated by physics. The Manhattan Project was at once a scientific episode and one of the engineering and industrial production of a complex system. Our table shows that four conditions were necessary for the emergence of this leading science:

- A rapid harmonisation of research activities through design and central co-ordination;
- The construction of large facilities which permit the study of the phenomena and the testing of the prototypes.
- Captive markets (a small number of potential users worldwide, and a forced national user which is the State or national companies).
- A three-pronged mode of co-ordination via government management, a national body for the building of competences and a national industrial 'champion'.

Such a 'military'-type model was not specific to France. Indeed, two phenomena must be stressed: the programmes rarely remain national, and the national champions have become world-scale European champions, thus reducing the initial national public structures to ordinary institutions.

The *first transformation*, which is just as well known, meant the death of this military model, at least in France. Analyses converge to explain the failure of the ambitious French programme for the development of a national computer industry (known as the 'Plan Calcul'). Here, we

2 . See the latest version of the International Technology Roadmap for Semiconductors (ITRS), which is the fruit of the participation of more than 800 experts.

are dealing with the difficult transition from a captive market to mass markets; this was successfully carried out in two stages in civil aeronautics, a total failure in the case of computers but also successful in microelectronics, contrary to all expectations. In the last instance, the merger between France's Thomson Semiconducteurs and the Italian Società Generale Semiconduttori and the subsequent alliance with the Atomic Energy Commission's Laboratory of Electronics and Information Technologies (LETI, promoter of a start-up at the heart of the development of ST Microelectronics) were combined with a new form of government intervention, the European Strategic Programme for Information Technology (ESPRIT) and its co-operations between competitors on 'basic technological research' (Callon et al. 1995).

A triple movement thus characterised this new leading science:

(i) Growing co-operation between public-sector research and industry, and between industrial actors themselves. This mechanism produces distributed knowledge and interdependence which are reflected in microelectronics by the increasing numbers of patent pools, indispensable to the manufacture of any chip.

(ii) The creation of new markets through the continuous increase in processing capacities and the decrease in costs (Moore's Law): this movement leads to the replacement of centralised planning by bottom-up co-ordination of expectations through the microelectronics road map.

(iii) A complete shift of government intervention towards European level. Whether in terms of the European Commission or the Eureka programme, Europe is becoming the central public player (paralleling the changes in the National Research and Production Cooperative Act in the United States or the massive commitment of Japan's Ministry of International Trade and Industry, MITI).

The second transformation also arose from the failure of another major programme, that of the 'War on Cancer' launched by US president Richard M. Nixon in 1971. In order to fully appreciate this episode, it is necessary to read the remarkable article by Walsh and Le Roux (2004) on the anti-cancer drugs Taxol and Taxotère. This second transformation saw public funding for medical research concentrated on a bottom-up approach around molecular biology.[3] An admittedly schematic summary brings out the convergence of three phenomena:

(i) The tremendous increase in discoveries stemming from local clusters without financial or technological entry barriers;

(ii) Their radical nature, and the reluctance of the established pharmaceutical firms (this is not the case for plant biotechnologies: cf. Monsanto and the GMOs);

(iii) The institutional changes: the Bayh-Dole Act in the United States and the registering of patents by the universities, the change in the American rules on prudential supervision and the venture-capital boom.

An opening was thus created for a new model relying on individual discoveries and the start-ups created by university researchers. At the same time, the costs of placing products on the market most often implied co-operation with large pharmaceutical or chemical companies (with or without buyouts).

[3] In the US, this movement relied on two decades of sharp, sustained increases in the funding of the National Institutes of Health (NIH), which was not the case in Europe (with the partial exception of the United Kingdom).

4- Nanotechnologies and the convergence of the NBICs as leading new sciences

The nanotechnologies represent both a continuation of the earlier transformations through their top-down aspect and a bottom-up breakthrough owing to the change in scale and the potential convergences they promote between previously distinct fields (i.e., what are called the NBICs and the little BANG).[4] The implications of this development are already playing a considerable role in the structuring of government interventions. The three kinds of complementarities defined by Bonaccorsi are at work: cognitive, with the very broad interdisciplinary composition of the field (cf. Zitt et al. 2006 and Kahane et al. 2007), technical, with the importance of technology platforms (Robinson et al. 2007) and institutional, with the intense hybridisation between public-sector research and industry in patenting (Bonaccorsi 2007). This phenomenon is accompanied by a sharp concentration of scientific and technical capabilities in a limited number of centres worldwide (Zucker et al. 2007).

The notion of centre incorporates and broadens that of public-private partnership. It entails:

- A strong geographical concentration of capabilities at world scale;
- A rich, diversified breeding ground for future actors, associating a significant university presence, public-sector research laboratories, the R&D laboratories of large international firms and/or major hospitals and a host of start-ups coming from the earlier cycles;[5]
- A great capacity for clustering centres highly specialised in competences which can enhance those already present at the core.

Public policies reacted very quickly to these transformations. The emergence of the nanotechnology lobby at the end of the 1990s is in itself a topic worthy of research. It was this lobby which led the US government to set up the National Nanotechnology Initiative, on a typically 1960s OCDE model with a central co-ordinating structure reporting to the president and means allotted to pre-existing departments and agencies.[6] And just as noteworthy is the speed with which the European Commission was to organise Euro-American encounters and make the issue a cross-disciplinary priority by the time of the fifth Framework R&D Programme (FRDP) and then a veritable priority of the sixth FRDP. The same trend may be observed in Japan, South Korea and China.

In France, the incentive programmes were created just as rapidly but were to remain on a modest scale. At the outset, the only ambitious developments were bottom-up initiatives coming from the regions (MINATEC in Grenoble is the key figure). We have already demonstrated the importance of this example in the process which led to the November 2004 report by former Air France president Christian Blanc, 'For an ecosystem of growth', and then to the policy of competitiveness clusters and the selection of six world-scale clusters which were themselves associated with an incubator of nine clusters of 'worldwide call-

[4] NBIC= Nanotechnologies, Biotechnologies, Information and Communication Technologies and Cognitive Sciences. Little BANG theory = Bit, Atom, Neuron and Gene.

[5] Even in the US, 'national laboratories' are an important component representing a third of fundamental research according to National Science Foundation criteria.

[6] This means that a programme is gradually constructed in function of the discipline-based departments in charge of the different budgets.

ing' (Delemarle and Larédo 2005).[7] This competition reflects a major turnaround in the structuring of research policies: the State no longer considers itself capable of defining the new leading-edge sectors and delegates the task of proposing them to the actors. Its own role is then to select those centres which have a chance of successfully meeting the challenge of worldwide competition.[8]

5- What kind of government interventions for this new search regime?

This hypothesis of strong geographical concentration leaves open three key questions for the development of appropriate policy forms: the initiation of the explorations, the support measures for crystallisation phenomena and the selection processes, which will lead to one or several models of research organisation.

Exploration. Centres are not constituted through spontaneous generation. They are the result of a first wave of multiple explorations which bring out the potential for novelty and transformation to be found in the sciences in question (Van Lente 1993). The places where these discoveries occur (cf. the biotechnologies in California) have a clear advantage. But it is another matter to create such laboratories where varied explorations and breakthrough sciences are going to develop. Top-down approaches have revealed their limits and given way to bottom-up incentives (Delemarle and Larédo 2006). There are two possible models for this. A first one, whose effectiveness has been demonstrated by the history of Taxol and Taxotère, involves the management of specialised laboratories such as those of the US Department of Energy, the Max Planck Gesellschaft in Germany, Riken in Japan or France's National Centre for Scientific Research (CNRS). Today, however, given the fact that the key issue is stimulating the potential of university-based research, these specialised laboratories play a secondary role in the forging of public-sector competences. The other model advanced to explain the growing gap between Europe and the United States in the production of new paradigms (Larédo 2004) emphasises the fundamental nature of the institutional environment, as might be indicated, for example, by the number of Nobel prize-winners. Our hypothesis is that such institutional stakes call for a European approach, within which the newly created European Research Council could become a central actor.

Crystallisation. The nanotechnologies, as new leading sciences, combine the pursuit of earlier movements (but on different scales and under different conditions) with the emergence of new bottom-up approaches and the convergence of formerly distinct fields. The question which arises today has to do with the scope of the latter phenomenon and the nature of the sectors concerned. Materials also occupy a growing place in the definition of programmes. Similarly, while earlier movements mainly concentrated on business-to-business applications in their first phase, among the major R&D investors today, we find firms directly rooted in consumer markets (e.g., L'Oréal). Does this mean that the directions of research will be multiplied? Or, to put it another way, that there will be greater numbers of public/private centres with complementary focuses? What will be the role of start-ups or specialised firms? For policymakers, the question of the number of research directions which the consortiums of actors wish to pursue is central. Even if each direction leads de facto to concentration around several centres (3 are mentioned for nanoelectronics in Europe), the fact that the consortiums of actors propose to explore five, ten or fifty research directions is essential, because it permits greater spatial distribution and, in the process, limits the violence of the trade-offs. From this standpoint, French policy may be considered a precursor of this movement, which is more easily implemented in region-sized countries like Finland than in the large countries of the European Union. But once again, the different countries' concentration on the same options raises the question of the adequate level of crystallisation and thus of possible coordination at European level.

Selection. The issue for policymakers is no longer the choosing of the good options, for we have seen that this depends on 'markets' and/or 'users'. It is the 'infrastructures' of these markets which must be chosen, whether in terms of rules for intellectual property, the definition of technical standards permitting interoperability, or the security of workers and users. This is also true for the fixing of the economic forms of competition (cf. mobile telephony, air transport or wind energy) or access to generic physical networks (cf. transportation infrastructures, high-tension power lines or communications networks). These government interventions to shape the markets are increasingly based on R&D studies which can no longer be reduced to those carried out by the promoters of the new options.

Here, we would like to stress two points. We have already mentioned the central role of European programmes such as Eureka in constructing GSM or DAB standards. It is necessary, however, to go back over the way this support has been implemented. What was created did not depend on a call for proposals, where the best would have been selected on the 'winner takes all' model. Rather, it involved building a collective framework for research where all the parties were included and the options provided were compared to one another. These programme-like efforts delegated to the actors correspond to the 'integrated project' concept advanced by the European Commission. But the changing forms of intervention have sharply reduced the area of the options and industry is calling for the adoption, in France and Europe alike, of major crystallising projects. France's new Agency for Industrial Innovation (AII) may be seen as an expression of the desire to develop such an approach. This once again raises the question of the relevance of non-coordinated national efforts, unless these are to be taken as the embryo of the 'lead markets' which the Aho Group Report (2006) recommends for Europe.

Issues of security and risk are assuming a growing place in public debate, whether we think of the successive food or health crises, the repeated sinking of merchant ships or, even more, asbestos or GMOs. These constitute a de facto complement to the market 'guidelines' which are subject to democratic debate and the expression of divergent expectations about the kinds of worlds we want for the future. The fact that there is debate over the ways researchers can carry out their studies (cf. the open field trials for the GMOs, the use of stem cells or the recent US

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[7] A clear distinction must be made, however, between this policy and the complementary one of 'industrial districts' which is illustrated by the second kind of centres: the so-called national centres which combine a limited territory and a field of specialisation (60 have been given the official label out of probably more than a hundred potential districts). In both cases, we are far from the 'sprinkling' of resources which is so often stigmatised, since, theoretically, by tripling the means (i.e. going from 500 million to 1.5 billion euros) it is possible to envisage allocating 150 million per world cluster, 20 million per cluster with a worldwide vocation and 5 million per national centre.

[8] Callon (2001) calls this 'procedural policy' and Lascoumes (2005), 'government by instruments'.

debate over carbon nanotubes), or the fact that research institutions such as the National Science Foundation in the US are promoting national centres for research on ‘nanotechnologies and society’ are indications of this transformation.

Exploration, crystallisation and selection constitute three unavoidable phases in the gradual building of new activities and markets. Identifying the critical moments does not mean advocating yet another linear model, however. Whatever the concrete forms this process will take and the iterations it will generate, it will lead to calling our sector-based approaches to government intervention into question. The so-called industrial policies are rediscovering a forgotten dimension from the 1950s.

They are required to adapt themselves to the ‘leading-edge sectors’ which they promote. But the key difference relative to the earlier period is that top-down national regulation, the national policy, has no influence over the transformations now taking place. It is outflanked by the local actors who are organising the concrete areas of production and by global policies, in this instance European ones, which shape rules and standards.

What is the future of national policy in a country like France? It is our hypothesis that the twofold support for the actors in the upstream phases of exploration and, above all, crystallisation, constitutes a powerful instrument for shaping the activities of the future. Industrial policy, in the sense of developing new economic activities, is being displaced towards the conditions of knowledge production. And beyond buzzwords, this what the term ‘knowledge economy’ means

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