

SHARING RESEARCH FACILITIES: TOWARDS A NEW MODE OF TECHNOLOGY TRANSFER?¹

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ABSTRACT

Academic science commercialization through University spin-offs or patents has been growing since the mid 90's. The first biotech firms started up within academia to be able to use unique research facilities with the complementary competences. Since the development of genomics and tools for "mass gene and protein exploration", instrumentation has become more and more resource-consuming, making sharing research facilities a growing issue. The aim of this paper is to analyse the evolution of technology transfer mechanisms and the sharing of research facilities as a mean to transfer technology. It specifically focuses on the organisation of large-scale research facilities (LSRFs) as a means to facilitate and organize technology transfer from public sector research organisations (PSROs) to industry.

Key words: biotechnology, technology transfer, research facilities, organizational design, bricolage, hybrid.

1. INTRODUCTION

Academic science commercialization through University spin-offs or patents has been growing in OECD countries since the mid 90's, especially in the case of biotechnology (Mowery *et al.*, 2001). The early years of biotechnology have also been the scene of close collaborations between start-ups and academic teams within academic labs. McKelvey (McKelvey, 1996) reports that during Genentech's start-up phase, a strong connection existed between the firm and its academic founders, under the guise of informal incubation, as an academic lab of UCSF was hosting Genentech and shared its research facilities with the start-up. This situation tends to generate legal disputes over appropriation, and the 90's have seen a clear separation between start-ups which are supported through incubators and academic labs which may participate to the start-up activities through R&D contracts or temporary or permanent mobility of scientist (through participation to the scientific advisory board, part time or full hiring (Catherine *et al.*, 2004)).

In the more recent years, biotechnology has experienced an increase in the number of instruments and equipments needed to explore living mechanisms at the gene, protein and even nanoscale levels. Thus, instrumentation is more and more resource-consuming (money and competencies), and sharing research facilities becomes a growing issue for an effective development of the biotech sector. Academic labs, start-ups, SMEs as well as some large firms need to have access to large facilities like synchrotron, clean rooms or production capacities to perform research and even to start production (micro-arrays, lab-on-chips, dedicated or high value added research materials, etc.). The aim of this paper is to analyse the sharing of research facilities as a technology transfer mechanism. It specifically focuses on the organisation of large-scale research facilities (LSRFs) as a means to facilitate and

organize technology transfer from public sector research organisations (PSROs) to industry. Large-scale research facilities are usually defined as a set of experimental instruments and components that are available to academics and to a certain extent to industrials. They can be very large-scale equipments, unique to a country or a continent, but can also be a technological hall in which start-ups can initiate production processes. However, technological platforms or large-scale facilities do not simply imply up-to-date instrumentation and facilities to perform scientific research: they are also embodied by a large scientific and technological community, which develops competencies in a specific geographic area. In this sense, the Genentech case is emblematic of successful start-up creation in a favourable environment, which includes access to instrumentation as well as access to key (scientific) resources within the UCSF. The main difference between LSRFs and Genentech's situation in the early 80's is the formal organization of LSRFs with two main goals: stimulating the biotech sector (economic side) by building available research facilities for start-ups and academic labs, and *ex ante* repartition of intellectual property rights. Twenty years later, technological changes lead to the re-examination of facilities sharing as a means of stimulating efficiency and collective learning processes through university/industry relationships.

Section 2 of the paper explores the linkages between technology transfer mechanisms and the industry life cycle. It concludes by showing the importance of large-scale facilities at the end of the emerging phase, during the transition between exploration and exploitation of knowledge. Section 3 presents three archetypes of LSRF organisations to analyse the rationales for organisational design and its consequences on technology transfer (section 4).

2. THE INFLUENCE OF TECHNOLOGY AND INDUSTRY LIFE CYCLES ON TECHNOLOGY TRANSFER MECHANISMS

Identified technology transfer mechanisms

In the last two or three decades, universities and public sector research organizations have witnessed evolutions pertaining to their research objectives and sources of funding. Academic research institutions have gradually become more connected with the economic sector (Argyres & Liebeskind, 1998; Geuna, 1999; Geuna & Nesta, 2003) and research teams have become more and more "entrepreneurial" (Etzkowitz, 2003). Academic research is supposed to be more and more embedded in the economy and to stimulate innovations through technology transfer. comes in various forms, ranging from development and commercialization of new technical artefacts (*e.g.* databases, software, patents) to collaborative research conducted between public and private organisations (*e.g.* via research contracts) Four main technology transfer mechanisms are however usually identified (Siegel *et al.*, 2001): patents and licenses; joint research projects; mobility of human resources (temporary and permanent); and creation of start-ups. These technology transfer mechanisms are linked to the degree

of tacitness or codification of the knowledge being produced, to the degree of instrumentation required to produce it and industrialise its production, and to the existence and characteristics of firms in the industrial sector being considered.

Licenses and patents: After the Bayh-Dole Act of 1980, which emphasized the role of academic research in the economic competition, American universities reinforced their patent policy. The implicit assumption behind the Bayh-Dole Act was that technology transfer from university to industry would be greatly facilitated if universities were issued patents on inventions arising from their research results, and licensed these patents to industry on exclusive or non-exclusive bases. The argument (Nelson, 2001) is that when universities publish their results and release them in the public domain, instead of patenting them, firms have little incentive to use them. Academic results – especially in sectors like the life sciences – require much testing and development before they can be turned into industrial innovations and their utility be fully assessed. Firms would therefore have little incentive to do this follow-up work unless they were assured of reaping the returns in case of success, a guarantee they can only have if they own an exclusive license. Patents and licenses are one of the traditional instruments of technology transfer available when scientific results have already been obtained. However, such a technology transfer mechanism assumes that the industrial sector as well as firms in the sector do exist, and that the latter have the high absorptive capacity needed to successfully conduct the follow-up work on scientific results. This may correspond to mature sectors in which established firms have developed internal research capabilities.

Joint research projects: These simultaneously group academics and private firms on a scientific project. In the recent decades, the nature of university/industry relationships has become more formal through the development of explicit research joint ventures and partnerships. “Research joint venture” is a notion that applies to a wide range of situations, from the arm-length research contract to long-term relationships. Compared to patents and licenses, joint research projects represent a technology transfer mode in which the partners conduct the on-going research together. Since the division of labour is defined within the contract, it is not required for firms to have a high absorptive capacity, as is the case in the selling of license or patents.

Human resource mobility: D. Leonard-Barton (Leonard-Barton, 1995) argues that knowledge transfer requires various communication mechanisms such as the transfer of human resources when the level of codifiability is low. When, owing to its tacitness, knowledge is difficult to separate from those who produce and possess it, hiring people from other organizations is a way of transferring otherwise immobile knowledge. The phenomenon of postdoctoral fellows illustrates this importance of human mobility in knowledge circulation. From the individual’s point of view, this is a way of acquiring specific tacit knowledge and know-how developed by a given organization. From the firm’s point of view, hiring skilled people is a way for an organization to acquire critical knowledge (Almeida & Kogut, 1999; Song *et al.*, 2003). The mobility of experienced scientists not only provides a one-time

technology transfer of information – as is often the case in technology licensing – but also facilitates the transfer of competencies, allowing further knowledge-building (Kim, 1997), especially because experienced people bring their own networks into the firm (Kaplan *et al.*, 2003). Human resources as a technology transfer mechanism cover a wide set of situations in which knowledge transfer can be permanent or temporary, and may apply to start-ups as well as large firms. They provide a way to increase the firm's absorptive capacity (Shane & Stuart, 2002). This is specifically important to staff new ventures in emerging sectors.

University spin-offs and firm creation: In science-based sectors, firm creation is usually viewed as a mechanism of technology transfer (Mustar, 1998; Shane & Stuart, 2002). Knowledge transfer between universities and firms occurs when university-based scientists found a firm with the explicit goal of developing knowledge created in the university lab they belong to (Murray, 2004). Biotechnology being a new knowledge-based industry which is predominantly composed of new small firms having close ties with university-based scientists, start-ups tend to play a crucial role in bridging academia and industry (Catherine *et al.*, 2004).

Industry Life Cycle and technology transfer

Industrial Life Cycle theories underline the intrinsic changing nature of industry structure as the sector matures. It is linked to the technological evolution. They exhibit two major phases in industry development, each being related to the state of the technological paradigm at stake (Dosi, 1982; Tushman & Anderson, 1986). The first phase is characterized by radical and rapid technical change. The emergence of a new technological paradigm may potentially destroy the traditional barriers to entry, representing a threat to incumbents using the old set of technologies. The second phase reveals some sort of technological consolidation and stabilization around a dominant design (Anderson & Tushman, 1990). New firms may well be created on the basis on the differentiated knowledge as to test, refine and exploit new opportunities.

The establishment of a new dominant design calls for knowledge exploitation more than knowledge exploration. During the exploration phase research and innovation are based on inter-organizational collaborations and alliances (March, 1991). During the exploitation phase, the propensity to collaborate should decrease when the technology matures and gets closer to commercialization (Vermeulen & Barkema, 2001). Firms tend to appropriate temporary rents generated through innovation.

Table 1 summarizes the hypotheses about the linkages between industry life cycle and technology transfer. It shows that the emerging phase (exploration stage) is mainly based on transfer of tacit and embodied knowledge through human resource mobility and start-up creation while technology transfer in the exploitation phase can be based on a wider range of vectors, including patents and joint research

programs, as large firms do exist and have developed absorptive capacities (Mangematin & Nesta, 1999).

Table 1: Technology transfer and industry life cycle

	Exploration phase	Exploitation phase
Patents and licenses	Patents are mainly filed by academics. Universities sell exclusive licenses to start-ups created by academics	Large firms buy research results as they have high internal absorptive capacities.
R&D collaboration	Informal between academic labs and start-ups or small firms created by PhDs or researchers. As the firm grows, formalization increases.	Division of R&D tasks between partners with high R&D competencies.
Mobility of human resources	Critical for creating start-ups Role of star scientists in firm creation even if they keep their academic position Crucial for tacit knowledge transfer	Hiring of highly skilled employees (scientists and engineers) by large firms (from academia – PhD and post docs – and from other firms)
Start-up creation	Critical until the growth of barriers to entry	Slow-down of start-up creation Creation of start-ups that are suppliers in equipment and materials

Biotech industry is now maturing towards its exploitation phase (Mangematin & Nesta, 2002; Nesta & Mangematin, 2002). As a consequence, rivalry among existing competitors is higher than in the previous phase because products and processes are now sufficiently developed to penetrate the market (Afuah & Utterback, 1997). Existing firms have invested in capacity, brand name, patents, exclusive licences and contracts, distribution channels and commercial networks. Making it into the industry is therefore harder for new entrants than in the previous phase. Firms also tend to contract specialized materials and equipment. This suggests that the mechanisms of technology transfer might correspondingly change through the various stages of the industry life cycle. Between the exploration and the exploitation phases, Afuah identifies a transition phase in which a dominant design can be identified, at least for some components, *e.g.* emerging and higher-structured markets, larger series of production. In that framework of expanding markets, the development of industrial tools to systematise scientific exploration and to increase the size of the production appear to be a key challenge: life science industry (the seed, agro-food, chemical, and pharmaceutical industries) which has gradually awakened to the potential of biotechnology has subsequently attempted to integrate and to master it. Table 1 pictures the two phases of the industrial life cycle. However, it neither explains how industry moves from exploration to exploitation nor does it describe the modes of technology transfer during the “transition phase”.

Based on the example of biotechnology, the next sections of the paper explore the role of large-scale research facilities as a technology transfer mechanism in the transition phase. The argumentation of the paper is based on two propositions:

P1: When the industry is maturing, instrumentation is more and more important and LSRFs are a technology transfer mechanism.

P2: The organization of LSRFs influences technology transfer dynamics.

3. TECHNOLOGICAL PLATFORMS IN THE LIFE SCIENCES

Modern biotechnology, derived from the convergence of molecular biology and genetic engineering, has introduced a radical change in what life sciences produce, and how they produce it (Morange, 1998). Working at the genetic level, the rise and development of biotechnology aimed at understanding living mechanisms, by reducing uncertainty in the exploration and manipulation of living materials. This entailed designing new tools for generating and analysing mass data, and improving the efficiency of research and production in the field. Advances in this direction greatly improved the ability of researchers to raise the predictive power of R&D activities based on mass data production (high speed sequencing, etc.), and on the calculation of the functional properties of given molecules (mainly proteins). For instance, novel techniques such as high-throughput DNA sequencing, functional genomics, bioinformatics and proteomics have become fundamental tools in modelling the structure of nucleic acids and proteins, thereby providing researchers in the pharmaceutical industry with new rational tools for drug design and development. Today, it is clear that the converging knowledge of molecular biology and genetic engineering represented a discontinuity with respect to the technological and scientific knowledge, artefacts, know-how and practices previously used in life sciences (Arora, 1994; Oliver, 1999). The emergence of technological platforms in the field of life sciences is a direct expression of this historical evolution towards new instrumental logics (Gaudillière, 2000) which heavily rely on instrumentation and computers for generating, storing, analysing and representing vast amounts of data.

Technological platforms can be broadly defined as research and/or production facilities required to explore and exploit new knowledge. These facilities are complex assemblages of instruments and expertise, whose importance, cost and structuring power for the scientific community often call for decision processes at the national level, as well as pluriannual funding. Technological platforms are more than often “cross-boundary” devices, whether geographic, scientific, or organisational. From another perspective, they can also be viewed as devices that regulate production, access to and control over critical data in a given field (Hilgartner & Brandt-Rauf, 1998).

For historical reasons, technological platforms have traditionally been associated with the (very) large-scale research facilities found in high-energy physics, particle physics, or astrophysics. Such devices

as CERN (European Organisation for Nuclear Research, founded in 1954), Tokamak confinement devices used in investigating nuclear fusion (invented in the 1950s), the Large Hadron Collider, or the Very Large Telescope (at the European Southern Observatory), to cite a few, have in common a solid set of characteristics, which seem to provide an epitome of what technological platforms are about. Indeed, these research facilities are typically embedded in “community-based” regimes of scientific production, based on vast transnational collaborations within a large body of scientists (physicians, astronomers). For producing knowledge, these regimes are heavily dependent upon unique, large-scale and highly complex instruments, requiring very high initial investment costs, as well as high upkeep and maintenance costs (in return, the instruments’ life-span is fairly important). These single, central instruments around which everything revolves are set up in specific geographical locations, and rely on a specialised scientific and technical environment in order to be correctly handled and exploited. While introducing new modes of exploring living mechanisms, instrumentation not only modifies the technological methodologies to develop new products (therapeutics, diagnostic kits, etc.) but also the “technology of technological change” itself (Arora, 1994; Arora & Gambardella, 1994). As pointed out by Hackett *et al.*, in the case of nuclear fusion (Hackett *et al.*, 2004), instrumentation influences the day-to-day working conditions within laboratories, the division of labour between scientists and engineers as well as the relations with public authorities. Labs become more dependent upon public funding for the investment and the running of the instrumentation.

However this traditional model alone, inherited from the field of experimental physics, is not enough for an adequate understanding of the nature of technological platforms, especially in the life sciences. Large-scale, single-instrument-centred facilities such as those depicted above do exist in life sciences as well, *e.g.* the European Molecular Biology Lab’s synchrotron. Nonetheless, as thoroughly analysed by Karin Knorr-Cetina (Knorr-Cetina, 1999), molecular biology and experimental physics are two highly contrasting “epistemic cultures”, in which the fabrication of scientific knowledge and the role and place of instrumentation very much diverge. Compared to physics’ large colliders, tokamaks, etc. most technological platforms in the life sciences can hardly be considered “large scale”, whether in size or cost, being most of the time medium-size assemblages of collected instruments used for gene sequencing, functionalising, etc. Moreover, these devices, while serving academic goals, are also embedded in an emerging industrial sector, with high research and production needs, and therefore often have various surrogate goals as well (improving the efficiency of existing tools, instrumental innovation, new product development *e.g.* commercial diagnosis kits, etc.) At the other end of the spectrum, private-owned technological platforms can also be encountered, which are specialized in a segment of the production cycle, such as Contract Research Organisations (CROs), which deliver production services for the pharmaceutical industry. Other models exist as well such as incubators with shared facilities (clean rooms, animal houses, etc.).

In order to account for such diversity, we propose three organisational models for technological platforms found in the life sciences. These should be considered as “archetypes”, in the sense used by Greenwood and Hinings (Greenwood & Hinings, 1993), when they make the following two statements: “First, organizational structures and management are best understood by analysis of overall patterns rather than by analysis of narrowly drawn sets of organizational properties. [...] Second, patterns are a function of the ideas, beliefs, and values – the components of an interpretive scheme – that underpin and are embodied in organizational structures and systems.”

Research on archetypes generally focuses on large firms; only one of the archetypes identified by Teece (Teece, 1986) describes a small organisation (the individual inventor and the stand-alone laboratory). Greenwood and Hinings note that these typologies are multidimensional. Generally, they are based on organisational structures (rule-making, formal structures of authority, etc.) or on decision-taking processes. Yet a range of writings reflects this view of archetypes as configured structures expressing underlying values. Ranson, Hinings and Greenwood (Ranson *et al.*, 1980) emphasise the necessity to investigate the social mechanisms which determine the structuring process and shape the ensuing structural forms if we are to fully understand the formation of organizational structures. The aim here is not to validate each archetype precisely, but to highlight the impact of a specific model of organisation on industrial dynamics. Each archetype is based on the study of real cases which has its internal coherence of an organisation in an archetypical framework.. The paper not only analyses the actual organization but also studies the effect of each organisational archetype on the industry dynamics, appropriation regimes and flexibility to adapt to the future.

Archetype 1: The academic model –Synchrotron Radiation Facility (SRF)

The Synchrotron Radiation Facility (SRF) is a large-scale research facility that uses synchrotron radiation sources to study physical phenomena at the atomic scale, thus functioning somewhat like “super-microscopes” using very bright X-ray beam lines. Operating as from the mid 90’s, the SRF is a non-trading company with a staff of around 550 employees, and is financially supported by a consortium of States (public funding), with an average annual budget for operating costs of about 65 million Euros in 2002. Beam lines devoted to life science projects represent only a small fraction of those available at the SRF. In this specific field, use of synchrotron radiation has permitted the development of highly specialised X-ray crystallography techniques, making it an essential tool for biologists who wish to investigate the structure and function of proteins at the atomic level (structural biology): when scientists need to identify and characterize a protein in order to stimulate or inhibit its activity, a 3-dimensional vision of the protein helps understand how it behaves and know the structure of its inhibitors. Obtaining these 3D “photos” of proteins through the analysis of diffraction images is exactly what the macromolecular X-ray crystallography experiments conducted at the SRF facility are about.

The SRF offers partial services to its users: the beam line is prepared before experiments take place; users receive training courses on beam line utilization and data-collecting software; technical assistance is provided in case of problems arising during experiments, due to the tool's complexity. Once the experiment is over, the beam line generates raw data representing the diffraction images, and uploads these data – left untreated – to the users' account. If they wish, users can start data treatment on provided workstations, but receive no assistance from the facility's staff.

The SRF is essentially dedicated to academic, university-based research. However, such a facility is also relevant for industrial applications. For instance, pharmaceutical industries show great interest in the X-ray crystallography techniques offered at the SRF, in order mostly to obtain diffraction images of protein-ligand complexes. The SRF's functioning (experiment scheduling, beam time allocation, etc.) reflects its priorities: access rules and procedures differ depending upon whether applicants intend to use the facility for academic, university-based research, or proprietary industrial research.

For academic, university-based research (as well as non-proprietary industrial research) beam line access is free of charge. The SRF furthermore offers financial support for travel, accommodation and subsistence expenses directly related to the experiment. Access to the facility is however granted on the basis of a selective scientific assessment performed by a review committee that gathers every six months, examines applications and allocates beam time according to scientific merit. There are 5 "runs" (opening of the beam line dedicated to macromolecular crystallography) per year, each run lasting 2.5 months, and operating on a 24-hour basis, in three 8-hour shifts. Since the competitive nature of those beam schedules, research teams are highly encouraged to group together in order to obtain beam time. Applicants who are granted access to the SRF have one main obligation: they must publish the results of the experiments they perform, and submit a report with the protein's references to the Protein Data Bank (in the field of protein crystallography, scientific articles can only be published if there is a reference to a deposit in the data bank.)

For proprietary industrial research, beam time is limited to 10% of the synchrotron's global activity, and to 30% per beam line. At the time of the interview, despite growing demand, beam time devoted to industrial applications in protein crystallography was limited to 2% of the facility's activity (the beam line devoted to protein crystallography is one of the most used by industrials.) Industrials doing proprietary research have no publication obligation, and the SRF scientific officers assisting them are bound by confidentiality agreements. These industrial users must however pay for access to the facility, the price being supposed to cover the total cost.

To sum up this model's main characteristics, SRF is a non-for profit organization mainly dedicated to academic research. Due to industrial needs to explore living mechanisms, accesses to research facilities have been granted to industry, which are however full of constraints due to the access procedures. Being a unique, centralised instrument with a "monopolistic" perspective, the SRF focuses on academic, non-proprietary research and the accumulation of publicly available knowledge, through

publication constraints, and a clear, “hardcoded” limitation of industrial use. This model remains close to large scale research facilities in physics.

Archetype 2: The private model – Multimodal platform (MMP)

MMP was founded in 1985 as a spin-off of the University of Liège (Belgium). Its mission is to design and deliver reliable and innovative products and services to the life science community. As a leading supplier for genomic and proteomic research, the firm offers its customers – academic and industrial alike – integrated solutions, whether they use DNA, antibodies, peptides or proteins as research tools. MMP also offers specific research and development services for the biopharmaceutical industry.

MMP has developed a broad platform of enabling technologies, with activities organized around 3 business units: a “Genomics” department, which offers oligonucleotide synthesis, DNA sequencing, Real-Time PCR, DNA micro-array services, as well as a wide range of commercial kits and consumables; a “Proteomics” department, which gathers know-how and expertise in the design of peptides, antibody production in a wide range of animal models, custom transgenic services as well as peptide-, antibody- and protein-arrays; and a “Biologics” unit, which is a full-service Contract Research Organisation (CRO) delivering research, development and production services for the manufacturing of pharmaceutical grade synthetic oligonucleotides, in compliance with the Good Manufacturing Practices (GMP) standards for therapeutic drugs.

The company’s headquarters are located in Belgium, and has subsidiaries in France, Germany, the UK, the Netherlands and a branch office in Switzerland. In 1999, MMP acquired a British company and enlarged its presence abroad by developing joint venture in Japan and USA. The Group currently employs 300 people, including 14% of PhDs. Revenues grew from 7 million Euros in 1995 to 30.6 million Euros in 2002-2003, with a 3.5 million Euros EBITDA.

Here, the model’s perspective is clearly a flexible, commercial one, with an indiscriminate supply of integrated services to public and private actors alike. In this model, the strategies of public authorities do not directly influence or shape the platform’s organization, access rules, or functioning. Two main linkages with academia do exist: commercial ones, since MMP produces research materials, reagents, services for sequencing, functionalising, etc., and academic labs are amongst the clients; and research ones, through the development of co-operative research programmes with universities all around the world. However, the linkages with higher education remain weak, as MMP is a private for profit firm.

Archetype 3: the public/private model: GenoHybrid (GH)

GenoHybrid is a spin-off of a French university in the north of France, which spent its start-up years at the local bio incubator. The local university has been subsidised to invest in equipment for biotechnology. However, the university does not have the capacities to offer up-to-date and high tech

services to all actors involved in biotech research and production. Thus, the university rents the equipment to GenoHybrid, a service company that offers services in genomics and R&D activities, and develops sequencing and genotyping services for both academic and industrial research (PSROs, private labs, pharmaceutical industries, health institutions.)

Since its creation, the firm has been operating on public equipment (high speed genomics platform) by performing services in DNA sequencing, SNP detection and characterization, genotyping, PCR amplification, conditioning and storage of genetic material.

By outsourcing its high-speed genomics activities to GenoHybrid, the University has been able to focus its in-house activities on the exploitation of data acquired through the platform. This organizational solution has also provided the University with an efficient solution in regard to maintenance and renewal of the equipment, production costs reduction as well as human resources management.

This university accepts applications from industrial and academics alike for high-speed genomics projects. However, since GenoHybrid's platform is integrated in the French Genomics program, access to the platform is primarily granted to PSROs, and especially to regional university-based labs.

Aside from this high-speed genomics platform, the University also runs technological platforms in functional genomics and proteomics, two fields in which techniques are very much less routinized than high-speed sequencing or genotyping, and whose research agendas still remain open. These platforms primarily focus on a pool of users performing local, university-based, non-proprietary research. They are operated onsite by a team made up of local scientists and technicians, access being granted by local scientific committees, which select projects, perform peer review, and set publication rules much akin to those encountered in the first model.

This third archetype is therefore a somewhat hybrid model, in which the operation of part of the facilities is undertaken by a private company for the sake of a public sector technological platform, whose access rules and priorities continue to be shaped by public research strategies, although at different levels.

Through these three archetypes, an attempt has been made to present each business or functioning model, as well as the main linkages with academia. Each archetype is however somehow static. Table 2 tries to capture the dynamic development of the three archetypes' characteristics.

Table 2: Criteria for characterizing LSRFs

	Academic	Public/private	Private
Aims	Providing research facilities to produce scientific results	Fulfil academic needs with outsourcing strategy to maintain efficiency	Generate turnover through the sale of services and products
Status of the users	Access to the research facility is granted to <i>users</i> , mostly academic researchers	Mixed approach between users and clients, service and access	A service is provided to <i>clients</i> (academic and industrial alike) who can afford
Assessment procedures	Based on scientific merit and interest.	Some access priorities	Propensity to pay
Technological maturity	Low maturity Further developments required	Complementarity between different components reaching different stages of maturity	Mature enough to generate turnover and meet market needs
Industry life cycle	Unfair competition between public and private?	High uncertainty and possible market failures Trajectory: dedicated platforms for academia and industry?	Fluidity of the market Creation of monopolies?
Learning curve	Scientific quality Education and training	Cost reduction Possible appropriation of learning processes Structural problems in human resources in French PSROs	Cost reduction Appropriation of learning processes (scientific and technological know-how, etc.)

Each archetype is pursuing a different aim even if the means are quite similar: developing new competencies around instrumentation in modern biotechnology. The academic archetype aims at developing new tools to explore life to make research more efficient and more powerful. It allows the scientific community to better understand living mechanisms, to produce new results and new scientific artefacts. If the technology is mature enough to be exploited without additional research, it can be outsourced to private companies. Some technological platforms are highly stabilized, completely operational tools which run on a routinized basis (*e.g.* sequencing platforms), while on the other hand, some facilities rest upon technologies yet to be developed, which require further investment in costly research and instrumentation before they can be expected to work routinely (*e.g.* proteomics platforms). Research facilities that are operational may be run by private organisations while those which need scientific and technological development may be designed and run by academic organisations.

Indeed, in each technological platform, the status of the user is not the same. When research facilities can be run in a routinised way, a set of services can be offered to clients. Production of services can be done with a standardised quality and with low uncertainty of time delivery. At the opposite, when platforms are built and used for research purposes at the same time, two kinds of uncertainties are combined: the scientific and technological uncertainty of the development of the platform and scientific uncertainty of the research object. Scientists who study living mechanisms through the platform and those who work on the platform's development are co-producing scientific results. They are not clients of the platforms but rather users. Thus, the degree of maturity of scientific and technological developments of the considered instruments may influence the organisational choice.

In the different cases, the criteria of performance of the platform are not the same as well as the strategy of the platform leader, who can allocate different orders of priority to different types of clients/users. When platforms are run on a commercial basis, the propensity to pay is one of the key criteria to choose clients. When platforms are still under development, scientific or technological criteria prevail to give priority.

However, there are at least two limits for the private solution when technologies are mature:

- The emergent or mature character of the industry: are there existing firms and services in the given field? Are there monopolistic or quasi-monopolistic private companies in the sector, which could justify public intervention in the setting-up of technological alternatives (*e.g.* Affymetrix's quasi-monopoly in the field of micro-arrays)? Are there on the contrary risks of unfair competition between technological platforms receiving grants from local or national public authorities and existing firms in the sector, creating situations of jeopardy for the latter?
- The nature and outcomes of the learning curve made possible by the activity of the given facility: does it primarily allow to reduce costs, to create new knowledge, to accumulate learning and competencies building, etc. to what extent can it be connected to higher education? The future of both science and industry is based on the capacity of university and industry to train new scientists on up-to-date equipments and devices.

4. DISCUSSION

4.1. Organisational design and bricolage in technological platforms

Empirical study of the day-to-day work in French LSRFs show that these facilities, however specialized (whether they focus on gene sequencing, biochips, or proteomics, etc.), all have to face a strikingly constant set of issues and come up with organizational solutions to address the latter. For instance, LSRFs must devise ways of assessing the technical feasibility of projects submitted to them, and define standard operating protocols (technical characteristics and standards of accepted material for input, whether they be proteins, DNA samples, biochips, and so on; quality control processes; format of the output generated, etc.). Rules have to be set up in regard to priority and timetables for access to instruments. Moreover, it is often necessary to perform some kind of scientific assessment of the projects submitted by applicants (*e.g.* what is the project's scientific interest in extending knowledge in the field?), and ensure their adequation with the platform's technical specifications and scientific aims. Issues pertaining to intellectual property rights have to be properly addressed, such as defining clear modalities for the publication (or secrecy) of results obtained from direct use of the platforms. Personnel has to be hired and trained in order to operate the facilities (*e.g.* solutions have to be found to the recurring problem of human resources being wasted after temporary two-year contracts

in the French academic system.) Last, but not least, some kind of cost calculation has to be made in order to determine the platform's expenses, and set up price lists for users and/or clients.

Field data shows that in the French case, LSRFs display a fair amount of organizational improvisation and "bricolage" methods when trying to find solutions to the above-listed problems. Baker, Miner and Eesley (Baker *et al.*, 2003) suggest that improvisation, defined as the convergence of design and execution of novel activities, tends to occur for strategic reasons in knowledge-intensive organizations, in contrast with (or as a complement to) "design-precedes-execution" organizational models. Building upon the anthropological definition of "bricolage" (given by such authors as Levi-Strauss) as "making do with current resources, and creating new forms and order from tools and material at hand", a concept readily adopted by improvisation theorists (Weick, 1996), the authors show that bricolage and improvisational activities are strongly shaped by the pre-existing networks in which the organization is embedded.

We suggest that improvisation theory and the concept of "bricolage" provide a convincing framework in which the organizational characteristics of French LSRFs can be explained. Indeed, most large-scale research facilities in the life sciences were historically built around academic core components and competencies initially found in universities and PSROs. Left to their own devices, and having not only to manage scientific production in the field, but also its industrialization, the key players in the design and execution of these technological platforms resorted to bricolage methods to elaborate rules and regulations in order to run them. The scientific community relied on pre-existing and available networks, sets of rules, values and common practices as primary resources, hence the importance of scientific reviewing committees in regulating access to these facilities, and the role played by the "epistemic culture" of molecular biologists (Knorr-Cetina, 1999) as the primary resource in the design of rules and assessment procedures (importance of peer-review, scientific merit, etc.) These considerations suggest that morphological approaches in terms of organizational "archetypes" need to be supplemented with a minute analysis of who fabricates access and operation rules in LSRFs, of how and why they do so.

Moreover, while the outcomes of "bricolage" activities are highly uncertain, and may potentially be harmful or positive, such exploratory, context-sensitive processes ensure flexible conditions for building and transforming the organization of LSRFs, thus providing an efficient way of avoiding untimely lock-in phenomena (Callon, 1994), by keeping options open while technological trajectories for LSRFs are explored and paths are chosen. It might therefore be argued that "bricolage" activities play a strategic role, to be encouraged and not hindered, in the transition phase between exploration and exploitation, during which LSRFs become a crucial technology transfer mechanism. Michaud and Thoenig (Michaud & Thoenig, 2003) argue that this hybrid way to manage is one of the conditions to sustain exploration and exploitation activities.

4.2. Large scale Research platforms and technology transfer

Four main technology transfer mechanisms have been identified: patents and licenses, joint research project, temporary or permanent mobility of researchers and firm creation. Table 1 (section 2) shows that the more the sector is emerging (mainly in the fluid phase and to a lesser extent in the transition phase by Afuah's definition), the more technology transfer is based on transfer of tacit knowledge, *i.e.* mobility of researchers and creation of firms by researchers. Technology transfer through patents and joint research programmes, when they are used alone, suppose high absorptive capacity from the firm and are thus mainly dedicated to large firms. Large firms with high competencies in a specific field mainly exist when the sector is mature. Moreover, the emerging phase is mainly a period during which the knowledge is codified so as to be distributed amongst a large number of actors. Its circulation assumes the circulation of researchers, as the codification still has to be improved. During the exploitation phase, skilled engineers and researchers are available since training has been organised, codification has been improved and knowledge codified in patents or articles can be used and developed.

Circulation of tacit knowledge is crucial during the emergence phase. Access to genetic materials has been central during the emergence phase as pointed out by Hilgartner for the Human Genome Project (Hilgartner & Brandt-Rauf, 1994). Key resources were developed within academic labs and most of start-ups were located around scientific labs (Feldman, 2001; Liebeskind *et al.*, 1996). During the early 80's in the United States and the early 90's in Europe, biotech start-ups emerged in academic labs. Firms developed a symbiotic relationship with universities as they were founded by academics. Research for the firm's sake took place in the academic lab. The same persons working as academics or post-doctoral students also performed research within the firm, and used university facilities. Chapter 5 of McKelvey's book (1996) describes this situation of strong interplay between UCSF and Genentech.

When the sector is maturing and reveals its economic potential, it leads to more formal relations. First, it becomes central for research and innovation public policy. Public authorities (national and local) tend to stimulate innovation and firm creation through incubators and seed funding. The definition and implementation of public policies suppose designing specific tools such as incubators, technological halls and seed capital. These induce more formal linkages in university/start-up relations so as to identify the potential target of public policy measures and also to avoid intellectual property right problems, as it was the case for Genentech. Second, economic potential of the sector also leads each actor and especially university and public sector research to pay more attention to intellectual property rights to generate revenues from research (Mowery *et al.*, 2001). Third, the evolution from exploration to exploitation implies up-scaling production capacity from handcraft to mass production. Thus, the industry requires more and more investments and becomes more and more capitalistic. To convince private partners to invest, property rights have to be defined and the firm needs to be clearly separated

from the academic lab. Thus, when the industry is maturing, technology transfer is more formal and based on specific organizations. Large-scale research facilities play a key role in the sector's development. However, this role is really sector-dependent. In physics, research facilities require high investments and they are mainly used by the public sector research. In biotechnology, the economic potential of the sector leads to a higher pressure from industry. LSRFs are also smaller than in physics. Several platforms may exist and a single firm can invest in what it identifies as a promising technology and competency.

When the industry is maturing, instrumentation is more and more important and LSRFs are a technology transfer mechanism. Access to research facilities is a key factor for the development of firms. When the technology is revealing its potential, firms can invest in their own research facilities, as it is the case for clean rooms in informatics. Research facilities can also be defined as a commercial service when the technology has been routinized, as was the case for gene sequencing in the mid 90's or for small animal imagery in 2003. Shared facilities are mainly an intermediate stage during the transition between exploration and exploitation, to stimulate the growth of firms, as instrumentation is being a key issue.

LSRFs appear to be an intermediate phase in the industry development, which allows the economic take-off of the sector. It is thus necessary to adopt a flexible organisation for these research facilities. This is the reason why organization matters. The academic model cannot be generalised: when the sector is maturing, actors are specialising and services around specific technologies can be developed on a commercial basis, as has been the case in genomics. The case of MMP is emblematic of the number of firms that are set-up and developing by providing value-added services for life science industry as a whole. Hybrid models like GenoHybrid are useful when the technology still has to be developed and cannot be routinised – which is not the case for GenoHybrid. Public and private research facilities providing a similar service cannot co-exist: first, public facilities are highly subsidised and private firms cannot compete at the cost level. Second public sector research is often a market for services. If those services are internalised, this leads to a reduction of turnover for start-ups and SMEs, which is not favourable for the whole sector.

CONCLUSION

As at the early age of biotechnology developments, sharing research facilities appears to be a way of science production for academic teams and private firms. Developments are based on the conjunction in the same area (labs or building) of equipment and competences to explore new phenomena, new materials or living mechanisms at the frontier of science.

According to the degree of maturity of technology and to the strength of the industry (presence of large firms, existence of a dense network of SMEs and start-ups), sharing facilities may be punctual, temporary or can reach a certain degree of permanency. Punctual sharing facilities appears in a

problem solving perspective. A firm can pay academia to have access to specific equipment or specific training. On the contrary, an academic team may work in industry to perform a set of experimentations. In both cases, sharing facilities allows the two partners to be more efficient in their research and their cooperation is based on contractual research agreements. The case of Genentech reveals a temporary sharing of facilities. To start-up the company, research facilities may be shared or the academic team may host the start-up and rent its facilities after working hours. The same situation appears in case of spin-offs from large firms. The start-up cannot afford to buy all the required and up-to-date equipment and to development all the competencies to run these equipment. Collaboration with academia or with large firms may provide it with the relevant expertise, including access to equipment. When the start-up generates enough turnovers to buy its own equipment, or when its production activity is too intense to share equipment with others, it can invest in its own facilities. The sharing period has been only temporary, during the early period of the firm. Finally, sharing activities may be designed for the long term, especially for large-scale equipment like synchrotrons. The SRF is a good example of such a case. When investment is too high compared to the market or when no entrepreneur has identified the niche as a potential market, temporary sharing facilities can last on the long run.

It is thus clear that the organisation of sharing facilities for research and early production requires flexibility in its design: flexibility to move easily from public to private and vice versa, flexibility to adapt the rules of use depending of the stage of development of technology and the maturity of industry. Such a situation pleads in favour of hybrid or private solutions rather than public ones. Indeed, it is much more difficult to privatise public academic labs or public research facilities than to buy services to a private firm from an administration or a public university. The development of sharing facilities as a mode of technology transfer leads to a bizarre situation in which one has to see technology transfer from the private side: the necessity to integrate academic concerns within private firms rather than transferring academic science to private companies. This requires a radical change of point of view and also a leading role of firms.

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