Technological Transfers from the European Space Programs: A Dynamic View and Comparison with Other R&D Projects

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Technological Transfers from the European Space Programs: A Dynamic View and Comparison with Other R&D Projects

L. Bach*
P. Cohendet*
E. Schenk**

ABSTRACT. This article presents the results and lessons learned from a series of studies carried out by the BETA research team (University Louis Pasteur of Strasbourg, France) to measure the spin-offs and technological transfers that resulted from European space programs. Beyond the quantitative results that are analyzed in detail, the article examines some of the main qualitative characteristics that shape the technology transfer process generated by these programs. In particular, it is demonstrated that three main characteristics have a significant impact on the technology transfer process: the nature of the technologies at stake (their degree of maturity, their degree of diversity, the extent to which they are generic or specific), the nature of the network of participants to the programs (the degree of mutual trust, the existence of absorptive capabilities) and the nature of the organizational structure of those firms which participated in the projects (their degree of decentralization, their degree of vertical integration).

The article concludes by discussing how these lessons learned could be used to shape the procurement policies to be followed by space agencies in order to favor a high potential for technological transfers arising from future space projects.

JEL Classification: O38, D62, H5

1. Introduction

During the past three decades, the European countries, mostly under the initiative of the European Space Agency (ESA), have undertaken a significant effort in space. When compared to the NASA programs, the European programs may still appear modest in budget. Since the beginning of the 1960's, the European cumulative expenses in space have amounted to approximately 10% of the NASA cumulative expenses. However, as the European projects were clearly aimed at building a complete infrastructure in space (launchers, satellites, ground stations), in some segments they succeeded in competing with the corresponding infrastructure developed by NASA.

The BETA research team[1] had a unique opportunity, through a series of studies that started at the end of the 1970's, to measure the spin-offs and technological transfers that resulted from the European programs in space. The studies relied on an analysis of the process whereby innovations are diffused, and were based on the assumption that the process of diffusion (and the related mechanisms of technological transfers) originated in the contracting companies that carried out the space projects. BETA developed, validated, and progressively improved methodologies of evaluation of spin-offs and technological transfers based on direct interviews with these contracting firms. The studies revealed that these programs generated a large number of spin-offs (on average, every 100 ecus paid by ESA to industry resulted in a minimum amount of spin-offs of around 300 ecus via the ESA contractors). But, more importantly, they pinpointed some of the main qualitative characteristics that shape the technology transfer process of such programs: the influence of the nature of technologies that are developed and used, the nature of the network of participants, and the organizational structures of firms that participate in the projects.

The aim of this paper is to analyze the lessons learned from this series of studies from two

*Bureau d'Économie Théorique et Appliquée
Université Louis Pasteur
Strasbourg
France
**Bureau d'Économie Théorique et Appliquée
Université Louis Pasteur, and Laboratoire de Recherche en Productique de Strasbourg
ENSAIS
Strasbourg
France

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different and complementary perspectives:

- The first one is to proceed through a dynamic analysis of the evolution of spin-offs from the European space programs (Part 1). The results show that the intensity, nature and direction of spin-offs and technological transfers may strongly vary through time. The process of technological transfer is thus highly contextual, and depends on dynamic factors that have to be identified and explained.
- The second one (Part 2) is to shed light on the distinctive features of space programs in terms of technological transfers, when compared to other types of R&D projects funded by the governments to stimulate the economy. Space projects belong to a broader class of programs which will be referred to as *mission-oriented* (Ergas, 1987). They aim at reaching well-defined targets and they are usually organized in a hierarchical fashion. However, governments can stimulate economy through a whole range of other types of programs, in particular through *diffusion-oriented* programs (the objectives of which being to push the limit of the technological state-of-the-art frontier in a given domain). For sake of comparison, the process of technological transfer generated by *diffusion-oriented* projects (such as the Brite–Euram project of the European Union in the domain of new materials and new technologies of production, and German projects in fast trains) will be compared with the results obtained from space projects.

In the conclusion, the article will emphasize that the main lessons learned not only could be applied to understand the complex process of technological transfers that emerges from space programs, but also could be used to shape the procurement policy to be followed by space agencies when defining a new project in order to generate a high potential for technological transfer.

2. The evolution of spin-offs from space programs: A dynamic analysis

Since the late 1970's, BETA has performed three different sets of studies of technology transfers and spin-offs from ESA space programs.[2] The first was at the end of the 1970's, the second at the end of the 1980's, and the third at the end of the 1990's. BETA studies mainly used the *indirect effects* typology (see Box 1).

The first set of BETA studies (BETA, 1980) covered the period from the emergence of European space programs (mid 1960's) to the beginning of the 1980's. This period corresponds to the building of the European space industry, from a technological point of view and also from the point of view of the industrial structure (development of big firms by dramatic growth of small space departments or by mergers mainly at national levels). In this respect, ESA has played a central role.

The second set of BETA studies (BETA, 1988; BETA, 1989) covered the period from the late 1970's to the beginning of the 1990's. During this period, commercial applications of space were developing, accompanied by other vast modifications in the industrial structures (mergers, new consortia, etc.).

The period covered by the last BETA study was much more limited, essentially reflecting the present situation of space activities with mega-mergers at the international level and rapid development of space markets, but also some uncertainty about the challenges to be addressed in future space programs.

A dynamic analysis of spin-offs will attempt to draw some lessons about their evolution from ESA space programs through time, and their possible direction in the future. The following discussions are based on the quantitative and qualitative results gathered through years by interviews carried out in European firms. Some of the salient results are presented in Table I below. The results show what amount of Added Value is created by ESA contractors through indirect effects from their involvement in ESA programs.

The general evolution of BETA indirect effects

The general evolution of the indirect effects from the 1980 study to the 1988 study clearly confirmed the emergence of the European space industry (Bach *et al.*, 1992). The main results from the BETA studies (see Table I) are: the space technologies and products developed in the framework of ESA programs significantly expanded.

Technology transfer:

In a traditional and narrow view, technology transfer corresponds to the transfer from one sector (here space) to another of a technology codified in a patent or embodied in a product, a prototype, a production pilot or any device. The technology is not modified by the transfer and can be re-used as such. An analogy may be made with the emission/reception of information.

The term *technology*, as adopted here, has a larger meaning. It encompasses all the knowledge base of firms or laboratories, including the *traditional* forms of technology mentioned above, as well as the scientific principles, blueprints, problem-solving methods, workers' know-how, etc. The combination of all of them is the basis of the technological development. Therefore, technology transfer corresponds to the transfer of any type of scientific or technological knowledge, from one sector to another. More or less important mutual modifications and adaptations are then required of the technology itself and of the non-space environment (modification of the knowledge base, changes in organization and procedures, etc.). The technology transfer is an innovation process. It may happen that this process is the one that traditional sense referred to, but this is a very rare occasion. Therefore, the contemporary meaning includes the traditional one. There could be internal transfer (within the same firm or laboratory) and external transfer (between two different entities).

Spin-off:

Spin-off is often used as a synonym of technology transfer, according to both the traditional and contemporary meanings mentioned above. It also sometimes corresponds to cases in which technology transfer is achieved through the creation of a new firm in charge of the transfer and/or the commercial exploitation of its results (spin-off company). In a broader view adopted here, it is possible to envisage spin-offs as the transfer processes from (and the results of) any type of knowledge developed by one sector (here, space) to another sector: in particular, knowledge about sources and modes of cooperation, ways of managing the different processes at the conception, production or commercialization levels (quality management, project management, methods,), etc. In this respect, technological transfer is only one possible form of spin-off, related to one type of knowledge.

Indirect effects:

This expression is used by the BETA group in its studies to define the acquisition of any type of knowledge by one firm or laboratory through its involvement in a given program, and which this firm or laboratory exploits or may exploit for purposes other than this program. Four types of indirect effects are distinguished:

Technological effects

These effects essentially correspond to the transfer of technology (contemporary meaning) developed during the R&D program by the participants to it. There may be transfer of technologies related to products, production or services, and they can lead to the design of entirely new things or allowing the enhancement of existing ones. Another effect is the ownership of patents, not currently protecting existing product or process, but allowing the participants to secure future long term technological position.

Commercial effects

These effects are of two types: i) network effects, i.e., the impact of the program on the research and business connections of the participants involved (cheaper and/or better suppliers, new clients, or research organizations); ii) reputation effects: by working in large public R&D programs, participants sometimes acquire a "valuable" image (high-tech, internationally oriented), which is afterwards used as a marketing tool or reference.

Organization and Method Effects

Method effects occur when experience gained through the project allows the participant to apply new methods that were learned during the project. This experience can be related to quality control, experimental procedures, tests and measurement, management methods, etc. It can be provided directly by the public organization in charge of the program, or by other participants, or developed by the participant itself during the program. The organization effect corresponds to changes in the structure or the organization of the participants caused by the involvement in the evaluated project.

Work factor effects

These last indirect effects are of a different nature. They tend to describe the impact of the project on the "human capital" of the contractor. The induced work factor effects are related in particular to the heightened qualifications and skills acquired by the personnel employed in the public R&D programs, which enable them to feed expertise into the company departments not directly concerned by the same activities. Apart from promoting this permanent enhancement of skills, the programs support the creation, maintenance or growth of well-structured teams of specialists, scientists, engineers and technicians. The technological potential this "critical mass" represents is a decisive qualification for securing further activities relating to the increasingly complex systems in all sectors of industry.

It is important to emphasize three consequences of the definition of indirect effects put forward. First, there may be some knowledge that has not been wholly transferred when the evaluation is performed and is therefore mainly of a potential nature: this is the case of the *work factor effect*. Second, the analysis is made from the point of view of the R&D program giving birth to indirect effects, and not from a sectoral point of view: it means that there are for instance indirect effects from ESA programs to other space activities. And third, since indirect effects are obviously interconnected, it is always better to evaluate them together when analyzing one participant to a program. These three points explain why spin-offs are a sub-set of indirect effects as defined by the BETA group.

Box 1. A few definitions.

Table I
BETA studies on the spin-offs from ESA space programs

	BETA 1980 study	BETA 1988 study
Period covered	64-82	77-91
Number of ESA contractors	128	67
Total amount of indirect effects (Millions Euros 86)	7551	12680
Ratio : indirect effects/ESA contracts	≥ 2.9	≥3.2
Indirect effects out of the space sector	50%	21%
Breakdown of indirect effects (%)		
Technological	25	32
Commercial	27	8
Org. & Methods	19	6
Work factor	29	54

BETA 1989 study	
Number of technology transfers	133
Total Amount of technology transfers (Millions Euros 86)	2 179
Ratio : technology transfers / ESA contracts	0.6
Ratio : technology transfers / all indirect effects	17%
% if internal transfers	85%
Nature of technology transfers (%)	
Product technologies	61
Production technologies	10
Procedures and Methods	21
Others	8

However, technological effects from European space programs were less and less diffused out of the space arena. They were used more and more for other space programs, especially private commercial ones (increase in the indirect *technological* effects within the space sector). Correspondingly, the size of the space teams grew dramatically, as ESA programs allowed firms to reach *critical masses* of researchers and engineers (increase in the indirect *work factor* effect). This increase was followed by a process of structural expansion of space activities, with the original space project team becoming a "Space Department", then a "Space Division" and in some cases a self-contained subsidiary. Also noteworthy was the apparent decreasing impact in terms of reputation or "image" gained by firms through their participation in ESA programs: after some years, the fact that a firm was involved in ESA programs did not add to its image, while in parallel, the novelty of space programs faded as space activities became more and more commonplace.

Beyond this evolution of the general structure of the indirect effects, it is interesting to delve more deeply into the dynamics of the indirect effects that can be considered as spin-offs for this article. We can group them in three sets:

- technological spin-offs (or technology transfers)
- network spin-offs
- industrial management spin-offs

Technological spin-offs: Changes in spin-off and changes in spin-in/spin-off loops

For a long time, the role of space activities in technology development and diffusion had been discussed in two separate ways. On the one hand, what can be called the *engineers approach* was to claim that space activities had imported basic technologies previously developed in sectors such as defense or aeronautics. This is especially the case in Europe, where national programs (particularly in the UK and France) in both sectors had paved the way for the development of the first generation of launchers and satellites. On the other hand, the *political approach* considered that space was the archetype of a high-technology sector, from which leading-edge *space-born* technologies naturally spin-off or spill-over to other sectors. Numerous successful cases were cited as examples of a supposed largely widespread phenomenon. The defenders of the first approach (later called *spin-in*, by reference to the spin-off) were very skeptical about the significance of the examples provided by the second, while the defenders of the second approach tended to minimize the importance of the phenomenon put forward by the first approach, arguing that "technologies do not fall from the sky anyway" and tending to justify the space programs by the spin-off alone.

Extensive studies such as the ones conducted by BETA partially confirmed both points of view. The importance of the spin-off phenomenon was clear in qualitative as well as in monetary terms, attested by the figures of technological effects in BETA studies or figures provided by other studies (see for instance Hertzfeld, 1992 and Bach *et al*., 1992). It was true for product technologies as well as production technologies (with a particular emphasis on test facilities for the latter). But the knowledge base on which technologies were developed for space applications was also very often acknowledged by the space industry managers and engineers interviewed to be largely common with both defense and aeronautics activities and (probably less) with telecommunications. In some cases those sectors were obviously the first contributors to this common knowledge base.

Other lessons from these studies had also added to the understanding of the two approaches. It was shown that space activities had a specific role in integrating and interfacing technologies coming from different origins, and that new technologies dealing with the integration requirements were really specifically generated by space activities. These interfacing/integrating technologies become ideal candidates for spin-offs. Moreover, the extreme conditions in which spacecraft must operate often lead to an improvement in the performance of the technologies on which they are based. And correspondingly, these extreme conditions require a very detailed and fundamental knowledge of the properties of these technologies and of their real potential for use. For this purpose, specific scientific research work and very often new testing operations are required (based on adapted facilities and procedures), both turning into new sources of future spin-offs. Therefore, technologies imported from other sectors can be first tested (pioneer use for space applications) and/or upgraded and better controlled thanks to their use by the space sector, and then *come back* for larger or more efficient *ground* applications.[3]

More generally, these studies suggested or confirmed three hypotheses about spin-in and spin-off:

- The spin-in and spin-off phenomena may in some instances be interconnected, with a technology spinning in first and later spinning off.
- Technologies are never transferred from another sector and used as such: they are always modified, adapted, enhanced, possibly generating other potential transfers. This was consistent with new developments in innovation analysis in economics and management sciences, according to which technology is not fixed and defined once and for all, but always evolving and adapting.
- Different types of knowledge may spin-in or spin-off, some of a more scientific type and some of a more technical type.

In order to combine the different analyses about spin-off and spin-in presented above, we propose a simplified analytical framework. It is based on a classical breakdown of knowledge, which expresses what can be spun in or out of the space sector: scientific knowledge, technological knowledge, and knowledge incorporated (or embodied) in existing *artifacts* such as products, components, devices, software, and so on.[4]

In this perspective, apart form cases corresponding to *pure* spin-in or spin-off (that is the case when a *pure* terrestrial knowledge is transferred to the space sector or the reverse), spin-in and spin-off are often interconnected in two ways:

1. Through *short loops*, i.e. when knowledge is spining in and then is spinning off (spun in and off) at the same level; thus there are three types of short loops, corresponding to each of the three types of knowledge.
2. Through *long loops*, i.e. when knowledge from one of the three above mentioned types is spinning in, transformed into another type of knowledge which is then spun off, thus there are three possible types of long loops: scientific level to technological level, scientific level to product level, and technological level to product level.

The use of this framework in order to analyze the evolution of the spin-offs from space programs suggests that, from the first decades of space programs up to the present, there may have been changes not only in the spin-in and spin-off taken separately, but also in the spin-in/spin-off loops.

In a first phase of ESA programs (from the beginning to the mid-1980's), the main *one-direction* knowledge flows from terrestrial sectors to space sectors were probably at the scientific level (mainly spin-in) and technological level (spin-in and spin-off, especially between sectors having a partly common knowledge base, such as defense and aeronautics which "received" two-thirds of the technology transfers evaluated by BETA in the 1989 study), coupled with the main following loops: i) long loop from *ground* scientific knowledge to *ground* technological knowledge: this corresponds to the fact that ESA-type programs were mainly development programs instead of research programs, and were largely based on existing scientific results; and ii) short loop at the technological level. In both cases, integration and interfacing requirements in extreme conditions were the main driving forces. But one key point was probably that these requirements were mixed with other types of space requirements which corresponded to emerging society and industry needs: miniaturization (size and weight), energy savings, resistance to hostile environment, information processing, and knowledge of materials at microscopic or atomic level.

In a second phase (still running), the main one-direction flows have probably evolved. Spin-in at the scientific level may be less important,[5] but there is also more and more spin-in at the product level.[6] Correspondingly, it seems that the importance of the long loops starting from scientific level has decreased, because of the relative absence of big technological challenges (such as a Mars manned mission). On the other hand, other loops are becoming more and more important: long loop from technological level to product level and short loop at the product level. Pressure to enhance the performance of the development process in ESA programs (cost, time, technical performance), and pro-active initiatives such as the ESA Technology Transfer Program are driving the evolution in the same direction.

Although there are still spin-offs, what happens at the technological level is more uncertain because the consequences of two general trends are concentrated. These are the *fit* of space requirements to societal and industrial needs, and the rhythm of innovation. As it was suggested above, in the first phase of ESA programs, the potentiality of spin-offs at a technological level was related to specific requirements of space activities which by chance could have coincided with some more general needs (e.g., miniaturization). The problem is that at present, these needs are generalized in society and other sectors are ahead of space activities in providing answers (consumer electronics, information technologies). A first question is then: are there some new requirements in space activities that could meet some emerging requirements of industry and society as a whole?

In this respect, some examples clearly show that where this type of *fitting* still exists, the combination of different types of knowledge (scientific and technological) for space applications makes firms able to proceed very successfully.[7]

The other trend affecting the potential for spin-offs is the dramatic speed of the innovation cycle in industry in general: when technological development is very rapid, the spin-in/spin-off process becomes very time-consuming. This may also explain the increasing importance of short loop at product level because it is faster. For instance, in microgravity experimentation, time to experiment (especially if there are delays, or not enough continuity), interpret the results and transfer is sometimes too long compared to parallel terrestrial development. And it makes new answers to traditional space requirements possible. For instance, many firms claim that, in order to optimize the reliability of components or sub-systems, instead of developing something new specifically for space use (which was the *old answer* in earlier stages of space programs, since no other solution was available), it is now possible to use *older generation* terrestrial products, which have proved to be reliable. Furthermore, some firms also claim that space technologies are really not at the cutting-edge of technological progress anymore. Then a second question arises: how is it possible to make the *innovation cycle* of ESA programs be in phase with the *innovation cycles* of the non-space sectors?

The key point behind these two questions is obviously the connection of the ESA innovation process to the innovation processes of the commercial space sectors and of the non-space sectors. When ESA programs were in some way *apart*, there was enough time to import scientific and technological knowledge and turn them into technologies interesting for industry and society. But when on the one hand the non-space sectors are increasingly able to innovate continuously, quickly and in an adaptable way to societal needs, and on the other hand space markets are developing at their own pace, this connection becomes more and more crucial. This is not only true at a technological level, but there is also the question of sharing some qualification procedures, for instance in quality management, electronics, medicine, etc.

Facing this situation, it seems that firms involved in ESA programs have two winning strategies and a loosing one:

(i) To concentrate on space activities, and try to couple ESA programs and space markets which together may form a profitable business. Many space divisions of big firms are doing this, neglecting more and more spin-off opportunities as not really worthwhile (or for very small) specialized space services companies.
(ii) To develop from the very beginning *dual* knowledge, that is, knowledge (scientific or technological or product-embodied) that can be exploited in space and non-space activities. This strategy requires a capacity to forecast future needs of potential users. This is clearly the strategy of most successful firms in terms of spin-offs.
(iii) To keep on trying to develop technologies or products with only ESA space requirements in mind, and later on (for instance when ESA activities are declining in the corresponding field of activities), trying to find possible *terrestrial* applications, with very few chances of success.

The capacity of a given firm to successfully implement strategy (ii) (and the scarce cases of success of strategy (iii)) not only depends on its ability to build up a common knowledge base between space activities and non-space activities (scope or variety of scientific and technological competences, teams of open-minded engineers with multidisciplinary culture and experience at scientific and technological levels). Two other sets of factors appear to have growing importance. The first corresponds to the necessary knowledge about non-space markets. It is not only a matter of identifying potential uses for products or services derived from technology transfers which is problematic, but it seems to be the knowledge of how the markets are operating, of the formulation of an adequate pricing strategy, of the channels of distribution, of the relevant and leading prescriptors, and of the norms and legal aspects.[8]

Factors related to the specific competences required to manage the process of technology transfer were also emphasized by firms recently interviewed. Knowing the right partners for the different aspects of the transfers (from manufacturers to distributors), knowing how to cooperate with them (contractual arrangements, IPR problems…), knowing where and how to get funds, etc. seems to be crucial. This is particularly true as technology transfer is not only a matter of transmitting information from firm A to firm B (as the *technology broker* approach suggests), but a process of creation and adaptation of knowledge and networks. In some technological fields, there are examples of networks based on common and stable rules set up by scientists and industrialists which successfully combine research and commercial exploitation adapted to market needs. Conversely, the only receiver is sometimes a well-established firm with existing products in competition with the ones potentially derivable from technology transfers. This firm may *freeze* the technology transferred by buying it and promoting it only when existing products are on the decline or if the new product is significantly more profitable than the existing one.[9]

Network spin-offs: The lock-in problem

The network effect corresponds to the positive results of involvement in ESA programs that benefit participants beyond the ESA program itself. Participants may keep on collaborating with some of their ESA partners, or they may form an alliance with a firm or a lab due to the ESA program. This type of cooperation within ESA programs may be of a different nature from the one beyond the program (for instance, cooperation in research on behalf of ESA programs and commercial cooperation afterwards). Clearly we are in the domain of knowledge transfer (knowing who

Table II
Network effects

1960's-early 1980s	1980s-mid 1990s	end 1990s-?
• network built-up • space: leader in European cooperation	• ESA network = space club • space: not the leader anymore (EU, EUREKA, Airbus)	• willingness to renew ESA network (SMEs) • globalized R&D and industry
high level of network effects	**low level of network effects**	**high level of network effects for specific newcomers?**

is doing what, and knowing how to exploit this knowledge), but at the frontier of what is called technology transfer. This is why we will pinpoint the key points of the evolution of this type of effect (also because it is a piece of the puzzle for understanding the general evolution of spin-offs from ESA programs).

Between the BETA 1980 and BETA 1988 studies, the figures clearly showed that these network effects decreased. As it is summarized in Table II, the first study showed that the large network effects at an early stage were explained by the influence of ESA programs on the construction of the highly cooperative European industrial and research capacity, amplified by the fact that ESA was one of the only large public cooperative R&D programs at European level. This was particularly true for big firms and small university labs. The second study revealed the characteristics of a second period in which, roughly speaking, space networks had turned to space *clubs*. European cooperation increased within the club, but the club tends to become progressively isolated from its environment. As every participant knows almost all the others, there is no supplementary network effect from ESA programs, except for the very few newcomers. Another explanatory factor of the decrease of network effects is the emergence and maturity of other large public cooperative programs (EU framework programs, Eureka initiative, Airbus, and the military programs) which are additional triggers for networking at the European level. Nevertheless, links created sometimes years ago thanks to ESA were still being strengthened and finding exploitation in space commercial activities, especially at the system level.

In a more recent period, the risks of facing *locked-in space clubs* has encouraged ESA to invite new insiders (in parallel with the phenomenon of spin-in at the product level) to renew the network of potential ESA contractors. But the general environment has also changed, with an increasing globalization of industrial and R&D activity, partly driven by public R&D policies more and more oriented towards the promotion of cooperation, collaboration and networks. Thus it is more difficult to find firms with high technological potential that would not be connected to one or the other existing industrial or R&D networks, and for which ESA programs would still play a networking role. In this perspective, the potential interested population of firms could be newly established firms, and more generally SMEs from outside the high-tech sectors.[10]

Organization, methods and process management spin-offs: In search of the best of both worlds

Another clear evolution from the first BETA study to the second was the dramatic decrease in what was called Organization and Method indirect effects. These effects concern the different methods and ways of organizing research, conception, development and industrial processes that are learned through ESA programs and re-used by the participants in other contexts.[11] They all deal with the ability to organize and manage processes. Here again as illustrated in Table III, it is interesting to consider a dynamic analysis taking into account the general evolution of industrial practices.

There is strong evidence that, in the first period of ESA and space programs, space activities were at the leading-edge of progress in that field (notably by importing knowledge from

Table III
Organization and methods effects

1960's-end 1970s	1980s-early 1990s	mid 1990s-?
• ESA/space: leader in process management (project management, quality control, design view)	• Gap between ESA/Agency and commercial space • space: not the leader anymore (automotive industry)	• necessity of coherence between ESA and commercial space • adaptation of commercial space to industrial standard • space: model for small complex collaborative projects?
high level of O&M effects	**low level of O&M effects**	**new type of O&M effects?**

defense-related activities, another aspect of the spin-in process mentioned above). Despite being much more oriented towards project and prototype development than towards mass production, *space methods* were sufficiently ahead to be used out of the *space context* in conception activities (design review), in other big projects (specifications for hierarchically-organized consortia), in production activities (quality control methods), in day-to-day management (informal skills), in any project (PERT methods). It means that they were particularly adapted for project-type activity, and sometimes also fulfilled the needs for better codifying the management of mass production processes.

In the second phase, space firms have already learned and there were only a few new firms involved. But in parallel, other sectors (automotive and consumer electronics in particular) have dramatically improved their capacity to manage the processes. The space sector has not been the leader in the evolution of quality management systems towards quality assurance, ISO 9000-type certification and Total Quality Management, nor is it in just-in-time and lean production systems, new Cost and Value management (activity-based-management, added-value chain perspective, etc.), process reingineering, concurrent or *overlap* engineering and so on. In other words, mass production industries have been able to turn to smaller series and flexibility of answers to the changes in demand or market conditions, while keeping some advantages of the *old* industrial system (reliability and cost control). At the other extreme, large public space programs (smallest series possible -prototype- and best adaptation to *clients* who themselves define the product they want) have not really been able to respond in a similar manner.

This phenomenon was particularly prevalent during the 1980's, when one of the most important barriers to transfer space knowledge to *terrestrial* products was the lack of ability of space firms to switch from costly prototype performance-optimizing to cheap larger series cost-optimizing ways (see, Bach *et al*., 1992). At that time, it seemed that both spin-in and spin-off roads were cut.

As Table III illustrates, more recently (which leads us to assume the existence of a possible third period), the space industry has increasingly tried to learn from methods and organization principles used in other sectors (Ariane commercial series is a case in point), while these latter sectors keep on innovating very fast (for instance, through the possibilities opened by new information systems). Thus a spin-in process is observable, even if it is mainly true for commercial space activities.[12] But what about methods used in large public programs? Some recently interviewed firms gave contrasting answers: some seemed to learn a lot from their involvement in ESA programs (especially in terms of collaborating in small complex projects, in terms of ability to contract with other partners (specifications, scheduling and risk forecasting) and in terms of quality management; some others considered space programs as *exotic* when compared to standard industrial methods (lack of flexibility of the projects, bureaucracy, costly way of working). The fact that the first category of firms were mainly new firms (whereas the second were mainly rather well-established firms) suggests that some progress has to occur, hoping that the former firms will not only learn what is considered by the latter ones as *bad industrial habits* preventing them from later diversifying even towards space commercial markets.[13]

To conclude on this point, it may be that the two potential sources of spin-offs related to methods, organization and process management are insufficiently exploited at present and would be promising for the future. There is a general trend in the industry towards organizing activities as projects, coupled with a process-oriented thinking. Is (or would) it be possible for other sectors to be inspired by methods or principles developed from space programs? The question is open, but some very big European firms tend to claim that small highly cooperative international research projects, with limited budgets, objectives well defined in advance (such as microgravity experiments), and interaction with scientists, are a source of method learning for other non-space projects of the same type. Another potential source, although more hypothetical, could be the organizational devices and management tools that will be used to couple a large, public international and long-term oriented project of infrastructure (International Space Station is the best example) with small, mainly private and short term projects of infrastructure utilization. Some ways have already been tried with previous space facilities (shuttle with spacelab for instance, but on a smaller scale), and it raises a number of management problems. This could constitute a basis for a new model for the organization of large public–private R&D programs, and also for training firms to work in even more complex situations with public–private interactions, long term and short term perspectives, sharing of resources, and international relationships.

3. The determinants of technology transfers: A transversal analysis of space and other sectors

In this third part, we discuss the distinctive features of space programs in terms of technological transfers. Space projects belong to a broader class of programs which will be referred to as *mission-oriented* (see Ergas, 1987). They aim at reaching well-defined targets and they are usually organized in a hierarchical fashion. For sake of comparison, we also consider the EC Brite-Euram and Esprit/HPCN programs, which are typical instances of *diffusion-oriented* projects as defined by Ergas. Comparing the patterns of technology transfers in the ESA Space program and the EC programs (and especially Brite-Euram program) will be useful in order to identify those conditions which enhance the opportunity of technology transfers in *mission-* and *diffusion-oriented* programs. We will also refine our analysis by considering the German project on Magnetic Levitation (Maglev) trains. It resembles mission-oriented programs as it is aimed at producing a given output, namely a vehicle being able to compete with air transport for distances ranging from 300 to 500 km. However, the Maglev project also possesses elements of diffusion-oriented programs. Indeed, the precise characteristics of the target output were not defined *ex ante* but only revealed through a learning process which was driven by the *exploration* of various technological solutions.[14] The present analysis is essentially a qualitative one, and it results from a synthesis of results obtained at BETA on the several cases. First, the emphasis is put on the fact that technological and competence *diversity*, both within the network of participants and between sectors, strongly influences the importance and the nature of technology transfers. Second, we argue that technology transfers are affected by the way the *network of participants* is organized, which is itself influenced by the nature of the program: mission oriented programs call for vertically structured networks, while diffusion oriented ones favor less hierarchical networks. Finally, the role of the *internal characteristics* of firms as a determinant of technology transfers is put forward.

These elements are presented as three factors that shape the potential of R&D programs to generate technology transfers.

First factor: Technology and competence diversity

When bridging the concepts of diversity and technological transfers, one has to account for the fact that diversity, concerning either technologies or firms' competencies, may be present at different levels. On the one hand, the level of diversity prevailing between firms that participate in an R&D program is a key determinant of technology transfers that occur within the network of participants. On the other hand, the possibility of external transfers depends on the proximity between the requirements of the relevant sectors.

We present the way diversity influences transfers within the participants network and then turn to its role as to external transfers.

Diversity and transfers between program participants. Mission oriented programs such as the ESA space program could be considered as being demand *pulled*: they call for the integration of *advanced* technologies, with a given goal (for instance, the building of a given piece of space infrastructure). Advanced technologies are technologies generally located at the state-of-the-art frontier. There is no radical uncertainty as to the possibility of producing these technologies: they exist either on the shelves of laboratories, or in the form of prototypes, or through production on a small-scale basis. The actual novelty resulting from the mission-oriented programs is much more on the integration process than on the novelty of each individual technology that is involved. Most often, these programs require a rich and specific integration process from which new ideas, new industrial solutions and new combinations of technological principles will emerge.

As was shown in space and material studies, a condition for recombination to yield *significant* results is that technologies that are carried by the participants to the program exhibit a sufficient level of diversity. From a theoretical point of view, this can be explained by the fact that increasing diversity broadens the scope of exploration, i.e. the set of technological opportunities that can be reached through a combination of existing knowledge.[15]

Besides its obvious consequences in terms of *static* analysis, this argument has crucial consequences on the dynamics of knowledge creation. Studies quoted in the first section show that over time, many spin-ins from space programs tend to be followed by spin-offs. This is related to the idea that the inflow of new technologies and competencies is a prerequisite for persistent knowledge creation. In turn, this wave of novelty may significantly enhance the different individual technologies that were called for integration in the programs. The programs contribute to push the technologies from their prototype level to a more mature industrial level.

While technological and competence diversity is a key determinant of innovation in the space sector, the picture is less clear where technology transfers are concerned. Indeed, transfers occurring between participants show a great correlation between the activity stimulated by the research program and the core activity of participating firms. We could observe that technological and organizational competencies generated by the European space program were exploited by firms whose core activities were close to the one developed in the program. This stems from the fact that technology transfers require firms to possess absorptive capabilities. In most cases, the latter are related to the firms' core activities.

Firms endowed with the *right* competencies are able to process the knowledge acquired while participating in a research program. They are also able to identify those developments that are more likely to fit into the existing organization. Accordingly, we observed that when many such firms are participating in a program, there is a high risk for some technological opportunities to be abandoned because they are perceived negatively. This may be harmful from a dynamic point of view, since technologies that show few qualities while in the immature stage, might reveal their performances over time (on this point, see Cowan, 1991). To put it differently, dynamic efficiency might call for the preservation of options as soon as some uncertainty prevails concerning technologies or their potential markets (see Weitzman, 1992).

The fact that some firms possess high absorptive capabilities yields another risk with respect to other participants in the program. Indeed, a firm endowed with high capabilities may be able to reap other firms' competencies. As we will see in the next section, this risk is related to the relative size of participating firms and to their role in the research network.

Diversity and transfers to other sectors. Technological and competence diversity is a crucial determinant of technology transfers to other sectors. Indeed, BETA studies show that technology transfers from European space programs mainly occur in sectors whose requirements are close to the ones developed in the space sector.[16] More generally, one can establish that generic technologies or competencies developed in the space sector are more likely to be transferred to other sectors than specific ones. It is precisely from those space programs that anticipated or shared some common technological requirements with terrestrial applications that significant spin-offs have emerged. On the contrary, when very specific technological developments are at stake within a given program (for instance, propulsion in space projects), the potential for spin-offs appears very limited. This appears to be the case for the German Maglev program, which has generated very few spin-offs.

Comparison with diffusion-oriented programs. Diversity plays a different role when one considers diffusion-oriented programs (e.g. Brite-Euram). Such programs aim at pushing the state-of-the-art technological frontier in order to find relevant and promising industrial applications for innovations. The final goal of the research is not known in advance, which is a major difference with mission-oriented programs. Thus, the potential for spin-offs will not lie in the integration of different fields of technologies, but rather on the diversity of research tasks over a scale ranging from fundamental research to industrialization within a given technological field.

It turns out that, although the mechanisms at stake are different, technology transfers stemming from mission- and diffusion-oriented programs show the same kind of sensitivity to technological diversity at both levels explained above. For instance, with respect to diversity among participants, studies about EC programs have clearly showed that projects including a diversity of research tasks over a scale ranging from fundamental research to industrial work generate more technology transfers than those with narrower scope. They also showed the importance of the participation in each project of at least one partner involved in fundamental research work: this type of research was likely to be a key element in the process by which diversity leads to technology transfers. As to the respective roles of generic and specific technologies, the results provided another piece of understanding. Generic technologies (such as the ones related to automation, information systems or bonding, shaping and forming structural materials) supported the largest number of technology transfers observed, but were only minor in terms of economic value, while specific technologies (such as the ones related to functional materials, textile or food processing) supported few transfers of great economic value. It also seemed that generic technologies diffused quickly and rapidly reached most of the personnel involved in the R&D project, but needed a very long time to eventually generate large economic profits, whereas the specific technologies generally supported the creation of new markets with rapid and profitable returns.

Second factor: Nature of the R&D network

Mission- and diffusion-oriented programs can be associated with different types of research networks. We argue that these differences have deep consequences as to the way technology transfers are generated and can be stimulated. Some key results emerge from the different studies that have been carried out.

Vertical vs horizontal networks. First, the nature of the network of participants matters. In short, two extreme types of networks can be envisaged. On the one hand, mission-oriented programs are characterized by hierarchical networks, with different well-defined levels of responsibility (prime contractor, system and sub-system integrators, equipment suppliers, service providers, etc). On the other hand, diffusion-oriented programs give rise to horizontally shaped networks (generally one coordinator in relation with the public authorities and *standard* contractors at the same level). Differences concerning the types of targets are useful elements for understanding the existence of these shapes of networks. In space programs, reaching a specified goal calls for the coordination of research activities that must fit into a given scheme. Since the requirements of the space sector are well defined, an efficient way to achieve coordination is to promote the delegation of activities between participants. Core-competencies of the firms are the main criterion for the way delegation is achieved. For instance, big firms who are used to dealing with the management of complex projects lie at the *top* of the research network (e.g. as system integrators), while SMEs which are endowed with knowledge on specific fields are usually located at the *bottom* of the research network. Hierarchical location can also be driven by the fact that some firms are endowed with a key technology. For instance in the German Maglev case, the fact that Thyssen-Henschel is leading the Transrapid consortium, is related to its mastering of the levitation/traction technology (linear-long stator engine).

The picture is appreciably different in programs aiming at finding industrial applications for innovations (e.g. Brite-Euram). Here, participants' competencies are not assembled in a hierarchical fashion, but rather combined in order to foster the emergence of technological and competence diversity.

Since learning processes obviously depend on the hierarchical position of participants within the network, we could expect the subsequent transfer mechanisms to do so. This is indeed the case. BETA studies on the space sector have revealed how prime contractors tend to concentrate their learning activities on methods and collective coordinating rules that, once assimilated and tested, could be transferred to other domains. Further, these studies have shown that system integrators, equipment suppliers, and service providers, although participating in the same program, have experienced specific learning trajectories depending on their position on the network. System integrators acquired consequent knowledge on new technologies and were able to enhance the supply of existing products. Equipment suppliers were given access to international markets thanks to network effects and finally, service providers essentially benefited from reputation effects.

In BETA studies on EC programs, it appears that the specific role of coordinator was much more of an administrative type than a key role in the development of technological knowledge and in the ability to organize and manage complex R&D networks in order to make them reach the technical objectives of the projects. In fact, the actual role of coordinator and its influence greatly vary from one project to the other, and so do the results obtained by coordinators in terms of technology transfers. The only common feature seems to be the *bureaucracy* burden, which explains two phenomena: SMEs have dramatic difficulties in generating technology transfers when they are coordinators, and there is an emerging tendency to give the coordinator role to consulting firms specialized in "interfacing with Bruxelles". The difference with mission-oriented programs probably is fundamental in this respect: here the coordination competence is not necessarily coupled with the technological competences.

Absorptive capacities vs. upstream or downstream transfers. Second, some conclusions can be drawn concerning the relationship between firms' absorptive capabilities and spin-offs in the different types of networks. In vertically structured networks, absorptive capabilities shape the existence of upstream and downstream transfers between participants. Contractors, which are required to meet technical or organizational specifications determined at higher hierarchical levels, usually succeed in transferring such knowledge into their body of competence. Therefore we argue that downstream transfers are a natural outcome of mission-oriented programs. Conversely, studies of the ESA projects show that upstream transfers take place provided the candidate knowledge fits into the core-competencies of the upstream firms. Such transfers actually strengthen the initial core-competence of the upstream firm. When a project requires specific tasks to be achieved that are not in the domain of the core-competencies of the firm, two different situations may arise.

In some cases, the project can provide an opportunity for the firms to build a new core-competence to be used in other application domains. In space projects, firms could indeed benefit from the formation of a critical mass of internal expertise. This was shown to be the case for the most important examples of transfers that have been observed. In other cases, firms agreed to perform tasks that were not in their core-domain (which remained unchanged). Thus, the acquired knowledge tends to be externalized through a spin-off mechanism: the firm has no incentive to keep the new technological knowledge internally. This result can be ameliorated by providing incentives to signal potential transfers to external partners.

While comparing mission- and diffusion-oriented programs, a general observation is that SMEs tend to learn from big firms within mission-oriented programs, while their limited absorbing capabilities prevent them from fully exploiting their participation in diffusion-oriented programs. SMEs may experience significant transfers from mission-oriented programs, but participating in such programs also entails some risks. Big firms located upstream in the hierarchy usually possess higher absorptive capabilities and therefore may be able to catch the core-competencies embodied by smaller firms. Note that to some extent, this issue remains relevant in diffusion-oriented projects, when firms are not able to protect themselves through the use of industrial property. Here, asymmetries between participants in terms of absorptive capabilities are due to their roles in the market (e.g. user or producer) rather than to their mere *location* in the R&D network. We argue that such asymmetries are less systematic than the hierarchical ones, as is the risk of small firms being *taken-over* by bigger ones. The example of EC programs shows that the importance of technology transfers generated by collaborative consortia varied positively with the variety of roles in the projects (producers, researchers, users), but the capacity of specific partners to *capture* the economic value of the technology transfers depends on the asymmetries of the role (integrated user and producer in Brite-Euram studies, producers only in ESPRIT/HPCN for instance).

Codification of knowledge. The collective construction of new knowledge within the network is one of the main determinants of the diffusion of innovative ideas. Moreover the capacity of each participant to absorb from, exchange with and diffuse knowledge to the other members of the network strongly matters. Codification makes absorption of knowledge much easier and therefore strongly influences the opportunities for technological transfers. But codification also has serious drawbacks as to the creation of knowledge. First, codification is often perceived as a constraint that inhibits creativity within organizations. Along this line, codification procedures are becoming increasingly time-consuming as the requirements of the space sector become more and more precise. This might be a reason why some firms become reluctant to participate in space programs. Moreover, it is a possible explanation for the fact that innovations in the space sector are more and more *conventional* compared to the ones developed in terrestrial sectors.

Second, we suggested that big firms tend to internalize knowledge developed by downstream firms. Codification makes absorption of knowledge easier and therefore the risk for small firms to be *absorbed* increases with codification. Accordingly, small firms might be tempted to limit the scope of knowledge codification in order to protect themselves.

Codification has an ambiguous influence on mission-oriented programs. On the one hand, efficiency of coordination calls for a sufficient level of knowledge codification. On the other hand, excess codification tends to impede creation of new knowledge. This pattern appears in mission-oriented as well as in diffusion-oriented programs, but it is more dramatic in the former. Since the target is well defined and the research network is hierarchical, such programs have a higher propensity for excess codification. It must also be emphasized that diffusion-oriented programs very often are publicly subsidized (as is the case with EC R&TD programs). The public authorities have no way of *controlling* the work performed and the results achieved except by getting extensive reports from the subsidized firms. This type of codification for control purposes in diffusion-oriented programs is different from the codification for coordination purposes required in mission-oriented programs (even if managers of firms often refer to the *bureaucracy* for both types of codification), and the consequences on technology transfer may be of a different nature.

Trust between participants. Last, the diffusion of knowledge within R&D networks highly depends on the degree of trust between participants. A low degree of trust will limit the exchange between members to the pure adaptation to the prescription of tasks required to achieve the project, and most probably will entail a low potential for technological transfer. Conversely, a high degree of trust generally translates into the building of an active cooperating network where each partner can explore its domain of specialization more in-depth. With a high degree of confidence, complementary forms of knowledge needs can be provided by partners in the network.

Beyond its direct effects, trust also plays an indirect role, since it influences codification of knowledge as well as the use of IPPM.

Third factor: Internal organizations of participants

A key factor in the generation of technological transfer is the way firms are internally structured to produce and circulate new knowledge. Technological transfers often occur through the circulation of competencies within the organization. Accordingly, hierarchical types of organizations, including multi-divisional structures, can be considered as obstacles to technological transfers. They prevent the formation of cross-fertilization processes between different departments, and create strong barriers to the circulation and expansion of new knowledge. In such organizations, one might expect departments to suffer a *locked-in* competence, for they are not subject to constant inflow of new knowledge.

Matrix or internal network types of organizations tend to favor, accelerate and enrich the process of diffusion of innovation. The existence of a department in charge of promoting technological transfer could be helpful, but more important are a general attitude and openness vis-à-vis the circulation of knowledge, and a clear strategic commitment of the top management to generate transfers. To this respect, the results from studies on EC programs are fully consistent with the ones from studies on space activities mentioned above.

However, one should be careful when linking technological transfers to organizational structures of participants. Actually, the ways firms organize the circulation of employees and other modes of socialization between departments and the importance given to systematic training activities are also factors that contribute to triggering technological transfers. The former is of particular interest, as it is a source of diversity at the internal level of the organization.

Conclusion

The lessons learned from the ESA studies on technological transfers, and their comparison with other studies such as the Brite-Euram program, highlight the role of three main variables in explaining the nature and the intensity of the technological transfers that result from a given program.

The technological content of the program. The way programs are defined with respect to the technologies involved will strongly influence the path of future technological transfers. More precisely, the following characteristics of technologies are particularly important: i) the diversity of the technologies, ii) their degree of maturity, and iii) the extent to which they are generic or specific. A very general rule is thus the following: a program that has to integrate a very diverse range of emerging and generic technologies will have high potential for technological transfer.

In terms of diversity, the main nuance that has been proposed to encapsulate different patterns of technological contents is to distinguish between two extreme forms: *mission-oriented* programs and *diffusion-oriented* programs.

In terms of maturity, the earlier the degree of maturity of the technologies at the beginning of the programs, the higher their potential of technological transfer. One of the problems related to this issue is the fact that, in general, space programs are long-term and often last more than five or sometimes ten years. Since the technological content of a mission-oriented program is by definition fixed over the duration of a project, an emerging technology at the beginning of a project could become mature at the end of it. In terms of technological transfers, this property signifies that most of the potentials for spin-offs will concentrate during the very first years of a project. It also means that when considering sequential space projects that are articulated over time, if the new generation of space projects do not incorporate new technological challenges and new forms of technological integration, the potential for spin-offs may dramatically decrease over time.

Finally the extent to which a technology is generic or specific (to the space sector for instance) is important. The potential for technological transfer depends significantly on the generic aspects of the technologies. It is along the directions in which space programs anticipated or shared some common technological requirements with terrestrial applications (needs for miniaturization, monitoring of complex networks of telecommunications, etc.) that significant spin-offs have emerged. On the contrary, when very specific technological developments are at stake within a given program (for instance, propulsion in space projects), the potential for spin-offs appears very limited.

The nature of the network of participants to the program. The interactions between the participants to a given program dramatically shape the resulting paths of technological transfer. The way participants exchange information and knowledge, the choice of their coordinating devices, and the mutual degree of trust within their network influence to a large extent the intensity of technological transfers from the program. It has been emphasized that the collective construction of new knowledge within the network is one of the main determinants of the diffusion of innovative ideas and principles from a project. It permits the acceleration of the validation and testing process of the novelty, and the discovery of new fields of applications. This process requires each participant to have a critical level of absorbing capacity in order to be responsive to the knowledge that circulates within the network, and a minimal capacity to analyze, interpret and transmit the new knowledge. The pace of the technological transfer process will thus depend on the *cognitive* ability of each participant.

The internal structure of organization of participants. The properties of the organizational structure of each contractor in a space project (existence of vertical links, degree of decentralization of decision making, specific incentives to favor technological transfer) condition the stimulation of new ideas by cross-fertilization between the various fields of activity of the firm. The flexibility of the contractor to modify its organization to cope with new technical features is also crucial. For a transfer to be successful, the organization must be adapted to more commercial features in terms of quantity, price and timing, so as to be able to move its expertise from complex products to production programs. This often results in a shift from an aim of maximizing the technical performance characteristics of a product to one of holding down costs.

These three variables constitute the main *ingredients* that condition the nature and intensity of the process of technological transfer that may emerge from a given program. Technological transfer is, at the beginning of a project, a process that contains a strong uncertainty that can not be predicted. However, based on lessons learned, one can suggest that a way for a public policy maker to design a program with a high potential of technological transfer is to choose an appropriate procurement policy. The procurement policy will help select the participants to a given program, define the role and the place of each participant within the industrial network in charge of the project, and spell out the types of risks to be borne respectively by the participants and by the agency. It may incorporate specific incentive mechanisms to favor technological transfer, as well as some specific rules to favor some types of *virtuous* learning processes (for example, the Defense Department has implemented a so called *mentor–protegee* rule to encourage the learning process by SMEs from big firms in a given mission-oriented program). It is probable that, in the near future, most of the classical rules of procurement policy followed by space agencies will be significantly revisited to promote the highest potential for technological transfer from space programs along some of the main directions that have been highlighted in the above developments.

Notes

1. Bureau d'Économie Théorique et Appliquée, Université Louis Pasteur, Strasbourg, France.

2. BETA has carried out different studies about the spin-offs from space programs, especially ESA programs, some were about the so-called indirect effects from all ESA programs (BETA, 1980, BETA, 1988, BETA/HEC, 1989 and BETA/HEC, 1994 (for the unique case of Canada)); some investigated the narrower question of technology transfers from all ESA programs (BETA, 1979, BETA, 1989); while some others were more focused on analysis of technology transfer cases from specific public space programs, namely those related to life science (BETA, 1997), and manned space flight and microgravity experiments (BETA/NOVESPACE, 2000). All studies were based on a micro-economic approach at firm or research lab level, using direct face-to-face interviews with their managers to collect quantitative and qualitative data (since the end of the 70's, more than 250 interviews have been performed all over Europe and Canada). They were sometimes combined with written surveys of the same participants to space programs.

Studies on indirect effects were based on the analysis of large samples of participants to ESA programs, statistically representative of all ESA contractors during the period covered by the studies. Cases of indirect effects were identified and measured in monetary terms at participants' level, and the individual results were then aggregated, keeping the full confidentiality of the information provided by each firm or lab interviewed. Studies on technology transfers performed in the 1980's consisted of a deeper analysis of technology transfer conditions and success/failure factors, adding qualitative investigation to the results from studies on indirect effects.

In the last BETA works, mainly case studies from a limited number of public space programs (ESA or others) were conducted, again combined with a qualitative investigation. Fourteen interviews were carried out for the first one, and 20 for the second (and the latter benefited from the experience of NOVESPACE company in the field of technology transfers). Only qualitative results can be taken from them for confidentiality's sake (and also because the last study is not fully completed).

3. In recent studies performed by BETA (BETA, 1996, NOVESPACE-BETA, 2000), it appears there is a growing concern about using existing *ground* products or elements of products for space purposes, needing only to *space qualify* them. This had already been the case for some electronic components for a long time, and it is also true for instrumentation dedicated to experiments in life or material sciences. In this respect, the obvious economic advantages of spinning-in are that duplication of effort is avoided, costs are lowered, conception and development cycles are shortened, and the leading-edge technologies may be used by the space programs, while the spinning-out is facilitated. But this process is effective if there is an involvement of the non-space specialized firms in the spin-in phase (which means that it is not only a matter of taking a product from the shelf) in order to make it possible to appropriate the modification of the product required for space application and thus to exploit the spin-off result on the basis of its knowledge of the ground sector.

Put differently, it means that if the product is just bought, without involving the non-space firm in the process of *space qualification* and without receiving information in return for the use of the product in space, the non-space firm will not be able to spin-off the technology. Also, if the non-space firm is involved in the process but with inadequate conditions (for instance, if it is forced to work with a big firm which does not have the same constraints in terms of delay and cost), the spin-off has less chances for success.

Different cases in the instrumentation for medical use are particularly significant illustrations of this spin-in/spin-off process at the product level, and some firms even build their strategy on it. This type of spin-in/spin-off process (at the product level) seems to be more and more prevalent, but it is different from the ones identified in earlier stages of space programs.

4. Problems encountered in space programs at technological or product level (especially interface and integration problems) sometimes require solutions at a higher scientific level.

5. In the same vein although not directly similar, some firms interviewed two or three years ago were complaining of the rare direct contact between scientists and industrialists at the time of the design of equipment necessary for the experiments.

6. There are also other types of spin-offs, but stemming from new knowledge acquired in space conditions (microgravity research for instance, without mentioning astrophysics, earth observation and the like).

7. Spin-offs from manned space and microgravity activities (especially medical and material science) may give some hints. For instance, the need for medical diagnoses and tele-surgery, which could have significant impact on tele-medecine; the need to monitor experiments in confined, sterilized and fully controlled environments; the need to model and simulate experimental results; the ergonomics of specific medical instruments to match the problem of scarcity of resources (time, room, information systems, etc.) during space activities. There is a growing need for very fast shared time data acquisition and handling from multiple sources, and for very light, robust, reliable and easy-to-operate experimental devices. This is in line with the growing tendency to use autonomous, reliable and user-friendly designed medical devices for diagnosis and monitoring of patients, sometimes with a capacity of automatic analysis and/or diagnosis (e.g., emergency unit, at-home treatment of patients).

8. This is especially true for the medical sector, when new devices could be derived from space programs. Finding the relevant market is also an important point. SMEs often claim that they have difficulty targeting markets with sufficient added value to be profitable, but not enough value to attract big firms.

9. It is interesting to note that some of the firms that have been successful in developing dual knowledge or simply in transferring space technologies had prior bad experiences caused by their poor knowledge of market conditions and the technology transfer management process (i.e. failures because of unreliable partners, sale of technologies at a "price" largely under its potential commercial value which was later captured by other firms, agreements based on bad IPR assumptions, etc.) Subsequently they learned to control better the process for further technology transfer attempts. For instance, by choosing better partners, by integrating some parts of the process and by improving on some IPR guarantees.

10. Recent interviews carried out by BETA show that for this type of firm, the network effect is an important *added value* to their involvement in ESA programs, but in order to amplify the phenomenon, more finely tuned and *local oriented* procurement policies would be required from ESA.

11. Mainly project management techniques including planning, monitoring and evaluation of human, technical, financial and time resources; design specification and requirements, design reviews, etc; quality management; but also informal knowledge about how to interact with teams from other cultures, how to conduct successful meetings and the like.

12. This is especially true for the medical sector, when new devices could be derived from space programs. Finding the relevant market is also an important point. SMEs often claim that they have difficulty targeting markets with sufficient added value to be profitable, but not enough value to attract big firms.

13. It is interesting to note that some of the firms that have been successful in transferring space technologies had prior bad experiences caused by their poor knowledge of market conditions and the technology transfer management process (i.e. failures because of unreliable partners, sale of technologies at a *price* largely under its potential commercial value which was later captured by other firms, agreements based on bad IPR assumptions, etc.) Subsequently they learned to control better the process for further technology transfer attempts. For instance, by choosing better partners, by integrating some parts of the process and by improving on some IPR guarantees.

14. BETA studies from diffusion-oriented programs:

(1) *EC R&TD programs.* Two European programs which were part of the EC Research and Technology Development Framework Programs were investigated in the 1990's by the BETA group: i) Brite-Euram, which was focused on production and material-related technologies (see BETA, 1993, Bach *et al*., 1995 and also BETA, 1995 for a detailed investigation of the technology transfer from this EC program) and ii) Esprit/HPCN in the field of IT but focused on high performance computing and networking (BETA, 1997). Both programs have the following characteristics: a) they include hundreds of projects of two to 10 Millions Euros; b) their duration was three to four years; c) 3 to 15 (in average five or six) firms and/or labs (university or research centers) from different European countries are collaborating on each project (at least one firm and one lab from two different countries); d) the firms' project costs are at maximum 50% funded by the EC (100% for universities). The EC defines the general topics of research in which it is partly subsidizing R&D projects; then small ad-hoc consortia submit proposals to EC and independent experts who are in charge of the selection process. These R&D projects are supposed to be at a pre-competitive level.

(2) *German program on Magnetic Levitation Trains.* The study on the German program on Magnetic Levitation Trains has been performed by BETA (see Llerena and Schenk, 2001) on behalf of the French Transportation Ministry (PREDIT program).

The magnetic levitation train project started in 1971 as the German Ministry for Research launched its *mission-oriented* funding. At that time, predictions concerning the potential of the Maglev technology were rather accurate. Maglev trains were supposed to be an economic alternative to automobile and air transport for distances ranging from 300 to 500 km. However, precise knowledge about the best way of achieving a Maglev vehicle was not available. Krauss-Maffei pioneered the sector by developing an electro-mechanic (EMS) propelling system (using a short-stator electric engine). This was followed by MBB who developed its own system using the same technology. In 1972, a group formed by AEG, BBC and Siemens launched an alternative technology (electro-dynamic[17]). Finally, in 1974, Thyssen-Henschel and the University of Braunschweig presented a long-stator version of the EMS technology. In 1977, the German Ministry of Research decided to give support to the most recently developed technology.

Preservation of diversity (1971–1977) aimed at acquiring knowledge about the *best way* to produce a Maglev vehicle. This period was followed by a period of continuous improvement of the Thyssen technology. The German Maglev program entailed an overall public funding of about two billion DM.

15. The same goes for the German program on Magnetic Levitation trains (Maglev): the development of the Transrapid technology in the mid-seventies involved participants endowed with competencies in various fields such as electric engines (AEG) or mechanical construction (Krauss-Maffei, MBB). This diversity enabled the exploration of technological opportunities as well as the global level of knowledge.

16. For instance we have seen above that knowledge acquired in the space sector concerning miniaturization or energy saving have been very helpful for the development of terrestrial applications. The same goes for the mastering of quality control procedures or even for the ability of firms to deal with procedures associated with *big* research programs.

References

Autio, E. and T. Laamanen, 1995, 'Measurement and Evaluation of Technology Transfer: Review of Technology Transfer Mechanisms and Indicators', *International Journal of Technology Management* **10** (7: 8).

Bach, L., P. Cohendet, G. Lambert, M.J. Ledoux, 1992, 'Measuring and Managing Spinoffs: The Case of the Spinoffs Generated by ESA Programmes', in H.R. Hertzfeld and J. Greenberg (eds.), *Economics of Space Activity,* Washington: AIAA.

Bach, L., N. Condé-Molist, M.J. Ledoux, M. Matt, and V. Schaeffer, 1995, 'Evaluation of the Economic Effects of Brite-Euram Programmes on the European Industry', *Scientometrics* **34** (3), 325–349.

BETA, 1997, *Pilot Economic Evaluation of Esprit HPCN Results*, Final Report for EC DG III-F1, January.

BETA, 1996, *Transfert de technologie entre l'espace et les sciences de la vie en Europe*, Final Report for the European Space Agency, Paris.

BETA, 1995, *Technological Transfers in BRITE-EURAM*, Final Report for EC DG XII–C, May.

BETA, 1993, *Economic Evaluation of the Effects of the Brite-EuRam Programmes on the European Industry*, Final Report for EC DG XII, H4 Evaluation Unit, January.

BETA, 1989, *Analyse des mécanismes de transfert de technologies spatiales: le rôle de l'Agence Spatiale Européenne*, rapport final pour l'Agence Spatiale Européenne, (summary in English), Juin.

BETA, 1988, *Study of the Economic Effects of European Space Expenditure*, Results Vol. 1 and *Report on Investigation Theory and Methodology*, Vol. 2, Reports for the European Space Agency.

BETA, 1980, *Economic Benefits from ESA Contracts*, Final Reports for the European Space Agency, June.

BETA, 1979, *Innovations and Technology Transfers: The Role of ESA*, Final Report for the European Space Agency.

BETA/HEC Montréal, 1994, *Les effets économiques indirects des contrats de l'ASE sur l'économie canadienne – deuxième étude*, rapport pour l'Agence Spatiale Canadienne, Mai.

BETA/HEC Montréal, 1989, *The Indirect Economic Effects of ESA Contracts on the Canadian Economy*, Final Report for the Canadian Space Agency.

BETA/NOVESPACE, 2000, *Study on Transfers of Technology and Spin-offs Realised in Framework of Space Station and Microgravity Programmes*, Draft Final Report for the European Space Agency, unreleased.

Cowan, R., 1991, 'Tortoises and Hares: Choice Among Technologies of Unknown Merit', Economic Journal **101**, 801–814.

Ergas, H., 1987, 'The Importance of Technology Policy', in P. Stoneman and P. Dasgupta (eds.), *Economic Policy and Technological Performance*, Cambridge: Cambridge University Press.

M. Giget, R. Villain, and S. Bellin, 1996, *Les retombées et effets d'entraînement des technologies spatiales, Mythes et réalités*, Ministère délégué à la Poste, aux télécommunications et à l'Espace, Paris.

Hertzfeld H.R., 1992, 'Measuring Returns to Space Research and Development', in J. Greenberg and H. Hertzfeld (eds.), *Space Economics*, *Progress in Astronautics and Aeronautics*, Vol 144, New York: AIAA

ISU, 1997, *Technology Transfer: Bridging Space and Society*, Report of the design project of the ISU summer session students.

Lebeau, A., 1998, *L' Espace: les enjeux et les mythes*, Paris: Hachette.

Llerena, P. and E. Schenk, 2001, *Choix d'invest issements dans les projects de rupture technologique: etude du cas allemand,* Rapport final pour le contrat Predit, BETA: Strasbourg.

Weitzman, M.L., 1992, 'On diversity', *Quarterly Journal of Economics* **107** (2), 363–405.