The public and private spheres of knowledge within the field of space communications

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Abstract

The purpose of this paper is to examine the modalities of the organization of R&D activities between the main institutional sectors (higher-education, government, industry) within the field of space communications in the Triad countries. The analysis of these modalities is complex since the delimitations of the public and private spheres of R&D activities are liable to change depending on whether the funding, the production or the utilization of knowledge is considered. To that end, we show that the principle of an institutional diversity associated with the organisation of R&D activities between these sectors can in fact be questioned. Indeed, the specific logics and pratices of the main institutional sectors become rather interlinked. Implications of this "institutional overlapping" on the dynamic of R&D activities in the field are discussed.

Keywords : space communications, knowledge production, division of labor, allocation of resources, knowledge diffusion

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INTRODUCTION

Market failures and incentive structures in the production of knowledge

Knowledge as an economic good has particular properties that distinguish it from conventional goods. First, knowledge is a non-excluable good because it is difficult for its producer to control its ownership, i.e. to exclude other agents from its use without any compensation. Secondly, knowledge is a non-rival good because its use by an additional agent does not mean that an additional unit of it must be produced. Conversely, a traditional good is characterized by a physical rivalry between agents from the moment that a simultaneous use of it is required (David, 1993; Foray, 2000). Lastly, knowledge is a cumulative good insofar as it constitutes the main input of the process of knowledge production (Scotchmer, 1991). Therefore, knowledge can be described as a cumulative public good. This implies that its generation constitutes a major source "non pecuniary" positive externalities. In this respect, it has usually strong social returns and sub-consequently must be supported. But its implementation remains problematic because these positive externalities pose serious problems of resource allocation in a decentralized economy (Arrow, 1962). In deed there is no incentive for a private producer to produce new knowledge inasmuch as it is difficult to make its results exclusive. This paradoxical situation is generally qualified as the "knowledge dilemma" (Foray, op. cit.), i.e. the need to foster the broad dissemination of knowledge through the economy in order to maximize the value of positive externalities and the prerequisite to provide incentives to the private producer so as to he undertakes to produce new knowledge.

Three generic institutional mechanisms have been imagined in order to support the production of knowledge in presence of market failures and positive externalities leading to an insufficient and inefficient allocation of resources devoted to R&D[2]. These institutional mechanisms clearly derived from the ones identified by Pigou (1932) for the general provision of public goods and are refered by David (1993) in the framework of the economics of knowledge as the three P's, i.e. Patronage, Procurement and Property. The Patronage system characterizes the provision of funding by the society to institutions engaged in the process of knowledge generation. The compensation of this public support to the production of knowledge is the requirement of the full public disclosure of the knowledge created. However, this does not mean the non-existence of any reward. Indeed, the "priority rule" rewards the first producer how publishes its research and thus create incentives to the creation of knowledge through non-market mechanisms (Dasgupta & David, 1994). The Procurement system is combined with the engagement of the government into the production of knowledge through contract with mission-oriented agencies or firms. The public disclosure of knowledge is normally secured with few exceptions related to military or national security research activities. Finally, the Property system lies in the creation of markets for private knowledge through the use of intellectual property rights and commercial secrecy.

Institutional diversity in the organization of knowledge production and diffusion

In fact, these three mechanisms lead to describe the main features of the organization of knowledge production and diffusion between the main institutional sectors: the high-education sector, the governement sector (e.g. public research institutes) and the industry. These three sectors meet different objectives that are nevertheless complementary. For instance, the Patronage system has for principal objective the growth of public knowledge and the maximization of the value of positive externalities through the broad dissemination of knowledge in the economy. Conversely, the Property system has for main purpose the

[2] Natural or spontaneous corrective mechanisms also exist. However, they do not provide exhaustive solutions to the incentive to produce new knowledge. These mechanisms are related to the tacit

maximization of the economic value of the knowledge newly produced and sub-consequently the minimization of positive externalities. Lastly, the aim of the Procurement system lies on the generation of new knowledge either public or private according to the government strategic interests. From then on, the question of the public management of positive externalities is only tackled in terms of contingent externalities.

This institutional diversity remains essential because the activities of the main institutional sectors are highly complementary. The Patronage system generates public knowledge that constitutes a major input for private R&D in many domains (Salter & Martin, 2001). Moreover, it allows the training of high-qualified scientists whose competencies prove to be very helpful to the industry (Gibbons & Johnston, 1974; Zucker & Darby, 1995). Conversely, the Patronage system also depends on the Property system insofar as the latter offers efficient methods for the application and commercialization of the knowledge newly created according to the market needs. The Property system may in addition formulate specific problems related to the technological development that should be resolved by universities or non-profit institutions in the framework of long-term research (Rosenberg, 1991). Finally, the Procurement system usually meets the specific requirements of "big science" and large-scale projects for which the centralization of resources and decisions is crucial. In this perspective, it plays the role of a "catalyst" in the knowledge production.

The delimitations of the public and private spheres of knowledge

Finding the good balance between the three main institutional sectors is fundamental. Indeed, the way in which these sectors interact as a collective system of knowledge production and diffusion largely defines its capacity to generate positive externalities and sub-consequently

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character of knowledge, to the internalization of externalities through bilateral relationships and to redistribution effects. See Cohendet et al. (1999).

its performance (OECD, 1996). Nevertheless, this question remains complex because the modalities of the organization of R&D activities between these sectors produce public and private spheres of knowledge whose boundaries are liable to change whether the funding, the production or the utilization of knowledge is considered to determine their delimitations (Foray, op. cit.). Thus an overlapping of pratices and logics associated with the main institutional sectors remains possible inspite of an apparent institutional diversity. Effects of this overlapping on the dynamic of the organization of knowledge production and diffusion among these sectors can not be neutral because the latter is highly dependent on a certain balance between the three complementary incentive structures.

The purpose of this paper consists in the analysis of the modalities of the organisation of R&D activities between the main institutional sectors within the field of space communications in the Triad countries over the last decade. The paper is structured as following. In the first place, the recent changes in space activities and their consequences on the organization of R&D activities within the field of space communications are examined. Secondly, the modalities of this organization between the main institutional sectors are studied according to the funding, the production and the utilization of knowledge. In conclusion, the potential implications of the different modalities on the dynamic of the knowledge production and diffusion within the field are discussed.

THE NEW DEAL IN SPACE ACTIVITIES

The new geo-political and socio-economical context

The question of the organization of R&D activities between the main institutional sectors within the field of space communications is a question of overriding importance. In the cash in point, space communications have been at the heart of political, economical and technological stakes since several decades (Carpentier, 1997). A long time considered as a strategic field by governments in the context of the cold war, space activities were the favorite framework of mission-oriented research activities (Ergas, 1987; Chiang, 1998; Bozeman, 2000) for military and "psychological war" purposes in the United-States, the ex-URSS and to a less extent in Europe. In these conditions, most research activities were undertaken thanks to important public funds once civil and military following the Procurement schema and the question of the public management of positives externalities was no an issue of the highest importance. In fact, research activities were essentially focused on the development of radical innovations in order to fulfill these national strategic objectives and undertaken in the perimenter of space agencies or military laboratories (Carpentier, op. cit.).

Now, space activities have to face a new deal resulting from the total change of the geo-political and socio-economical context in which these activities fit into. Indeed, the political upheavals the world has known since the end of the 80's have put an end to the space race between the East and Western blocks and also to the symbolic programmes based on "national prestige" around which were focused all the efforts of the two super-powers and out of necessity those of Europe. This new geo-political context has also left the officials of great nations a clear field to question against the opportuneness of the important public expenditures devoted to great space programmes because of the new budgetary constraints (Giget, 1997). The great US, Russian and European space programmes developed during the cold war do not henceforth reflect any more the budgetary and political realities. All the great nations have been led to reduce the scope and spread of their programmes in order to restrict their expenditures[3]. This is the meaning of the American "faster, cheaper, better" which stresses the necessary of public investment returns in space R&D.

Space communications: a new stake for the public power ?

Moreover, the space sector was characterized by a sharp increase of the market for space applications, especially space communications[4], over the last decade. For instance, the GEO (geo-stationary) communications satellites market, i.e. the principal segment of space communications satellites, had a market value added up to US $ 2.3 billion (37 satellites) between 1972 and 1979, US $ 6.8 billion (96 satellites) between 1980 and 1989 and an market value estimated to be US $ 34.3 billion (343 satellites) for the period 1990-2000 (Euroconsult, 1998a). The growth of the space communications market was also accompanied by a multiplication of actors (Johnson et al, 1998). In fact, the number of new private operators at the world level strongly increased with the new profit prospects resulting from market deregulation over the last decade. This had for principal consequences a sustained growing of private contracts and an upheaval of the funding and demand structures in the field. In other respects, numerous manufacturers extended their activities to the supply of communications services. In fact, several mobile communications projects of a new generation, based on satellite constellations (Low-Earth-Orbit and Medium-Earth-Orbit constellations) such Iridium or Globalstar, were undertaken or planed by the main US or European satellites manufacturers. These projects used to be exclusively private and were

[3] In the United-States, the budget deficit and the limitation of military expenditures entail a certain stagnation of public funding devoted to space activities although there are still more important in other nations. In Russia, excepted for human spaceflights, the public support for space activities without practical usefulness has decreased strongly. Within Europe, the United-Kingdom, for instance, was lead to make choices among its priorities while Spain and Italy have turned into a withdrawal process and Germany, the second European space power behind France, had to take responsibility for the re-unification at beginning of the nineties.

[4] Its main segments are: fixed and mobile telecommunications through geo-stationary (GEO) satellites, mobile telecommunications through low-earth-orbit (LEO) or medium-earth-orbit (MEO) satellites, direct or digital audio broadcasting, and broadband communications for interactive multimedia (Carpentier, op. cit.).

consequently funded only by private funding. The development of space communications and the multiplication of actors have forced the space industry to find the best way to become more efficient and to adopt its management practices to the rules of the competitive economy. Heavy-handed rules from the past have become less and less in adequacy with the evolution of the sector. The slowdown or decrease of the space public budgets and the rise of private funding have forced firms (operators and manufacturers) to seek profitability of their investments (Euroconsult, 1998b).

The growth of space communications activities outside the public sphere, particularly space agencies (Euroconsult, 1998a), have led to convert them to "ordinary activities" and to the necessary evolution of the organization of R&D activities between the main institutional sectors. Indeed, knowledge diffusion and the increase of the value of positive externalities have from now been considered to be of primary importance. In other words, these mutations have questioned the soundess of mission-oriented research activities in the field. This constitutes a radical change insofar as space activities was for a long time, thanks to important public funding, the heart of the development of cutting edge knowledge without really considering the question of the investment returns and the management of positive externalities. It should be note however that several decision-makers in the United-States and Europe have intended to keep a supposed strategic character to the space communications activities and consequently gone on supporting their development through important public funds once civil and military. In fact, civil funding in the field has been justified by the important industrial and economical stakes associated with these activities because of the development of the information society since the beginning of the 90s (Carpentier, op. cit.). Regarding military funding, it have been defended by the existence of numerous regional conflicts (Gulf War, Balkans, etc.) and as a general rule by the critical role played by space communications for national security or defence concerns as they allow long-distance communications. According to them, space communications being intended for the army needs can not exclusively rest on the use of civil communications insofar as there is no protection against interception or jamming. Moreover, the army has no priority right on the use of space communications in relation to civil users (Johnson et al., op. cit.).

THE FUNDING STRUCTURE OF KNOWLEGE PRODUCTION

The share-out of public and private funding among the main institutional sectors: social and private ruturns

The understanding of the share-out of public and private funding among the main institutional sectors within the field of space communications can rest on the social and private expected returns of the production of knowledge (Brown, 1998). Loosely speaking, when the private expected returns exceed the social ones, the production of knowledge should be in charge of the industry under private funding. Conversely, if these social expected returns are higher than the private ones, so this activity should be undertaken by the public research institutions, in particular academia, under public funding. However, the question of the funding share-out between the main institutional sectors remains complex when the expected social and private outputs are both high. This occurs mainly with applied research and oriented basic research activities. In such a context, the funding share-out is usually highly dependent on national specifities insofar as funds can be either public or private. But in the framework of mission-oriented research as space communications R&D, the funding has generally remained public through national strategic programmes mainly undertaken by space agencies and military laboratories within which firms participate and to a less extent institutions from the higher-education sector. The question that arises is whether the growing of private funds and operators within the field had a significant impact on the continuity of the mission-oriented programmes and more generally on the way R&D activities are organized within the field. In other words, it is to be wondered whether the public research institutes (i.e. space agencies and government laboratories) still remain the "center of gravity" of the organization of R&D activities in the Triad insofar as they largely influence the way the positive externalities are managed within the field.

The space communications public programmes[5]

The US space communications public programmes

The US space communications programmes have usually been distributed between NASA and DoD according to their civil or military nature.

Space military communications in the United-States constitute the world largest market for satellites applications and have been developed under the aegis of DoD infrastructure. The DoD budget for space military communications varied from US $ 1 to 2 billion. To that end, it should be note that US space military communications satellites are from 2 to 5 twice expensive than the civil ones. These differences are mainly due to the amount of R&D expenditures needed in order to respond to the specific military needs but also to the less degree of competition between the manufacturers. Moreover, all DoD communications satellites have been constructed by the main US prime contractors such as Lockheed, Hughes and TRW. Among the DoD space communications programmes, the Milstar (Military Strategic and Tactical Relay) programme had a value added up to 50% of the DoD expenditures in that field over the 90's while the funding of the two other main programmes from the MILSATCOM (Military Satellite Communications Architecture), i.e. DSCS (Defense Satellite Communication System) and UFO (UHF Follow-On), was declining. The

[5] Information on space communications programmes draw extensively from Euroconsult (1996b) for the United-States and Euroconsult (1999) for Europe and Japan.

Milstar started in 1981 and is still in action despite political conflicts because of its high costs and its new orientation after the end of the cold war. The DSCS (DSCS-1, DSCS-2 and DSCS-3) started in 1966 still remains a critical feature of the US space military communications. The Flsatcom satellites (Fleet Satellite Communications) batch initialized in 1978 was also operational up until the last decade. However, this batch has been replaced gradually by UFO satellites since 1993. DSCS and UFO batches will be integrated with a same programme called UHF/SHF that will come into force on 2002. The Army is also used to relying to several commercial communications satellites systems. In fact, the US army resorted to many existing commercial systems during the Panama and Gulf operations. Commercial systems such as Inmersat, Intelsat, TDRSS and others represented nearly 25% of the US army communications during the Gulf war. After that, DoD decided to use more and more commercial systems given the stagnation of military State budgets all the more since the army needs exceeded what UFO and DSCS satellites could offer because of the growing of communications traffic. So, DoD opted for an increasing use of commercial satellites by renting out existing systems in the framework of the CSCI (Commercial Satellite Communication Initiative) initiative.

NASA has played a critical role in the development of civil and commercial communications satellites. Echo, Relay, Syncom and above all ATS satellites constituted the technological knowledge base upon which US firms built their competencies in the field. Budgets had been highly significant (e.g. US $ 30 and 40 millions in 1972 and 1973) until NASA decided to let the private sector fund its own satellites in 1974 because of its maturity (Bromberg 1999). The total NASA R&D budget devoted to communications satellites fluctuated between US $ 50.5 and 20 millions over the period 1990-1997. In 1997, the budget added up to US $ 23.3 millions. However, a new policy was formulated at the end of the last decade with the decision to carry out the ACTS (Advanced Communications Technology Satellite) programme. The latter was launched in 1993 in spite of funding difficulties caused by political rivalries between the Congress and the presidential administration. The US congress sustained the ACTS programme in order to thwart the growing of Europe and Japan within the field of space communications (Bromberg, op. cit.). Today, the NASA programme is dedicated to the development of critical technologies to support scientific missions and to meet commercial needs within the field of space communications. The programme has three sub-programmes: the near Earth communications; "Mission to Planet"; and the deep space missions.

The space communications programmes in Europe

The space communications programmes in Europe are undertaken at three levels: The ESA level, the EU level and the national level.

At the beginning of 70's, the ESA space communications programmes had for main objective to support the rising of competencies in the private sector in order that firms were able to respond to the European needs and be competitive at the international level. The first generation regrouped the vertical OTS (Orbital Test Satellites) and ECS (European Communication Satellites) programmes and the horizontal R&D ESA programme (Basic Technology Research Programme). In the 80's, the second one comprised the vertical Olympus programme and two R&D programmes: TRP (Basic Technology Research Programme) and ASTP (Advanced Systems and Technology Programme). Finally, the last generation started at the beginning of the 90's. It included several programmes such as Artemis, ARTES (Advanced Research in Telecommunications Systems), ASTE (Advanced Systems et Telecommunications Equipement), GSTP (General Support Technology Programme) and TRP (Basic Technology Rsearch Programme). ARTES and ASTE are two oriented R&D programmes to support Artemis whereas TRP et GSTP constitute the two horizontal R&D ESA programmes (Euroconsult 1996a). The total ESA budget in that field wavered between Ecus 137 and 339.5 millions over the period 1990-1997. In 1998, the budget amounted to Ecus 179.4 millions.

The European Commission also intervenes in the funding of R&D activities within the field of space communications in the framework of its own telecommunications programmes. For instance, the Fourth framework programme contained a section called ACTS (Advanced Communications Technologies and Services) including several sub-programmes such as DIGISAT (Advanced Digital Satellite Broadcasting and Interactive Services), ISIS (Interactive Satellite multimedia Information System) or SECOMS (Satellite EHF Communications for Mobile Multimedia Services). Many public research institutions (e.g. ESA, CNES, DLR) and European firms (e.g. European prime contractors) were active in these programmes (EC, 1998).

Finally, few national space agencies have developed their own programmes within the field in Europe. Part of them has been devoted to military purposes because ESA remains a civil agency. In France, the national space communications programme Telecom has been launched in the framework of a cooperation between France Telecom, DGA and CNES. The satellites system has been effective since 1984 but transferred to national operators in the meantime. This explains the reason why the CNES budget for space communications is relatively low. Today, the space part of telecom-2 is directly funded by France Telecom insofar as CNES exclusively has in charge the technical responsibility of the system. Nevertheless, the CNES budget increased with the launch of Stentor research programme over the second half of the 90's. This programme has enabled the French industry to test new technologies devoted to the commercial market. Regarding the space military communications activities of CNES, the current Syracuse 2 system launched in 1991 is still operational. In Germany, the space agency (DLR) mainly focalizes its national activities on scientific research and Earth observation. The agency is less active at the national level within the field of space communications. Indeed, only two programmes have been undertaken outside ESA activities: the Tvsat direct and the DFS programmes. In Great-Britain and Italy, the budgets of both space agencies (BNSC and ASI) devoted to national space communications programmes were near non existent over the last decade.

The Japanese space communications programmes

The Japanese space agency (NASDA) supported in the same way as the majority of space agencies in the Triad the development of communications satellites during the 70s. Its activities were carried out in the framework of bilateral cooperation agreements signed with the United-States in 1969 and the technological satellites programme called ETS. Two satellites were constructed and launched, namely the CS and BS satellites. The former was developed by Ford Aerospace (Space Systems/Loral) with a Japanese contribution added up to 24% while the latter was mainly assembled by RCA Astro-Electronics Division. These two experimental programmes enabled NASDA to supervise the subsequent fabrication of the CS-2 and BS-2 operational systems. The contribution of the Japanese industry increased over that period. It amounted to 64% for the CS-2 system and to 29% for the BS-2. The Japanese cooperation policy with the United-States was latter reinforced with the CS-3 and BS-3 systems launched at the end of the 80's and the beginning of the 90's. The participation of the Japanese industry was higher for these systems. For instance, it added up to 80% for the CS-3 system. However, NASDA reoriented its funding policy because of the market deregulation and the US pressure on Japanese operators to choose US systems. In fact, the Japanese agency decided that the construction of communications satellites had to be exclusively fund by the users. The talks between the United-states and Japan ended up on the decision in 1990 to split up market-oriented and R&D functions for the creation of future Japanese satellites.

The experimental content of CS-4 and BS-4 programmes was re-defined in the framework of an experimental programme called COMETS (Communications and Broadcasting Engineering Test Satellite). Satellites from this programme were to be constructed by the NASDA and the CRL (Communications Research Laboratory) in accordance with the US/Japanese agreement signed in 1990. This entailed a sharp protest by the American since US manufacturers could not anymore participate to the development of satellites in the framework of the COMETS programme because of its experimental character. Another experimental communications satellites programme was launched over the 90's: OICETS (Optical Inter-satellite Communication Engineering Test Satellite). The CS-4 withdrawal led the main Japanese operator NTT to buy its own satellites.

The previous developments show that industry has benefited in the Triad from valuable public funds for several decades in order to foster the rise of its competencies within the field of space communications. NASA and DoD have supported to a great extent the US industry. In these conditions, the US prime contractors but also sub-contractors have created breakthrough innovations especially through ATCS and Milsat programmes. Nevertheless, the US industry has also developed numerous applications thanks to private funding (Bromberg, op. cit.). For instance, important efforts have been undertaken since the last decade in order to create small satellites devoted to commercial LEO and MEO constellations (NRC, 1994). In Europe, the ESA[6] and national communications programmes have also been major sources of industrial innovations. Consequently, the European firms have intensively benefited from public funding at either national level or European level in spite of the will of ESA to reduce its intervention by means of new forms of funding, in particular co-funding contracts (Benetti & Elia, 1999). The existence of numerous public programmes related to space communications in these two regions over the last decade in spite of the State budget limitations and the growing of private funding due to the rise of private operators and the emergence of constellations reflected the new industrial and economical stakes associated with these activities. In other words, space communications activities tend to maintain a mission-oriented character in the United-States and Europe despite the will of decision-makers to change the rules of game within the field. But, it should be note that space agencies have in the meantime increasingly promoted cooperations between firms and universities in order to foster the diffusion of knowledge especially in the United-States and latter in Europe (Technical University of Dresden, 1998; Turku School of Economic and Business Administration, 1998; Raitt, 1999). Finally, the Japanese industry was supported too by NASDA funding for years so as to create commercial satellites. However, the space communications R&D with commercial goals seems to be from now funded only through private funding in Japan.

DIVISION OF LABOR AND KNOWLEDGE PRODUCTION

The main institutional location of R&D activities

The way the main institutional sectors participate in the production of scientific and technological knowledge within the field of space communications in the Triad is an essential issue. Indeed, it also tackles the question of the institutional diversity, i.e. the upholding of a certain balance between the three incentive structures. Of course, the division of innovative labor between the main institutional sectors tends to become blurred in some R&D fields or sectors (e.g. biotechnology , the pharmaceutical industry, ect.) because of close links between science and technology, an increasing in university patenting and finally a high propensity of

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[6] Although the ESA R&D activities (TRP, GSTP, etc.) weigh less than 4% of the total agency budget, it should be note that about 85% of this budget are spent through contracts with the European space

firms that performe scientific research and publish their results. However, most empirical studies (EC, 1997; Hicks & Katz, 1997; Godin & Gindras, 2000; NSB, 2000) show as a general rule that: the higher-education sector is strongly specialized in the production of scientific knowledge without any commercial goals and has a negative index for the production of technological knowledge; firms are active in the production of technological knowledge generating private returns on the short-term or mid-term; lastly, public research institutes have the least emphasized profile which characterizes their critical role played in mission-oriented research[7]. In fact, these differences between the main institutional sectors in the division of innovative labor reflect the dissimilarities of their objectives (Pavitt, 1998) as we saw previously. The particular characteristics of the division of labor between the main institutional sectors[8] in the production knowledge in the Triad countries within the field of space communications are compared with these general empirical results.

The distribution of the technological knowledge production among the main institutional sectors

The distribution of the technological knowledge among the main institutional sectors within the field of space communications is roughly similar in the three Triad regions (Table 1.). In fact, the production of technological knowledge is nearly exclusively due to the industry except in the European Union where public research institutes produce almost 15% of the European technological knowledge[9]. Within the EU countries, the distribution of

industry (Euroconsult, 1996a).

[7] Nevertheless, the theoretical foundations of the division of labor between the main institutional sectors remain subject to debate since the works of Nelson (1959) and Arrow (1962). The degree of codification and/or the generic character of scientific knowledge are usually argued in different manners (David et al., 1992; Romer, 1993; David & Foray, op. cit.) to justify the public funding of scientific production especially through academia. See Callon (1999) for a criticism of these arguments.

[8] Research institutions such as CNRS (France) and Max Planck Institutes (Germany) are classified in the category "Public research institutes". Space agencies are also classified in this category.

[9] It is necessary to mention that the NASA applies mainly for US patents. Consequently, its technology activities measured by means of EPO patent applications are "under-estimated" conversely to the

technological production among the main institutional sectors is quite similar to the ones of Japan and the United-States. Indeed, the industry produces the most technological knowledge. However, France distinguishes from the other European countries and also from Japan and the United-States as regards its organization of technological activities. The French public research institutes seems in fact to be quite active in the generation of technological knowledge[10]. Thus, the production of technological knowledge within the field of space communications is mainly the work of the industry in the United-States[11] and Japan but to a less extent in European level. This confirms the general empirical results mentioned above about the characteristics of the division of labor between the main institutional sectors in the production of technological knowledge.

(Table 1 about here)

The distribution of the scientific knowledge production among the main institutional sectors

Scientific activities are more dispersed among the main institutional sectors in the three Triad regions and the EU countries than technological activities even though countries and regions show different patterns. At the Triad level, the higher-education sector dominates the production of scientific knowledge in the United-States and in the European Union where its contribution is close to 50% (Table 2.). In Japan, its share is lower as it adds up to the third of the national scientific production. Indeed, the industry is the first producer of scientific knowledge in Japan with a contribution near to 50%. The scientific production of the industry sector is also significant in the European Union and above all in the United-States. Finally,

European Space Agency whose technological activities measured by the means of European patent applications are "over-estimated".

[10] It should be stress that the technological activities of the French public research institutes are over-estimated by ESA patents.

[11] See footnote 7.

the government sector is active too within the three Triad regions, in particular in the European Union where it ranks second in the scientific knowledge production[12]. Nevertheless countries show differences as regards the organization of their scientific activities at the European level. For instance, the industry sector contributes to the growth of scientific knowledge especially in France and Great-Britain while its activities are low in the other EU countries such as in the "Small European Countries". In all, the share of the public insitutions, especially those belonging to the higher-education sector, in the production of scientific knowledge are relatively expected insofar as these institutions usually concentrate their R&D activities on scientific activities as shown earlier. However, the important contribution of the industry sector in the generation of scientific knowledge, principally in Japan and the United-States, demonstrates that firms do not exclusively focalize their R&D activities on technological developments insofar as they produce scientific knowledge within the field up to compete even with the traditional scientific system.

(Table 2 about here)

Consequently, the industry sector appears as a major player either in the technological or the scientific activities within the field of space communications. In particular, the scientific investigation methods have been diffused far beyond the public sphere, mainly in the United-States and Japan. Such a phenomenon can not only be explained by the will of firms to create an efficient absorptive capacity (Rosenberg 1990 ; Gambardella 1992 ; Hicks 1995) given the high level of the scientific knowledge output of the industry sector in the field compared to other ones (Hicks & Katz, 1997; NSB 2000). Other explanations may be find in the strategic and specific nature of the space sector in some of these countries. For several decades, the

[12] These results should be interpreted with caution as the classification of CNRS (France) and Max Plank Institutes (Germany) in the category "public research institutes" tends to over-estimate the

space industry, especially the space defence industry, have been characterized by a near monopsonic structure, i.e. very few buyers or even only one, in most of the Triad countries. These buyers with space agencies saw to it that numerous contracts were signed with the private sector in order to stimulate the growth of firms able to respond to their specific needs rather than emphasized on the development of their own structures because of administrative constraints (Carlier, 1995; Bromberg, op. cit.). This choice may explain why the higher-education sector is not the main producer of scientific knowledge within the field of space communications in most the Triad countries. Nevertheless, the situation of Japan is particular because previous developments suggested that its industry benefited from only limited public funds compared to the US and European firms over the last decade.

THE UTILIZATION OF KNOWLEDGE: PUBLIC AND PRIVATE KNOWLEDE

Social modes of knowledge production and diffusion

R&D activities within the field of space communications have been described according to two criteria, i.e. either the funding or the production structure. But these activities can also be characterized in relation to the social modes of production and diffusion of knowledge among its various actors. In this perspective, a crucial distinction exists between “open research” and “proprietary research” communities (David & Foray, 1995). “Open research” can be associated with the world of academic research and its specific norms of organization (autonomy of researchers, freedom to publish, etc.). It is characterized by the full public disclosure of the knowledge produced and a reward system based on non-market mechanisms, i.e. the “priority rule” (Dasgupta & David, op. cit.). Unlike “open research”, “proprietary research” corresponds to either the world of military laboratories operated under

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contribution of this category in the scientific activities and to under-estimate the one of the higher-education.

the control of governments (Chalk, 1985; Ferguson, 1985) or the world of business firms. In this context, researchers must not diffuse or disclose the knowledge produced outside their institutions without explicit permissions. In these worlds, commercial secrecy and patents are extensively used as means to protect knowledge and to restrict its use by others without compensations. Nevertheless, it is necessary to note that the higher-education, the government sector and the industry sector are not constrained by the dominant norms of their milieu. Indeed, each of these sectors may find it to its advantage to organize its R&D activities on occasion according to different norms. In that perspective, the examination of the diffusion of "open research" and "proprietary research" norms among these sectors enables us to analyze the modalities of the knowledge share-out according to the criterion of the utilization of knowledge within the field of space communications.

Measuring the diffusion of "open research" and "proprietary research" norms among the main institutional sectors

A specific indicator is constructed to characterize the social mode of production and diffusion of knowledge associated with each sector. This indicator is defined for a given institutional sector as the ratio between its world share in European patent applications and its world share in scientific publications[13]. Therefore, the belonging of the main institutional sectors to the "open research" or "proprietary research" communities is only determined by the legal property regime of the knowledge produced and disclosed by means of patents and scientific publications. Thus, the public or private nature of knowledge is not determined by its degree of codification/tacitness[14] even though the tacit character of knowledge can be considered as a natural appropriation mechanism (Zucker et al., 1994). In other respects, the knowledge

[13] Consequently, this indicator does not compare the public and private knowledge outputs of an given institutional sector in absolute value because it is standardized by the worldwide public and private knowledge output in the field.
[14] See for instance Nelson (1992).

disclosed by means of patents remains private from a legal perspective even though patents are major channels of knowledge dissemination (Kitch, 1977; Ordover, 1991).

The diffusion of "open research" and "property research" norms among the institutional sectors

At the Triad level, the value of the index shows that the higher-education sector is totally associated with the "open research" community (Table 3.) because it does not apply for patents. Public research institutes produce also exclusively public knowledge in the United-States[15] and Japan. However, the belonging of these institutions to the "open research" community is more moderate since the value of the indicator amounts to 0.8. Indeed, the European public research institutions produce a substantial part of private knowledge even though the production of public knowledge is higher. Lastly, the industry sector is mainly oriented towards the norms of "proprietary research" in the United-States and the European Union. Conversely, these norms are less diffused among the Japanese firms insofar as they are quite active in the provision of public knowledge. With the EU countries, the norms of "open research" are largely adopted in the higher-education sector and to a less extent among the public research institutes. Research institutes show in fact affinities with the "open research" community which are variable in the EU countries. For instance, the government institutes produce mainly public knowledge in Italy and Germany but to a less extent in Great-Britain and the "Small European Countries". But all these institutions remain "open research" institutions. Only is France the exception in the Triad insofar as its public research institutes create mostly private knowledge in spite of public funding[16]. The norms of

[15] This result should be interpreted with caution. See footnote 7.

[16] This belonging of French research institutes to the "proprietary research" community is probably over-estimated insofar as the scientific publications of ESA are linked to the Netherlands, i.e. the "small European countries" due to the localization of its research centres while its patents are counted as counted as "French applications" since its intellectual property department is localized in Paris at ESA Headquarters.

“proprietary research” are even more diffused in this sector than in the industry sector in the “Small European Countries”, Italy and Great-Britain.

(Table 3 about here)

CONCLUSION

All in all, we show that the public and private spheres of knowledge within the field of space communications do not totally overlap from the moment that the modalities of the knowledge share-out among the main institutional sectors are examined in relation to the following criteria: funding, production or utilization. Indeed, the private domain of R&D according to the criterion of production is larger than the private of domain of R&D according the funding criterion because the production of knowledge is still driven by important public funding in the framework of mission-oriented research policy, especially in the United-States and Europe. Moreover, there is not a perfect match between the public/private nature of the institutions which undertake knowledge production activities and the public/private nature of their results. For instance, the norms of “proprietary research” are largely adopted the French research institutes and to a less extent by the public research institutes in the “Small European Countries” and Great-Britain. On the other hand, most US and Japanese firms contribute to the growth of the stock of public knowledge even though the norms of “proprietary research” prevail in the industry sector within the Triad. Consequently, the question of the neccesary upholding of the institutional diversity associated with the organisation of R&D activities in the field of space communications can not be resolved by means of a unique solution from the moment that the various facets of the knowledge share-out are considered.

Nevertheless, the “institutional overlapping” within the field of space communications due the interlinks between the logics and pratices among the main actors and its implications on the dynamic of knowledge production and diffusion in the field can be discussed. It should first be stressed that compromises between the social modes of knowledge production and diffusion of the main institutional sectors can generate strong positive effects. For instance, the US and Japanese firms are probably more inclined than the European ones to participate to the scientific networks of knowledge production by means of their significant proposenty to publish and sub-consequently to benefit from the advances of public science for the development of technological innovations[17]. In other respects, the relevance of public science for their technological activities can be improved since their scientific publications allow them to give signals to the public research institutions on their specific needs (Hicks, op. cit.). Secondly, the diffusion of the norms of "proprietary research" among the public research institutes in some EU countries (e.g. France) which can be explained by the will of these institutions to capitalize and to market part of their research results does not mean a danger for the dynamic of knowledge production and diffusion within the field insofar as the positive externalities are mainly contingent in the framework of mission-oriented research (Jaffe & Lerner, 1999). Finally, the issue that deserves special attention is rather the question of the appropriate role of space agencies in comparison with the higher-education sector, other government instititutes and industry within the field of space communications today.

[17] See for instance Cockburn & Henderson (1995) for a similar situation in the drug industry.

ANNEX: INFORMATION SOURCES AND METHODOLOGY

This annex briefly describes the methodology and the data mobilized to measure the indicators presented in the paper.

Delimitations of space communications

First of all, a common definition of space communications for both the scientific and technology activities was chosen. This was effectively required to represent the cognitive relations between the scientific and technological KBs at the levels of sub-fields and countries. Hence, a list of ten priority R&D themes related to space communications was defined thanks to U.S. National Research Council (NRC, 1994, 1998) and Institute for Defense Analysis (IDA, 1996) reports. These priority R&D themes are: high-dielectric constant patch antennas ; high-frequency (> Ka Band) antennas ; phased-array antennas ; multi-beam antennas ; on-board satellite transponders ; multiple access ; ka band power module ; optical frequency (laser) communication systems for space-to-space links ; radio frequency space-to-space links for complex spacecraft constellations ; and lastly space solid-sate amplifiers.

The space communications database

The definition of each priority R&D theme was translated into bibliographic search equations thanks to technical experts from the European Patent Office (EPO). Each equation comprised a set of significant keywords and/or indexing codes. This step was a requisite to select properly the relevant data on European patent applications (either direct EPO applications or Euro-PCT applications) and scientific publications (reports, articles, book reviews, conference proceedings, etc.) at the world level. The identification and extraction of European patent applications were performed through EPAT and WPIL databases while scientific publications were first obtained from INSPEC and COMPENDEX databases. The time period 1990-1998 (publication years) was chosen as the reference period for the identification process. Next, COMPENDEX and INSPEC data were matched at CWTS[18] with data from all ISI files (SCI, CompuMath, etc.). This implied the exclusion of all non-articles data (e.g. books, reports, etc.) and data from non-ISI journals. In doing this, the most relevant articles related to space communications were identified in ISI files since the process was completed at the level of individual scientific papers. Moreover, this method enabled us to include in our space communications database a large coverage of information from these three databases. At the same time, the extracted patent applications were linked to the references contained in OST patent database[19]. As a consequence, duplications between (direct) EPO applications and Euro-PCT applications were avoided as well as applications from non-legal entities. Finally, the adress of each institution was unified (country and name) and its type (higher-education, government, industry) determined.

S&T outputs indicators: counting scheme and reference date

S&T output indicators were measured at the level of countries and main institutional sectors following a fractional counting scheme by country of residence of the institutions or inventors. Indicators are presented according to the publication date of publications and patent applications.

[18] Centre for Science and Technology Studies (The Netherlands)
[19] Observatoire des Sciences et des Techniques (France)

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Table 1. Technological output distribution (% national output)

among the main institutional sectors in the Triad countries (1990-98)

Regions/countries	Higher-education	Public research institutes	Industry	World share (% worldwide output)
USA	1.2%	0.0%	98.2%	47.5%
UE-15	0.8%	15.1%	84.1%	28.6%
Japan	0.0%	1.5%	98.5%	13.4%
France	0.0%	21.9%	78.1%	14.2%
Germany	0.0%	6.7%	93.3%	3.9%
Italy	0.0%	0.0%	100.0%	0.9%
Great-Britain	5.0%	5.0%	90.0%	4.9%
Small European Countries	0.0%	10.5%	89.5%	6.2%

Sources : INPI, EPO ; *Processing :* OST, Author
Notes : "Small European Countries" are the EU-15 countries except France, Great-Britain, Germany, Italy; see the annex for the description of the methodology and data sources

Table 2. Scientific output distribution (% national output)

among the main institutional sectors in the Triad countries (1990-98)

Regions/countries	Higher-education	Public research institutes	Industry	World share (% worldwide output)
USA	45.3%	20.0%	34.7%	26.6%
UE-15	50.9%	28.0%	21.1%	19.5%
Japan	30.8%	23.0%	46.2%	12.6%
France	44.0%	28.0%	28.0%	3.1%
Germany	23.5%	56.8%	17.7%	2.0%
Italy	62.1%	20.7%	17.2%	3.4%
Great-Britain	55.6%	8.9%	35.5%	6.9%
Small European Countries	55.2%	39.1%	8.7%	5.6%

Sources : Inspec, Compendex, ISI ; *Processing :* CWTS, Author
Notes : "Small European Countries" are the EU-15 countries except France, Great-Britain, Germany, Italy; see the annex for the description of the methodology and data sources

Table 3. “Open research” and “proprietary research” in the Triad countries (1990-98)

Regions/countries	Higher-education	Public research institutes	Industry
USA	OR (0.05)	OR (0.00)	PR (5.10)
EU-15	OR (0.02)	OR (0.80)	PR (5.87)
Japan	OR (0.00)	OR (0,07)	PR (2.28)
France	OR (0.00)	PR (3.47)	PR (12.33)
Germany	OR (0.00)	OR (0.22)	PR (9.08)
Italy	OR (0.00)	OR (0.00)	PR (1.52)
Great-Britain	OR (0.06)	OR (0.41)	PR (1.77)
Small European Countries	OR (0.00)	OR (0.50)	PR (2.15)

Sources : INPI, EPO, Compendex, Inspec, ISI ; *Processing :* OST, CWTS, Author
Notes : Indicator values are shown in brackets. A value higher than 1 for a given institutional sector means a belonging to the norms of “protected research” while a value lower tan 1 means a belonging to the norms of “open research”. “Small European Countries” are the EU-15 countries except France, Great-Britain, Germany, Italy; see the annex for the description of the methodology and data sources
Abbreviations : OP = “Open Research” ; PR= “Proprietary Research”.