New networks of technological creation in energy industries : reassessment of the roles of equipment suppliers and operators

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Abstract

Within a financial context of selection inducing either a decrease or a drop of their home R&D expenditures, energy industries companies have succeeded to maintain and even to increase their knowledge production during the last 15 years (1985/ 1998).
To understand these apparently paradoxical changes, elements of analysis are looked for within an evolutionary framework, and more specially referring to the related developments to network-firms, user-supplier relationship, and interactive nature of innovation processes.
Empirical data are set on granted patents to a sample of the top 15 world largest companies on both sides of operators and equipment suppliers, and for the two industries of oil production and power generation.
Interpretation of the results suggests that two dynamics ought to be distinguished. On one side, dynamics of the networks of technological creation is characterized by an upstream going-up of the head of the network towards suppliers. On the other side networks of creation of competitive advantages and bargaining power continues to be based on the operators and their strategies of adaptation to the constraints and opportunities of their institutional, financial and competitive environment.

Key Words: environment of selection, technology creation, user-supplier relationship, competitive advantage, network firm.

JEL Classification: L1 (market structure, firm strategy and market performance), L2 (Firm objectives, Organization, and Behavior), O3 (Technological Change).

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Introduction

Institutional and competitive changes caused by markets globalisation and deregulations have deeply transformed energy industries. The competitive structure is today mainly based on large multinational firms, which are involved in a process of industrial merger and diversification on a worldwide scale, and confronted with the threat of new entries on some promising niches in energy markets[1].

At the same time, energy technological stakes also become worldwide, as so far they are associated with urgent problems of protecting planet's natural resources. While efforts of international coordination of energy and natural environment public policies started, firms' intensity of research and development (R&D) was noticeably reduced since about fifteen years. Should we worry about such an evolution? The answer to this question requires to take into account not only R&D expenditures level, but also its effectiveness -for example in term of a number of granted patents-, and to check the orientation of the technological improvements. In the same way energy experts and advisors are asked to look at the industry dynamics in the broad sense, by including among the potential actors of the technological effort the heavy equipment suppliers as well as the energy producing firms.

The goal of this paper is to characterize technology dynamics of firms in energy industries within two of their technological fields : production of electricity and production of oil. During the sixties and seventies, the firms of these two industries faced significantly different institutional, competitive and financial environments. But since the eighties, a growing convergence of those environments occurred, due principally to changes in regulation policy concerning the production of electricity. It is therefore primarily a question of understanding how these two industries have

been reorganizing during the last fifteen years to preserve, and even to increase the rate of their knowledge production whereas their economic and financial environment of selection pushed them to reduce their R&D efforts.

The used conceptual framework to understand this evolution is based on the one hand on the firm-network, on the other hand on the role and modalities of the interactions between users and suppliers in the innovation. After a recall of certain analyses of the evolutionary literature dealing with network dynamics of technology creation, we aim to test the validity of such a conceptual framework in the case of the firms of energy industries. A general presentation of the changes in their selection environment since the end of the seventies will make it possible to put forward assumptions on the capacity of both the equipment supplier firms and user firms to fall under this evolution towards network dynamics. Then we obtain relevant results allowing to answer our interrogation by using a specific data base including the granted patents to the firms of a selected sample. Thus we highlight specificities of energy industries firms in implementing networks of technological creation.

1 Issues and assumptions

Mutations in technological strategies of large firms may be looked as reactions to dramatic changes in competition dynamics, and in the processes of innovation as well. The evolutionary literature, either dealing with the processes of transnationalisation of the firms or with the characteristics of their knowledge accumulation, allows a focus on the transition to new models of organization of the capabilities of technological creation in large firms.

J.Cantwell (1999) [2] thus proposes an historical viewpoint on the profit search and growth of the firms during last decades. Two models are identified which followed one another : in the first one, growth is based on improvements of labour productivity, an increased flexibility in the use and allocation of the production factors ; in the second one, growth results from capital productivity increases, through innovation and temporary monopoly advantages, such as described by J Schumpeter. This second model arises from an economic context of globalisation and gives incentives to the multinational firms (MNF) for an integrated innovation strategy at a worldwide scale.

However in some industries, reality does not fit with the second one of these models. What can be observed here? MNF continue to manage the labour productivity (redundancy, use of the low wages labour force) and to focus on flexibility in particular in their interindustrial relations (renegotiation of the subcontracting and supply agreements). In the same way the number of reengineering increases : it allows first new integration of activities for a higher financial profitability (in order to satisfy the financial pressures of short-term profitability) ; second it increases market power to rebuild captive markets. All these strategic orientations do not favour the innovation capabilities, whose organisational evolution within the large firms is a by-product of financial and commercial strategies (Guercini and Paoli, 1997)[3].

According to Cantwell, far from cancelling his analysis, these attitudes correspond in fact to an ultimate attempt of the firms of these sectors to benefit from the first race to profit model. Nevertheless taking into account a foreseeable exhaustion of this model's advantages, priority laid on the innovation will be the essential way out for the long-term competitiveness of the MNF.

This evolution will not have to face the risk of difficulties related to the appropriation of the results of the innovation efforts, if one adopts an evolutionary design of knowledge: for the

firms, the intensification of the technological activities does not involve a risk of costly leaks, but on the contrary a renewal of specific cognitive resources dedicated to innovation[4].

The analysis of Cantwell thus is closely akin to the whole of evolutionary work, by establishing an opposition between logic of resource allocation and logic of resources creation in research and innovation. Within a logic of resource allocation, the firm makes an arbitrage between the realization by it's own of the research effort and the acquisition of the results of this effort which is performed by a third party (" make or buy "). The leading criterion of arbitrage is the transactions costs one's. However the evolutionary authors regard this logic as ineffective in the long run for the firms. They showed (Amendola and Gaffard, 1988 ;Cohen and Levinthal, 1989 ; Foray and Mowery, 1990)[5] that innovation results from specific cumulative learnings which cannot completely and punctually be transmitted from an organization to another one within the framework of an arm-length transaction. A firm cannot innovate if the whole of its R&D effort is outsourced. Arbitrage does not imply any more the choice between make or buy, but between various methods in the control of the effort of research and innovation. For Cantwell, intensification of the technological activities is the mark of the firms which categorically chose a logic of creation of technological resources.

Within this framework, there is a proportionality link between the importance of the effort of in-house accumulation of specific cognitive resources dedicated to innovation from a firm (in particular through its capabilities of R&D) and its skill to benefit from co-operative researches and other activities of innovation open on technico-economic networks (Callon,1993)[6]. This skill is all the more essential today since the processes of innovation are largely directing towards an operation of network relationships. M. Gibbons and alii (1994)[7] insist on this subject on the role of the evolution of the model of production of knowledge. The fordist context has matched a model of knowledge production where the academic scientific community leaded ; this scientific

community was itself divided into not very permeable disciplines ones with the others, the impulse coming from the very center of this community and linearly diffusing towards industrial applications. In this model National System of Innovation (NSI) was operated through the academic scientific community, with an obvious national benchmarking, within a framework of overall excellence (as so far the nations resources were available). The fordism crisis allowed the emergence of a new model of knowledge production, where heterogeneity of knowledge producers and users (transdisciplinarity, organisational diversity, geographical bursting) and flexibility of the implied groups in the innovation are emerging, as well as an highlight on collective and dynamic aspect of the production of learning (Kline and Rosenberg, 1986)[8].

In the very leading former model, NSI is based on the stable domination of an educational and academic component. Mutation towards the new mentioned model might have mishandled the national issues and diluted the NSI. Nothing such happened : the NSI were rebalanced towards other components (firms, SME, intermediate institutions), operating today much more like technico-economic networks such as described M.Callon (1993)[9]. Giving up the ambition of overall excellence, they become specialized in a dynamic, decentralized and cumulative way. They thus appear reinforced, and they generate a cognitive division of work on a worldwide scale (excluding in fact the non triadic countries), with visible centers of technological excellence.

How did the MNF react ? Far from seeking to replace the universities and public research centers, they took into account (and contributed to) this new cognitive division of work in the world and above all sought to reach localised knowledge. They used two means to do it : by shifting knowledge towards themselves (access to licences, purchase of patents, R&D subcontracting...) (Howells, 1997)[10] or by shifting their assets towards knowledge (implementing local R&D facilities). In short, they internationalized their technological activities in order to implement a strategy of " technology sourcing ".

However, whatever the selected policies, internationalization of their technological activities finds its consistence only under the following condition : the collective, tacit and network nature of the knowledge production-circulation requires relations which incorporate co-operation with the foreign interlocutor, and not only pure market transaction. New forms of industrial organization appeared, and are primarily developing according to two axes : outsourcing of technological activities with partnership relations, and horizontal co-operation between firms (with the emergent role of " strategic brokers " playing the role of setting up the horizontal co-operations) (Gibbons and al.)[11].

Concerning the vertical dimension of this networking, B.Lundvall (1992)[12] defined the conditions allowing rich relations between users and producers, including interactive trainings and generation of knowledge in the context of this new organization of the innovation processes. According to him the most favorable type of relations is the organized market, i.e. the implemented co-operation between a producer and a user around the design of the product (or equipment). Indeed a hierarchical structure (vertical integration within the same organization) limits incentives to interactions by its financial rigidity, whereas a pure commercial relation excludes by nature any interaction : it is the case of the contract where schedule of conditions is imposed by the user, or at the opposite, turn-key contract.

The organized market requires effective mechanisms of dissuasion from the opportunist behaviors on both sides, because exclusion of the inter-firms network is a credible threat. In addition to the institutional mechanisms, a means of dissuasion consists in creating on the long term a base of cognitive resources common to the supplier and the user of the equipment. Incentive to continue the relation is then strong, and each actor increases its learnings. In this relation of " smart " supply (with the image of ‘smart subcontracting‘ in the car industry), user does not transfer the full burden of the technological innovation : he requires a strong

participation of the supplier in the efforts of R&D, but remains leader in the definition of the " functionalities " and the checking of their capacity to be coordinated. That requires, on both sides, in addition to common research on certain projects, the continuous implementation of distinct resources of R&D. Despite the contribution of third-parties, the company is still in a logic of resources creation.

The opposition between logic of resource allocation and logic of resources creation lets think that, if in the majority of the cases, the technological strategies concern organizations dealing increasingly with a logic of resources creation, the resource allocation is not therefore removed in certain fields. However two modes of organization seem to have dominated : until the years 70-80 the managerial approach prefers a vertically integrated firm which peforms its innovation activities ; more recently, the network-firm focuses on the interindustrial relations and the partnerships as components of the total process of innovation of the firm.

We can thus identify two models of technological strategy of the firms, which followed one another within the framework of the dynamics of the worldwide capitalism in the end of the 20th century.

Table 1

2 Changes in the environment of selection of the energy industries firms and the adaptation of their technology strategies

During 1985/1998 period, changes in the environment of selection of both oil and power industry tend to get closer the conditions of their economic activities, despite maintained specificity either at industry level, or at operator/supplier level.

Two very general changes may be quoted : liberalization/privatization linked with deregulation on one side, financial globalization on the other side. Both have boosted competition at a much higher degree, tended to establish higher financial return on equity standards, and incited corporate firms to increase their internationalization. Because consumers have greater flexibility to choose their provider of energy services, energy marketing and services have become more dominant.

Despite these common trends, there is a reduced but still important gap of internationalization intensity between oil and electricity industry. Moreover technology evolution has tended to be quicker and more intense in upstream oil industry than in the electricity industry, while in the latter a star technology, single or combined gas turbine, tends to become a new standard. That particular evolution associated with liberalization have given a strong advantage to newcomers in power generating activities, and thus to an increased competition.

Suppliers have also experimented a higher competition level due to the effective possibility for operators to select their provider at a world level. Equipment suppliers have both suffered great volatility of orders, decreasing selling prices to their customers and higher financial profitability requirements from their shareholders. Moreover with operators's outsourcing non core activities and their new expectations of larger service supplies, clear incentives have played in favour of a greater scope of products and services, including within R&D activities, and finally to much larger size companies than before.

These changes in the environment of selection led the firms to adapt their technology strategies.

Since the middle of the eighties, in the case of oil industry, large operators (producing oil firms)

have implemented new technological strategies under the influence of two factors. Initially the constraint of decreasing costs did not leave other possibilities except reducing also the financial effort for the in-house R&D. Then the conviction emerged that a new active and sustainable technology policy in the medium term could be developed by outsourcing, under some conditions, part of this R&D with reduced costs and an increased efficiency. This evolution led the operator companies thus to divide their average intensity of research by a factor 2, from 1 to 0,5% approximately. An initiative taken by British Petroleum in 1992 consisted in considering that within the operations of R&D formerly carried out in-house, a part – the so called "not patrimonial" or "pre-competitive" one - could be either completely, or partially (in partnership) outsourced. Moreover, whereas the cases of technological co-operation between operators and suppliers remained the exception until in the 1970's, one observes since the counter-shock an increased sub-contracted research and/or research undertaken in collaboration.

For the oil services firms, suppliers of equipment, the challenge to take up is also difficult. Faced with a partial disengagement of the large oil companies from a range of technological activities, and considering their modest size compared to their customers/operators, a new organisational capacity is required. The majors of the oil services industries rather systematically carried out in the 1990's decade the widening of their lines of activities, generally by external growth. Finally the integrated oil services companies keep a competitive advantage in this field, especially when this specificity rests on an very reactive internal organization close to the oil companies needs. Available information on the research intensity of the American oil services firms seems to show at the same time a preservation of a 3% average intensity, and important variations for individual firms around this average ratio.

Between the two categories of firms, the technology relations seem to evolve from commercial relations in the short run in open and competitive markets (during the decade 1980) towards

partnership relations founded on more integrated oil services.

In the case of electric industry, the general observation on technology strategies starts from a basic statement : the massive disengagement of the operators from technological creation and the corresponding fall in efforts of R&D since the mid-eighties *(*Dooley, 1998)[13]. Because of institutional changes instituting or reinforcing competition, new entries on the power market and new types of operators closed to merchants of services, explain the major transformations of the power producers' job. However, what is true as regards creation of specific cognitive resources dedicated to innovation is not valid for the whole of the specific cognitive resources of these firms : if on one hand it is possible to note a fall of the efforts of creation of the formers by the firms producing electricity during these 15 last years, it is also clear that on the other hand these firms strongly developed specific cognitive resources in the knowledge of markets and the management of financial assets, in response to their new environment of competitive selection.

Moreover with this first evolution between 1985 and today, technological partnerships between operators and suppliers disappear, if they still existed, and technological networks focus around the four or five largest world suppliers. Geographical corrections must be made in the national variety of the old model. When relationships between operators and suppliers at a national level are closely assessed, such as S. Thomas (1995)[14] does it, they apparently existed only in the United Kingdom, France, Japan and Italy, with a very variable economic efficiency according to the specific cases. A contrario the disappearance of this relation did not take place in the countries where it had never really existed, such as in the United States, and to a lesser extent in Germany.

The overall assessment of the R&D efforts by the electrical equipment suppliers is more delicate insofar as i) activity of production of heavy electric components is only one segment among many others for these multi-products firms, ii) R&D intensities for each of these activities can

vary within large range, iii) finally these indicators are not in general documented by line of activity. Information on the evolutions of average intensity of R&D suggest the assumption of a tendency to an erosion of the R&D effort, approximately from 4,2% to 3,8%.

It is important to recognize that R&D intensity figures may be quite fragile concerning the biggest energy firms. Indeed, all these firms share several points for that. First, figures are given all included activities. The major operator firms do not only have energy production activities but also, for example, electricity distribution or oil refining activities. The big firms in electric equipment are highy diversified, as mentionned above. Figures are consequently too much aggregated, insofar as R&D intensity strongly vary from an activity to another. Second, we know that firms are reluctant to give information concerning R&D expenditures. Thus data available are often partial and disrupted in time, and as a result present a lack of consistency. Third, firms use accounting manipulations to overestimate, or on the contrary underestimate R&D expenditures, if it is better for reputation in the first case, or for shareholders' trust in the latter. However all these caveats, we can stand on several majors sectoral information sources (UNIPEDE, 1998[15] ; Dooley, 1998 ;Defeuilley and Furtado, 2000[16]), which all converge to the same conclusion : that of a fall in R&D efforts by the operator firms, and of a slight decline in R&D efforts by the equipment supplier firms.

The whole of these transformations can be linked with the highlighting, in the literature, of the evolution of the technology strategies of large firms ; that evolution is drawn from observed stylized facts concerning all the industrial sectors. We can make a series of assumptions regarding the ability of the firms of the energy industries to follow this evolution.

Table 2

To assess the validity of these assumptions in our energy industries case, we use a quantitative test based on the number of granted patents to the firms. We thus have indicators of the technological production of the firms[17], which makes it possible to identify where are located the dynamics of knowledge production in energy industries, within a general context of stagnation of R&D efforts by the firms.

3 Methodology and data

The quantitative analysis is based on the indicator of the number of granted patents to each to the first fifteen world groups belonging to the four categories of actors over the period 1985/1998 (selected according to their decreasing turnover) and in a given technological field (see in methodological appendix 1 the list of the selected firms, and in appendix 2 the technology field definition). To limit the effect of the annual fluctuations within an analysis of mid-term period, five reference years are defined: 1986 (the three cumulative years : 1985, 1986, 1987), 1989 (the three cumulative years : 1988, 1989, 1990), 1992 (the three cumulative years : 1991, 1992, 1993), 1995 (the three cumulative years : 1994, 1995, 1996), and finally 1998 (the two cumulative years 1997 and 1998).

Regarding the numerous fusions/acquisitions of this period affecting mainly, but not only, the supplier companies, the variations of the composition and of the frontier of the firms are taken into account by counting these patents under variable frontier definitions for each of the five references years. To implement this method, a data base was made up starting from various

sources of which those of the dictionary " Who owns whom " of Dun & Bradstreet to establish the composition of each group at these five different dates.

To limit the effect of national bias, the recension was carried out on the granted patents in the United States (by the USPTO) and on the filed patents in Europe (by the OEB) ; these data have been provided by two specialized patent data suppliers.

The recension is initially carried out on the level of the granted (filed) patents to the patentee, then this one is attached to the parent company of the group if they are two distinct firms, for example in the case of a subsidiary company, and if the case arises bearing a different name. Thus a consolidation is obtained at the corporate level for the controlled patents and for each of the five years under review.

The two electric and oil technological fields, called FELEC (Fields of technology implied in ELECtricity production) and FOIL (Fields of technology implied in OIL production), were respectively defined by the agglomeration of respectively 30 and 8 classes of patents (see in methodological appendix the identification of the corresponding International Patent Classes)[18].

A complementary qualitative analysis was carried out by several interviews in two supplier firms of world level importance, Alstom Power for the heavy electrical equipment related to electricity production, and Schlumberger for the oil fields services and equipment related to the production of hydrocarbons.

4 Evolution of the technology performances of the energy industries firms

The below presented results come from the exploitation of the granted patents by USPTO.

The granted patents to the the firms of our sample, for all technological fields together, represent over the period between 9,3% and 10,8% of the total of the granted patents including all patent classes and all patentees. These are thus important firms, which count in the world granted patents by USPTO, all the more since average low R&D intensity is observed in their sectors of origin.

Granted patents for the firms to our sample represent in their technoloy fields Foil and Felec between 0,98% and 1,38%, over the period, of the total of the granted patents, all patent classes and all patentees included. In 1992*[19], the share is the weakest one : it seems that this period marks a transitory fall of the granted patents to these firms in the Foil and Felec fields.

The relative share of the in the Foil and Felec fields patents to their grants within all classes included globally tends to decrease : from a 15% in 1986* to 12% in 1998* (with a fall to 9% in 1992*, which deals with the above remark). In general these firms are diversifying their technology activities, or they are leaving energy sector, or they are moving away from energy precisely in the Foil and Felec technology fields. These three assumptions can explain simultaneously or separately that trend.

Between 1986* and 1998c*, the absolute total number of granted patents of our sample firms in the Foil and Felec technology fields has noticeably increased: +61% (that is to say 3055 in 1986* and 4932 in 1998c*) in spite of the fall of 1992* (- 21% compared to 1989*) then over compensated (table 3). Thus efficiency of the R&D efforts seems to be high when taking into account the slowdown of R&D intensity.

Table 3

Splitted data by category of firm

Table 3 brings the following major result : the considerable increase in the technology performances of the equipment suppliers compensates for the continuous erosion of the granted patents to the operators.

As a preliminary the two following technical observations can be stated :

- the 1992* fall relates to all the categories.
- granted patents to the electricity equipment suppliers (se) are much more numerous than those of the other categories : 2 to 3 times more than those of the suppliers so, 2 to 10 times those of the operators uo, 50 times those of the operators ue. Thus propensity to patent is characterized by sectoral differences, although this gap is linked, but not only, to the more important number of electricity patent classes than the oil ones : 30 in respect to 8.

The presented results by firm's category show primarily that :

1) se and so suppliers have a strong progression over the whole period : +118% for se (with a rise from the very start of the period) and +85% for so (with a later rise, started in the nineties)[20].

2) Oil operators uo have an almost continuous fall of their patents (- 63% over the period).

3) Electricity operators ue have very few patents[21] (some tens per period of 3 years) from the very start of the period. Their increase over the period (33 in 1986* versus 67,5 in 1998c* : +103%) must be relativized by the weakness of the absolute figures, in respect to the total amount of granted patents in Felec classes. Moreover, when taking into account the financial size of our sample's firms, this increase does not seem to imply an effective change of their R&D strategy[22].

These results support the assumption of a relative technological disengagement of the operators while at the same time the suppliers reinforce their technology contribution.

Splitted data by category and geographical origin of the firms

They show (table 4) that these trends are variously followed in Europe, United States and Asia (Japan and South Korea).

Table 4

Presented by category of firm, the tendencies are the following ones :

1)For suppliers, increase in the granted patents mainly come from european firms (+265%, that is to say from 357 in 1986* to 1305 in 1998c*) ; their relative weight shifts from 23% to 39% in total patents (first place in 1998c*). In comparison the increase for the Japanese firms is +76% and +70% for the United States firms. One thus observes a technological specialization of the European firms in electrical engineering.

2)For so suppliers[23], the increase in the granted patent is drawn at the contrary by the United States firms (+99% , i.e. 507,5 in 1986* in respect to 1008,75 in 1998c*), although this rise only concerns the nineties. The european firms [24] record a lower increase (+25%), which reduces their relative weight in the total of the patents from 18% to 12%. Thus a technological specialization of the United States firms in the oil services industry is confirmed.

3)For oil operators (uo), the reduction of the number of granted patent is equally distributed between European and United States firms (- 63%). The relative weight of European firms is consequently maintained to 16% of the total, and the technology domination of the United States firms is confirmed.

4)For electricity operators ue, technological withdrawal is only noticeable for European firms (19 en1986* and 18 en1998c*) whereas the Asian firms know a strong progression (2 in 1986* and 12 in 1998c*), as well as EPRI institution (principal actor controlling the electric power operator patents) in the United States (12 in 1986* and 37,5 in 1998c*). But these absolute values show generally very low technology effort throughout the period.

These results show that the technology efforts by suppliers vis-a-vis the relative withdrawal of the operators was simultaneously carried out with an international specialization : for the United States firms, it was based on a historical advantage of their nation in the oil sector, whereas for the European firms, it was built in about fifteen years without starting from a dominant position (in 1986* they arrived in last position of granted patents, behind the Asian and the United States firms) in the heavy electrical equipment[25] .

Distribution of the granted patents between firms

Table 5 shows that concentration, measured by the share of the granted patents to the quarter of the largest patentees firms, is variable according to categories.

se and so suppliers commonly have a stronger concentration. Oil operators keep a weak concentration even if it slightly increases. Concentration in the electricity operators increases at the end of the period, but always remains not very significant because of the low implied numbers.

Consequently one can see that for suppliers (and electricity operators at the end of the period), there are technological leaders and " small " firms (at the technology level) whereas for the oil operators firms have more comparable technological weights.

Table 5

Distribution of the granted patents between the countries of origin of the firms

Table 6 reinforces the conclusions on increasing respective specializations of the United States and Europe.

Table 6

The oil operators uo are clearly characterized by a high geographical concentration for the patentees firms, which corresponds to the leadership of the United States firms in this field.

The concentration is also rather high in the so suppliers, there still because of the leading United States firms.

On the other hand, for se suppliers, geographical concentration decreases and becomes weak, which shows the reinforcement of the European firms, these firms originating from various countries.

All in all, geographical concentration is higher in oil because of long term technological advantage for the United States firms in this sector.

The whole of these results underlines the rise of the equipment suppliers in the technology creation in the energy industries, as well as the international specialization which accompanies it.

How to interpret these results ?

5 New networks of technological creation in energy industries : going upstream and redistribution of the roles between suppliers and operators

To what extent the observed changes in performances and technology strategies of the operators on the one hand, and the suppliers on the other hand, are convergent with the analyses of the literature predicting the shift from an integrated managerial strategy to a network coordinated strategy ?

Patents data show a general shift of technological production from operators towards suppliers in energy industries. In order to assess if that shift lies on organizational changes of the firms with a growing importance of networking, we met research and development executives in both operator and supplier firms[26].

If one may display a common dynamics to both industries consisting of the formation of technology learning networks more and more focused on suppliers, notable differences remain which origin lies in the operators role. Nevertheless, even when these latter ones withdraw completely from technology creation, they keep an essential function in the definition of the directions of the technological standards within their sector.

Unequal relevance of the predictions of change of technology strategy model for the operators

The case of oil operators

Two types of firms must be distinguished in this field.

- General evolution of the four or five Western majors lies rather within the scope of the predictions. Indeed, the prospect for a restriction of their technology activities to the only function of " architect " seems not very likely, insofar as the continuation of a reduced but still effective effort of in-house technology creation remains decisive in their technological advantage, and thus a necessary aspect of their competitive survival. However the outsourcing policy carried out since the beginning of the nineties decreases their role of head of network in the technology learning for drilling-exploration.

- Second-rank firms on the other hand move away more from the ideal model of coordinated learning in network. Technology fields, they have outsourced, are less and less controlled and become the object of speciality subcontracting. It is not only any more a question of rationalizing the technology efforts while externalizing elsewhere investigations and developments for which skills are preserved, but of costs decreasing by giving up technology fields to outside organizations in charge to take up the dynamics of learning.

The case of the electric industry operators

Their quasi-total withdrawal of technology activities radically diverges with the predictions of pattern change. Whereas until the eighties, they constituted in certain areas a central actor[27] of the system of learnings shared between their suppliers and themselves, taking care with the tests, maintenance, definition of the improvements by using, they are limited today either to broadly specify technical requirements founded on objectives of management, or to require minimum technical performances from their suppliers ; they do not any more express concern for pushing back limits of knowledge in the field of energy conversion.

Such an evolution could characterize, on the technology level, an industry arrived to a maturity

stage and to satisfying standards for society. However it is far from being the case. This industry on the contrary is concerned with major technology stakes, at a world wide scope, and with an increasingly time-constrained agenda, in a context of awakening to ecologic issues and need for conversion systems based on renewable resources and clean technologies.

Moreover, the advantages for these firms of such strategies are destined to be exhausted in the medium term. They are likely to pay dearly for the preservation of their short-term profitability and their withdrawal of the effort of innovation. For their aging and not renewed cognitive base will not allow them any more in the long term, either to keep the control of the their plant operations (transferred to engineering companies or to equipment suppliers), or to face possible irruption of a major technology from a competitor (their capacity for absorption being insufficient), or finally to face a possible natural gas price increase (which would make alternative technologies cheaper than the gas turbine with combined cycle, but more complex to control and operate).

In the case of the electricity operators as well as the second rank oil operators, a consistency problem is thus likely to arise with their medium-term selection environment. Moreover technology stakes, more defined at a society level, are considerable, and therefore require the continuation of research, whereas these firms do not renew sufficiently any more their technology knowledge to face them. The dynamics of learning of the whole industry may continue to develop under these constraints only if it is fulfilled by other actors who can replace the withdrawal of the operators : it is the role now played by the equipment suppliers.

Do these latters organize their technology activities consistently with the general evolution towards network dynamics ?

The supplier firms are incited to self-organize in networks, but moreover to take the lead

The displacement of the head of the technology networks towards suppliers

The technology dynamics of the two energy industries depends today on the main contribution of the equipment supplier firms. Our empirical results, and in particular the granted patents indicator, show that this contribution, in about fifteen years, became exclusive for electricity, and increasingly dominant for oil.

The suppliers thus appreciably increased their technological efforts in spite of their increased constraints on selling prices and of the mediocrity of their profitability ratios. By doing that they succeeded in acquiring specific capabilities which they hope to market to other customers while continuing cumulative learnings.

During these last 15 years, we asssited to an undeniable rise of the suppliers in steering the technology networks, where they become the " heads " of these networks, either in all technology fields (electricity case), or in a majority of them (oil case).

This phenomenon of "going upstream", i.e. towards the suppliers of specialized equipment, in the technology creation is to be compared to similar movements in other oligopolistic industries. As described by A. Kesseler (1997)[28], a shared design between suppliers of specialized equipment and car manufacturers in the car industry is emerging. Whereas car manufacturers previously distributed design issues to suppliers while keeping necessary skills to carry out it, today they give up specific skills for certain areas, and consequently require from their suppliers an important development of their R&D resources. However in the car industry, it seems that the general organization of technology dynamics continues to be based on the car manufacturers[29]: the head of network remains downstream.

In energy industries, the many mergers and acquisitions by suppliers allowed the constitution of very large firms. These last ones, requested to increase their technological effort, reorganized their technology activities in order to fill expectations in term of steering while preserving a minimum profitability. This reorganization seems to correspond to the network evolution which is mentionned in the literature.

The network organization of the technology activities of the suppliers

If the technology contribution of the suppliers considerably increased since about fifteen years, it falls under a very clear trend of the operators to outsource part of their technology activities in order to decrease costs while developing the interactions with third parties for increasing learnings.

Thus suppliers, at their turn, do not any more hesitate to outsource part of technology activities related to their job, either by progressive investment withdrawals, or by new contracts with their own components and systems suppliers, or universities. However, skills preservation in the outsourced technological fields seems to remain the rule : it is a characteristic of the head function.

We can notice that this network development goes at the same time with the quasi-removal of traditional partnership relations with the customers/operators, because of their absence of will and/or skills to do it. It thus appears that suppliers rebuild network relations with their own "upstream" suppliers, with an aim of continuing the vertical interactive learnings essential to the dynamics of creation of knowledge, in accordance with the thesis of B. A. Lundvall (1988,1992)[30].

Moreover the validity of Lundvall analyses about the essential character of the user-supplier

relations in learnings must be emphasized if we do not forget that the heavy electric component suppliers profitably use the imposed constraints by their customers to implement " learning by using "types (Rosenberg, 1982)[31] during maintenance and operation activities which their customers ask them to carry out[32]. In that configuration learnings are not very interactive because of the customers' inertia, but nevertheless suppliers recover first hand information on the performances and problems of their equipment, information which later on can be transformed into learning capabilities.

Finally suppliers improve their networks in a complementary way in direction to other partners than their own suppliers and subcontractors and their customers. The multiplication of partnership agreements with the universities (for example with the observation of the Schlumberger case) as well as the licence agreements (for example in gas turbines) or technology co-operations between competitors (for example between General Electric, Rolls Royce and Pratt & Whitney in the field of the maintenance/reparation of turbojets) are the demonstration.

An apparent paradox : the increased technology efforts by the suppliers remain defined by the operators' expectations

If the network head was transferred "upstream" concerning technology creation, bargaining power by operators and impulse of the great technical changes remain still "downstream".

Asymmetry of bargaining power between suppliers and operators

This asymetry is partially based on differences in average size between operators and suppliers companies, which are very obvious in the oil case. Even if suppliers' size grew under the effect

of a powerful movement of concentration, these firms are not able or do not want to react by operations aiming at the capital control of their customers, which often are very large firms. But beyond this starting limit, two explaining factors of the operators' bargaining power may be mentionned. They mean now lower entry barriers on energy markets, which were previously looked as weakely contestable ones by firms suppliers.

On one hand despite the suppliers' rise in technology networks, the electric as well as the oil operators, with the new competing rules, may constantly select their suppliers at the world level on the basis of best quality/price ratio. The only exception is observed when prices increase during the rare period of simultaneous – and partly mimetic - orders from the operators. Apart from such periods suppliers cannot escape from the constraints imposed by their customers in the definition of the equipment specifications and in the the charged prices. For much of them that explains increasing diversification of their activities towards higher added value sectors.

On the other hand, despite the efforts by the suppliers to renew or improve technologies, those tend also to be quickly standardized because the 'tailor-made' practice is expensive in investment and operation for the customers. Consequently the conditions of an effective use of technologies are less difficult to fill than before, for example with the extreme case of gas turbines in opposition to the nuclear power stations. The active contribution of suppliers is thus necessary, less for reasons of their knowledge and skills specificity than for reasons of costs and withdrawal of the operators from this category of activities of the production. One illustration is provided by the increasingly important place which is reached by specialized firms in architecture-engineering (Bechtel for example), in particular in the United States, for the supply of maintenance and operation services.

To the exception of the leader, equipment suppliers thus loose gradually their bargaining power by not controlling exclusive and absolutely necessary knowledge for their customers any more ;

these customers can consequently put suppliers in a competitive bargaining, and even with incumbant specialized firms which are committed in a market shares race.

The impact of the principal technology orientations by operators

The respective evolutions of suppliers and operators concerning the sources of technology dynamics of their sectors are very contrasted. By using again the K. Pavitt's (1984)[33] taxonomy, it appears that the suppliers belong more and more distinctly to the category of the sectors whose technological trajectories are based on science (" science based "). On the other hand, the operators shifted from sectors with technological trajectories based on science to sectors with technological trajectories dominated by the suppliers (" supplier dominated ").

However, it does not mean that these operators remain passive in the configuration of the technologies they use. On the contrary, their capacity of initiative in the great technological stages reached by their equipment suppliers did not stop growing. It is not based on an improvement of their skills in the field since their withdrawal of the technological effort is clear. But it is based on the reinforcement of their bargaining power.

In that negotiation to their advantage, operators lean express requirements due to new institutional rules, new competitive conditions, and also to a lesser extent, society's new expectations. The requirements consist of criteria of reliability, costs and broad design features (size, flexibility for the electricity production, adaptation to the new natural conditions for oil exploration and exploitation). Thus it is increasingly frequent that the respect of minimal performances for the user is guaranteed by contract with the payment of possible penalties.

The evolution of the technologies produced by the suppliers since the eighties thus was almost entirely determined by the goal of matching the requirements of the operator firms. Capacities of

initiative, of mobilization of scientific knowledge to propose entirely original and new configurations (for example in the nuclear power) by suppliers were reduced to the profit of the concentration of research in fields increasingly considered as standards (for example the gas turbine and tomorrow may be fuel cells). These equipment suppliers in energy industries, while dealing with " science based " sectors, know today a technology dynamics which is typically drawn by market demands, to refer again to the opposition of J. Schmookler (1966)[34] between technological dynamics pushed by the science and pulled by demand.

6 Conclusions

The principal lesson is ultimately the following : to entirely understand network dynamics which is described in evolutionary litterature, it is advisable to widen the empirical field of analysis by associating to the operators of energy industries their suppliers of equipment. Then the networks formation appears more complex than an approach limited to the operators does. Indeed dynamics of the networks of technological creation must be distinguished from that of the networks of competitive advantages and bargaining power creation.

If the first one is characterized by an upstream going up of the head of the networks towards suppliers, the second one continues to be based on the operators and their strategies of adaptation to the constraints and opportunities of their institutional, financial and competitive environment.

On the whole a confirmation thus appears about the validity of the analyses about the interactive processes of the innovation and the rise of the network organization of the firms, as well as about the eminent role of the user-supplier relations in these processes. It is however the assessment of

the strategies and performances of the supplier firms which gives an illustration of these relations, and in addition allows to note the increased efficiency of declining research efforts. But structuring of these relations in the networks, and its more or less great efficiency, also depend on new competitive rules, in which strategic initiatives of leader supplier companies and customers operators, new financial environment of selection, and the institutional changes play each a role.

Appendix

Appendix A-List of the firms

The table below reproduces the complete list of the four categories of firms which constituted our sample. Taking into account the many fusions, acquisitions or impartitions which have occurred during the 1985/1998 period, each category is based on a set exceeding the figure of fifteen groups.

1-Group of the suppliers of equipment of production of electricity : Siemens Ag (D),General Electric Cy - Ge (US), Abb Asea Brown Boveri Ltd/ABB Ltd (CH), Alstom (F), ALCATEL Alsthom, then Alcatel (F), The General Electric Co plc- GEC- (U.K.), Hitachi Ltd, then Hitachi Corp (J), Mitsubishi Corp then Mitsubishi Electric Corp then Mitsubishi Heavy Industries Ltd (J), Toshiba Corp (J), Fuji Electric Co Ltd (J), International Babcock Group plc (U.K.), Foster Wheeler Corp (US), Framatome (F), British Nuclear Fuels plc (U.K.), Rolls-Royce plc (U.K.), Gec Alsthom (50% GEC 50%Alcatel)(F/UK), Abb Alstom Power (50% Abb 50% Alstom) (F/CH), Westinghouse Electric Cy a subsidiary of CBS Corp (US), J M.Voith GMBH, then J M. Voith AG (D), JV (50/50) between Siemens AG (hydraulic) and J Mr. Voith AG, Allied Signal Engines (US) a division of Allied Signal Inc Building, Kvaerner Group Have, then Kv Rner Asa

(N), Asea AB, then ABB AB (S), Brown Boveri &Cie AG, then ABB AG (CH),Westinghouse Electric Cy (US), AEG, a subsidiary of Daimler Benz-Daimler Benz AG, then Daimler Chrysler (D), Nuovo Pignone (I), Ansaldo has sub of IRI (I), Jeumont Industry (F), Combustion Group Engineering (US), Northern Engineering Industries (NEI-UK), MAN Energy (D) - a division of MAN group, ACEC Energy (B), Franco Tosi S.p.A (I), Ercole Marelli & Co. S.p.A.-Marelli (I), Allgemeine Elektrizitäts Gesellechaft-AEG (D), FKI electricals group a subsidiary of FKI plc. (U.K.), Babcock (U.K.), The Signal Companies (US),Allied Corporation (US), Mitsubishi Heavy Industries Ltd (J).

2-Group of the suppliers of the oil fields services industry : Halliburton Cy (US), Dresser Industries Inc (US), Schlumberger Limited Inc (US), Baker Hughes Inc (US), International Weatherford Inc (US), International Smith Inc (US), BJ Services Company Inc (US), Coflexip SA (F), R&B Falcon Corporation (US), Nabors Industries Inc (US), Global Marine Inc (US), Bouygues Offshore, a subsidiary of Bouygues (F), Compagnie Generale de Geophysique SA-CGG (F), Western Geophisical then Western Atlas Inc Building, a subsidiary of Litton Industries Inc (US), Dailey International Inc, a subsidiary of Lawrence Industries Inc Building (US), Landmark Graphics (US), Energy Ventures (Inc) (US), Enterra Corp (US), Falcon Drilling (US), Reading & Bates Corp (US), Camco Inc a subsidiary of Pearson Inc (US), Stena Offshore (N), Western Atlas Inc (US), Baker International Inc (US), Hughes Tool Inc (US), Camco (CA) Ingersoll Rand (US), Hydrill (US).

3. Group of the operators of the production of electricity : Tokyo Electric Power Cy Inc (J), Electricité De France (F), RWE AG (D),VIAG AG (D), ENEL Spa (I), Kansai Electric Power Cy Inc. (J), Chubu Electric Power Cy Inc (J), Duke Energy Corp (US), PG & E Corp (US), RAG AG

(D), Dynegy Inc (US), Southern Cy Inc (US), Entergy Corp.(US), International Edison Inc, Preussenelektra AG a subsidiary of Veba AG (D), Texas Utilities Cy Inc (US),Vattenfall AB ,National Power Plc (UK), Powergen Plc,Central Electricity Generating Board-CEGB- (U.K.), EPRI(US) .

4-Group of the oil operators : Exxon (US), Mobil (US), RD Shell (Netherlands / U.K.), BP (U.K.), Amoco (US), Total (France), Petrofina (Belgium), Elf Aquitaine (France), Texaco (US), Chevron (US), ENI/Agip (Italy), PDVSA (Venezuela), Petrobras (Brazil), Dupont de Nemours/Conoco (US), Statoil (Norway), USX/Marathon(US), Phillips Petroleum cy (US), Atlantic Richfield/Arco (US).

Appendix B The selected patents classes in the oil and electricity production according to the nomenclature" International Patent Classification"

Foil includes the whole of technologies of oil and gas exploration/extraction, for the oil operators, and for the firms of the oil services industry, with the following patents classes (IPC nomenclature) : E21B, G01V,B66 C,F04,G01 R, C09K, H04,G05.

Felec includes the whole of technologies of production of electricity, for the operators (electricity producers) and for the firms of the heavy electrical equipment, with the following patents classes (IPC nomenclature) : E02B, F01D, F02B, F02C, F03B, F03D, F22B, F23, F24 J, F28, G2Ç,

H01M, HO2K, E02D, F01K, F01P, F02D, F02G, F02K, F04, F22D, F22G, G21B, G21D, G21 F, G21 H, HO2N, HO2P, G05, HO5K.

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* *

Table 1 : Technological strategies of the multinational firms (1970-2000)

Years 1970-1985 Integrated managerial strategy		Years 1985-2000 Network coordinated strategy	
Core activity of the firm + several closely related areas	Strong in-house R&D Centralized R&D	Core activity of the firm	Lower in house R&D Increasing internationalization of R&D
Other closely related areas	Technology acquisitions, by R&D subcontracting , by purchasing of equipments	Closely related areas	Horizontal and vertical partnerships (in particular with the equipment suppliers) Increased internationalisation of the partnerships (directly by international cooperation or indirectly by benefit of international network of partners)
	Technology acquisitions by integration of new merged units within the firm	Secondary areas	Technology acquisitions: -R&D subcontracting -purchase of inputs and equipments -takeover of small units

Source : authors

Table 2 : Schematization of the technology strategies by category of actors and period (1970-2000)

	1970-1980 decades	1980-1990 decades
U (Users)	**Uo**: managerial integrated firms (in-house R&D) + sub-contracting by small batches of goods and services **Creation of technology resources**	**Uo** : network firms : externalize a part of R&D, technology partnerships with their suppliers, function of 'architect' **Creation of technology resources**
	Ue: closed to the network firm, integrated local or national monopolies, partnerships with national suppliers **Creation of technology resources**	**Ue**: withdrawal from any R&D, acquisition of turnkey equipment **Allocation of technology resources**
S (Suppliers)	**So** (**S**upplier of the **o**il industry): sub-contracting suppliers, small size, dominated R&D, rather weak **Creation of technology resources**	**So** : increasing,even leading, role, in technology creation, search for partnerships with Uo **Creation of technology resources**
	Se : national suppliers of home based monopolies (exception : United States with international markets), partnership in R&D **Creation of technology resources**	**Se**: single technology generator, in relationships with public authorities Turnkey suppliers, and sometimes with financial guarantee of technical performances **Creation of technology resources**

Source : authors

Legend : (U : firms users of equipment with Uo : firms of the oil production and Ue : firms of the production of electricity ; S : firms suppliers of equipment with So : firms of the oil services industry and Se : firms of the heavy electrical equipment)

Table 3 : Granted patents at the USPTO per reference year and per category of firm (Foil and Felec)[35]

Patents number	1986*	1989*	1992*	1995*	1998c*	1998*
Se	1524	2151	1823	2281	3322,5	2215
So	622	618	524	841	1152	768
Ue	33	38	28	43	67,5	45
Uo	876	833	509	546	390	260
Patents total	3055	3640	2884	3711	4932	3288

Source : authors from Derwent

Table 4 : Granted patents by USPTO per reference year, category of firm and geographical origin of the firm (Foil and Felec)

Se	1986*	1989*	1992*	1995*	1998c*	1998*
USA	560	881	798	932	951	634
Europe	357	493	445	681	1305	870
Asia	607	777	580	668	1066,5	711
Europe in %	23	23	43	30	39	
So	1986*	1989*	1992*	1995*	1998c*	1998*
Usa	507,5	483	403,5	692,5	1008,75	672,5
Europe	167	221	198	242	143,25	95,5
Asia	0	0	0	0	0	0
Europe in %	25	31	33	26	12	
Ue	1986*	1989*	1992*	1995*	1998c*	1998*
Usa	12	5	11	24	37,5	25
Europe	19	19	9	15	18	12
Asia	2	14	8	4	12	8
Europe %	58	50	32	35	27	
Uo	1986*	1989*	1992*	1995*	1998c*	1998*
Usa	733	709	396	401	327	218
Europe	143	124	113	145	63	42
Asie	0	0	0	0	0	0
Europe in %	16	15	22	27	16	

Source : authors from Derwent

Table 5 : Share of granted patents by USPTO to the quarter of the firms constituting the largest depositors, by category of firm (Foil and Felec)

	1986*	1989*	1992*	1995*	1998*
Se	0,73	0,68	0,64	0,60	0,67
So	0,75	0,76	0,75	0,77	0,64
Ue	0,45	0,51	0,48	0,70	0,69
Uo	0,46	0,54	0,51	0,58	0,52

Source : authors

Table 6 : Standardized Herfindahl index of the granted patents concentration according to the country of origin of the firm and by category of firm (Foil and Felec)

	1986*	1989*	1992*	1995*	1998*
Se	2170	2000	1926	1614	1203
So	5242	4576	4361	5438	5645
Ue	744	824	1782	2453	2498
Uo	6145	6815	5470	4939	6534

Legend : if the value is close to 0, the concentration is very weak; if it is close to 10000, the concentration is very high). Source : authors

Notes and references

[1] Such as, for example the case of Air Liquide which enters the field of the fuel cells, and then energy hydrogen markets.

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[4] The specific cognitive resources dedicated to innovation form part of a greater set: specific cognitive resources of the organization conceived as the base of specific competences in various fields (technology, knowledge of the customers and suppliers markets, knowledge of the regulations, lobbying, organization of the company and the employees, operations on the capital markets...). We focus here on a particular category of specific cognitive resources, those dedicated to innovation.

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[12] B. A. Lundvall, 'Innovation as an Interactive Process : From User-Producer Interaction to National Systems of Innovation', in: G. Dosi, C. Freeman, R. Nelson, G. Silverberg & L. Soete (eds), **Technology and Economic Theory**, (London, Pinter Publishers, 1988), pp. 349-369.

[13] J.J. Dooley, 'Unintended consequences: energy R&D in a deregulated energy market', **Energy Policy**, 26 (7), 1998, pp. 547-555.

[14] S. Thomas, **User-Producer Relations in a Competitive Electricity Supply Industry**, (Brighton, SPRU/STEEP, 1995, Discussion Paper n° 19).

[15] Unipede (1998), *R&D in Unipede countries, Overview of R&D organisation and projects, 1998 Update*, Research & Development group, December, Ref 1998-150-005 (Rapporteurs : J.Y. Delabre, E.M. Peresso)

[16] Defeuilley C., Furtado A.T. (2000), 'Impacts de l'ouverture à la concurrence sur la R&D dans le secteur électrique', **Annales of Public and Cooperative Economics**, vol. 71, 21 p.

[17] Indicators of granted patents are not however the only indicators of the technological production of a firm, as long as all technology innovations are not conditioned by a patent, and as propensity to patent an invention varies from one sector to another, from one firm to another, from one technological field to another. In spite of that, granted patents may be looked as a proxy of the output of the efforts of innovation of a firm (cf. the controversy between S.Rosenblum and F.Malerba and L.Orsenigo in Research Policy n°29, pp.1185-1188, 2000).

[18] To check the relevance of the top-fifteen firms choice, we calculated the part of both operators and suppliers in the total number of granted patents in their respective technlogical field (Foil for uo and so and Felec for ue and se). In 1985-86-87, ue+se represented 76% and uo+so 50% of the total. In 1997-98, ue+se represented 90% and uo+so 46%. The top fifteen firms' characteristics can therefore be considered as representative.

[19] Each year with an asterisk indicates one reference year, i.e. the median year of a 3 years period. For example, 1992* indicates the period 1991-1992-1993. However for 1998*, figures deal with the 1997-1998 period : they are thus multiplied by 1,5 to give 1998c* when we analyze quantitative evolutions of the granted patents.

[20] Part of the se increase could come from growing size operations towards small firms outside the initial sample, as suggests the shift from 76% in 1986* to 90% in 1998* of the part of ue+se in the total number of patents granted in Felec. However, that shift can also show a trend of the required size and power for innovating to elevate, and therefore a growing technological advantage for leaders.

[21] By assumption electricity transport and distribution patents are not taken into account in this paper.

[22] This statement would be obviously different in the case of small and medium size enterprises.

[23] Because of the bi-national character of Schlumberger and its home-based location in two different reference areas , we allocated half granted patents to the United States firms and the other one to the European firms.

[24] It is pointed out that our statistics do not include the upstream patents from IFP.

[25] These results are observed although in the same time General Electric, the world technological leader of the sector in particular in gas turbines, is American.

[26] The operator firms are TotalFinaElf and EDF ; the supplier firms are Schlumberger and Alstom Power. In these latters we made a series of interviews.

[27] To the already mentionned exception of USA and Germany.

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[29] In particular because the size of many supplier companies remains small.

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[31] N. Rosenberg, **Inside the Black Box : Technology and Economics**, (Cambridge University Press, 1982).

[32] This extension of their initial activities –hardware suppliers-to maintenance and operation activities is also looked for by the suppliers themselves, because they are more profitable than the traditional activities of production of material goods.

[33] K. Pavitt, 'Sectoral Patterns of Technical Change : towards a Taxonomy and a Theory', **Research Policy**, 13, 1984, pp. 343-373

[34] J. Schmookler, **Invention And Economic Growth**, (Cambridge, Harvard University Press, 1966)

[35] For the computation of the patents granted to the firms in Foil technology field, we consider only patents granted to uo and so firms. Similarly, in Felec technology field, we consider only patents granted to ue and se firms. In other words, patents granted to ue an se firms in Foil, and patents granted to uo and so firms in Felec are dropped.