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Eco-innovation, knowledge capital and the evolution of the firm

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Abstract: The purpose of this paper is to study the place of eco-innovation in industrial firms' current strategy and to understand how they achieve this change in their technological trajectory. It is mainly based on interviews achieved within eight corporations settled in France in 2009-2011. We find that in a context of crisis, the firms consider eco-innovation as a new path, able to generate growth in the future. To refocus their strategy, they have reorganized their “knowledge capital”, a concept which we consider as a tool to study the dynamic capabilities needed to achieve change. The capability to develop collaborative research appears central to develop eco-innovation for two reasons: the necessity to share the costs and the risks of development; the necessity to comply with the various aims and objectives of the stakeholders implied in this type of innovation oriented towards sustainability. Even if the importance of collaboration to develop eco-innovation is confirmed in the literature on eco-innovation, our study relies on eight cases and we aim to extend it to develop our understanding of eco-innovation development at the firm's level. This will also be done notably by including small firms in our population in order to understand the role of size in the development of the capabilities needed for scientific and technological networks management. This paper contributes to the literature on the capabilities needed to achieve change, improves the analysis of the roles of collaboration in the case of eco-innovation and illustrates these ideas with original cases.

Key words: eco-innovation, evolution, firm, capabilities, knowledge capital, collaboration

Eco-innovation, knowledge capital and the evolution of the firm

Introduction

The implementation of a sustainable mode of development has become a major aim of public policies in industrial countries and the evolution of economic agents' behaviours (producers and consumers) is considered as the engine of this "new economy". Enterprises are thus induced to develop socially responsible behaviours, that is to say to "integrate social and environmental concerns in their business operation and in their interaction with their stakeholders on a voluntary basis" (European Commission, 2001, p.1). For firms, the development of green innovations resorts to this necessity to develop responsible behaviours. "Green innovations", "Eco-technologies" or "eco-innovations" have been so far mainly defined by policy agendas and are still missing an economic definition that could be shared by the scholars (Andersen, 2010, Carillo-Hermosilla et al., 2010). In this paper, we retain the definition of eco-innovation proposed by the OECD (2009a), which adds two characteristics to the definition of innovation proposed by the Oslo Manual: its explicit emphasis on the reduction of environmental impact; the fact that eco-innovation is not limited to products, processes, marketing methods and organization methods but it also includes innovation in social and institutional aspects. If ethics was the first reason invoked by the tenants of a social responsibility of enterprises (Bowen, 1953), the literature on corporate social responsibility and on the objectives of the firm puts forward two main reasons for developing responsible behaviours (see notably Laperche, Levratto, 2012 ; Laperche, Uzunidis, 2011): the constraints that the external pressure from stakeholders namely employees, shareholders, customers, suppliers, the State and the civil society put on the firm (Freeman, 1984; Carroll, 1989, Donaldson and Preston, 1995); and the opportunity for the responsible firm to improve its economic results (Porter, 1991; Porter and van der Linde, 1995, Porter and Kramer, 2006). In any case, the question for many firms (as well as for institutions and scholars) is the following: How to change the firm trajectory and thus develop an eco-innovation strategy? This is the question we explore in this paper. It builds upon a recent enquiry made in eight corporations settled in France (Laperche et al., 2011). This enquiry deals with the impact of the current economic crisis, that triggered off in 2007 in the USA and then expanded throughout the world, on their innovation strategy. The first results show that firms took the

opportunity of the crisis to develop new innovation paths. Among these, the environmental strategy appeared to be central. In this paper, we build upon these first results and focus on the strategies adopted by firms to change their innovation trajectory towards innovation. To study the trajectory change, we rely on evolutionary theories of the firm as well as the broader resource-based theories that give us the tools and concepts necessary to build our vision of the role of the knowledge capital (and the methods of its constitution) in the firm evolution (Laperche, 2007).

The paper is organized as follows. The first part explains the methodology of the study and the way we decided to deepen our analysis (analysis of eco-innovation, theoretical analysis of the firm evolution). The second part focuses on the results of our study and puts forward the role played by the collaborative constitution of the “knowledge capital” in the trajectory change. It also explains how public policies may contribute to overcome the limits imposed by the costs of change.

1 How to change the firm’s trajectory: capabilities and knowledge capital

1.2.1 Eco-innovation as an answer to the economic crisis

This paper builds upon an enquiry achieved in 2009 and 2010 on the impacts of the economic crisis on the innovation strategies of 8 corporations located in France (Laperche et al., 2011). The chosen methodology for this enquiry consisted of series of face to face interviews on the basis of a semi-structured questionnaire. These interviews with directors and managers of R & D groups were conducted on a population of enterprises, after having collected and analyzed information available on these same groups (reports, interviews in magazines, ...) as well as scientific publications (reports, articles, ...). The selection of the enterprises that are part of our enquiry was done in a population of industrial groups whose efforts in research and development is both important and perennial. The selected companies thus have relatively high R&D budgets: with the exception of three of them, they devote between 5 and 23% of their turnover to R&D. Secondly, the groups were selected so as to be as representative as possible of all industrial activity and include capital goods, intermediate goods and consumer goods. The convergence of these criteria leads us to consider that the selected groups selected are exemplary cases, not so much in the sense of statistical significance (search for the

average person) than because they have in all probability, significant and informative experience for the questions we ask.

The interview guide has four parts. The first part provides general information about the corporation and on the speaker's function in the enterprise. The second focuses more specifically on the R&D and Innovation strategies of the Group: quantitative and qualitative information on R&D budgets, technological fields and research priorities, recent and on-going developments, nature of the research activities of the group and of its various R&D centers, Impact of public support for R & D. The third part deals with the constitution of the innovation potential of the firms. Beyond the numerical approach and the analysis of internal resources of R&D, the constitution of what we call the knowledge capital is captured through the use of external resources with subcontractors, complementary or competitors but also with academic research centers in France and abroad. Are these forms of collaboration stable or are they growing? What are their roles? Overall, did the crisis encourage groups to adopt a strategy of open innovation by developing collaborative research? The fourth part of the interview guide deals with the protection of the knowledge-capital and the impact of the crisis on this issue.

Table 1: Synthetic presentation of the population (Data 2009)

Enterprise	Sector	Date of interview	Turnover (billion€)	Staff	R&D Budget (billion €)	R&D staff	R&D /Turnover (%)
Thalès (aeronautics)	Electronics Aerospace	February 2009	2,60 (2007)	13 200	0,60	25 000 (group)	23
Lesieur (2008)	Agribusiness	May 2009	0,83	690	nd	24	0,1
GE Healthcare France* France (2008)	Medical and health devices	February 2010 March 2011	nd	2 500	nd	400	5,7**
Renault	Automotive	Sept. Oct. 2009 February 2010	33,71	121 422	1,65	17 547	4,9

		March 2011					
PSA Automotive	Automotive	February 2010	38,26	121 365	2,15	nd	5,6
St-Gobain	Materials Housing	February 2010	37,78	198 713	0,38	3 500	1****
Arcelor Mittal	Steel	April and May 2010	65,00	281 703	0,22	1 500	0,3
Valéo	Automotive Equipment	May 2010	7,50	52 200	0,47	5770	6,3

Sources : Interviews and Annual reports 2009, Unless precision.

* GE HealthCare France is part of GE HealthCare's global entity (46 000 employees, 17.3 billion \$ and 1 billion \$ R&D in 2008), a branch of medical imaging equipment and medical products, which is itself one of the activities of the North American group General Electric (250 000 employees).

** World R&D effort of GE HC

***Note, however, as stressed by the head of R&D group, the ratio RD / CA is generally 2% for industrial activities (we must exclude the distribution that although making the innovation does not recognize R&D) with however sharp differences ranging from 0.5% to 6% depending on the activities.

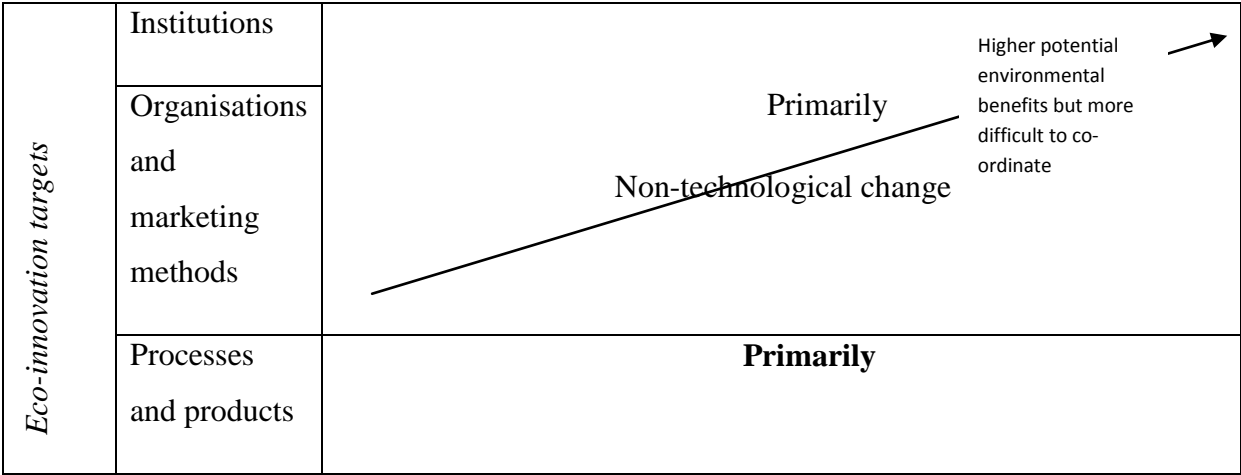
In the context of the economic crisis, our interviews (Laperche et al., 2011) revealed that the studied corporations did not reduce dramatically their R&D expenses but rather rationalized them. Globally the most upstream research programs were not cut, which was the case of some production projects, notably for the firms of the automotive sector. A large part of the firms took the opportunity of the crisis to make a “Carthasis” focusing on what they considered the most relevant programs in terms of future economic results. Regarding the organization of the innovation process, open innovation largely developed, with the aim of reducing the cost and accelerating the innovation process through the sharing of knowledge. One other important result of this enquiry lies in the exploration by firms of new innovation paths: one resorts to a low cost strategy put forward by some of our firms, which more and more concerns not only the production process but also the conception of new goods (with larger and larger parts of the R&D being located in low cost and fast growing countries). The other path consists in the development of an environmental strategy. The crisis plays as an engine for the development of the various forms of eco-innovation and thus for the evolution of the firm. In this paper, we have decided to exploit in depth our interviews to explain in

more details the way eco-innovation strategies are developed in the ongoing context of economic crisis. To our first interviews were added some new ones achieved in 2011 in some of the firms of our population. Also, to triangulate and supplement the findings from our interviews, websites and professional reports published by the firms helped us to develop our analysis. The main questions studied in the remaining of this paper are the following: what are the forms taken by eco-innovations? How did firms adapt to modify their trajectory toward eco-innovation and what kind of capabilities are needed to succeed in this strategy of change?

1.2.2 Eco-innovation in our population if enterprises

In this paper, we have chosen to refer to the OECD (2009a) definition for two reasons: it is a large definition of eco-innovation which includes products and processes forms of innovation and it also emphasizes the social and institutional changes involved in eco-innovation. The OECD (2009a) proposes a typology of eco-innovations based on the targets, the mechanisms and the impacts of eco-innovations (diagram 1). The targets of eco-innovation are products and processes, organizations and institutions. Four mechanisms – in other words the method by which change in the eco-innovation target takes place or is introduced – are identified: Modification – small, progressive product and process adjustments–, Re-design – significant changes–, Alternatives – for example introduction of goods and services that can fulfill the same functional need and operate as substitutes for other products – and Creation – design and introduction of entirely new products, processes, procedures, organizations and institutions. The impacts define the effects of eco-innovation on the environment.

Graph 1: Typology of eco-innovation (OECD, 2009)



		Technological change			
		Modification	Re-design	Alternatives	Creation
	n				
		<i>Eco-innovation mechanisms</i>			

Source: OECD (2009a)

All the enquired firms try to improve their production processes in order to reduce their environmental footprint (which includes the reduction of CO₂ emission and a controlled use of natural resources like water and other energies). They all develop process forms of eco-innovation. ArcelorMittal, the world's largest steel producer for example seeks to maximize the value of products throughout the production chain of steel. This goes from the search of cleaner ore (increasingly hard to find) to cleaner production in blast furnaces (emitting less CO₂, reducing water consumption) but also involves the valuation of co-products. Thus, the blast furnaces produce cement, "the slag", in manufacturing cast iron. However, this production is done without added CO₂ and the firm studies the possibilities of its valuation. Similarly, Thales has refocused its research on reducing the amount of CO₂ emitted by aircraft as well as their fuel consumption. From 2007, General Electric has developed a program called "Eco-imagination" to reduce the environmental impact of its activities through the development of clean technologies in particular, generalizing the use of solar energy, fuel cells, material sustainable techniques for water purification, etc. In the automotive sector, eco-design of a vehicle consists in carefully selecting its materials and promoting recycling at end of life. PSA thus ambioned to increase the share of green materials (recycled plastics, natural and biobased materials) to 20% of the total mass of polymer of a vehicle in 2011. Resorting to these materials reduces the use of plastics from fossil fuels and expands opportunities of recycling. 80% of the total mass of a vehicle are made of metals and fluids already widely recycled. In addressing the recycling at the design stage, PSA simplifies disassembly and the environmental remediation of out of service vehicles. His models are now recyclable in 95% of their mass, 85% through recycling and 10% by thermic treatment. Renault was the leader in this field for 10 years.

However, companies' efforts are not limited to process innovations and the development of new products, primarily for industrial country markets, is central to their environmental strategy. For ArcelorMittal, these new products are for example new lighter weight materials

for wind turbines ; More resilient and lightweight materials for car manufacturers ; New mixes of products with special glass of St-Gobain to improve insulation of buildings, etc. Lesieur counts on the development of containers. The company participates in the R&D of his supplier for the design of oil bottle in order to reduce their weight and the use of polyethylene. One of the flagship projects of the St-Gobain is the development of energy "autonomous house". By combining thermic insulation, quality of materials, heating equipment, high performance lighting and other innovative technologies and products, it is already able to reduce the energy consumption of the "low power" house over 80%. It is currently working to develop a "passive house" completely "autonomous" or even a house with positive energy, which produces more energy than it consumes. In 2010, the R&D management redefined its strategy by organizing it into eight "Strategic Programs." Environmental concerns cross all of them and the last one "New energy efficient processes and preserving the environment" is entirely dedicated to environmental aspects. Particular attention is given to facilitate the transfer of all the skills developed within the program "Innovative Materials" which primarily develops cleantech products to all ranges of products focused on the housing market. In the automotive industry, manufacturers are facing declining sales in industrial countries and their growth in emerging markets. The production of "clean" cars is a response to societal awareness of the need for a "safe and clean" vehicle but also a way to boost the markets of industrial countries. For Renault, the electrification of vehicles is now required as a constraint in the short term and launching electric cars has become the priority. But the sales estimates are limited to 7.3% of the global market for 2020 (JD Power & Associates, 2010), lower than the forecasts made by the manufacturers themselves (eg C. Goshn was counting on a global market share of 10% in 2020 for electric vehicles). PSA bets on the hybrid car. In all cases automakers consider a possible diversification of their activities "to the service of travel" (Renault), or the "broadening of the range of travel solutions to offer" (PSA). "Globally there will be no reduction of individual needs but profound changes in the use of the car," said one of the enquired firm. Thus, to the sale of individual vehicles may be added that of "travel" via a fleet of vehicles for rent, especially in urban areas. Manufacturers prepare themselves to become suppliers of services.

In sum, the companies we interviewed actually develop an environmental strategy based on eco-innovation. As also shown by the OECD (2009) they largely focus on technological forms of eco-innovation, even if they also consider non-technological changes, which may be organizational and institutional in nature. The example of the automotive sector, which is

more and more interested in the service of travel is a good example as it implies to change the business model and thus the organization of the firm as well as social norms and cultural values about the use of the car (which also resorts to institutional change).

The issue of change at the firm level needs to be mobilized here in order to understand the ability to change their technological trajectory to develop eco-innovation.

1.2.3 Roles of capabilities and of the knowledge capital in the development of eco-innovation at the firm's level

The Evolutionary theories – particularly initiated by Nelson and Winter, 1982 – try to understand novelty and to interpret change, taking into account the environment and the history within which systems evolve. In those approaches, the evolution and objectives of firms are defined through the processes of learning and coordination, according to procedures of trial and error (search), which should lead to satisfactory results. The adoption of procedural rationality (Simon, 1959) reflects the importance of uncertainty in which organizations operate and interact. According to the evolutionist approach (Dosi, Teece and Winter, 1991), the evolution of the firm's trajectory depends on and results in a learning process that creates specific assets and new capabilities.

The learning process is a process by which repetition and experimentation lead to the fact that, over time, tasks are done better and faster, and new opportunities in the procedures are constantly being tested. That process generates the production of cumulative knowledge materializing in organizational routines defined as models of interactions that are effective solutions to specific problems (see also Lazaric, 2000). They form an "organizational memory" embedded in the skills of workers and machinery (Nelson, Winter, 1982). Those tacit routines of the firm are clusters of specific resources/assets and are not easily transferable. The firm operates along a path determined by the expertise accumulated through learning. Specific assets thus, determine the evolution or trajectory path of the firm. The path dependence expresses precisely that evolution of the firm, constrained by past investments. Even if the accumulated skills can enhance the competitive advantage of the firm, they may also constitute a kind of trap – competency trap, in the words of Levitt and March, 1996; but the evolution of the firm is not necessarily gradual and does not exclude ruptures and bifurcations. The core or complementary assets present along the value chain can give the firm the possibility to change direction. The Evolutionary theory of the firm can therefore help us comprehend the endogenous transformation of the firm over time.

The literature on the management of innovation (evolutionist theories and more globally resource –based theories) emphasizes the role of capabilities. The capabilities to develop and renew the specific resources and assets gathered into organizational routines are named “dynamic capabilities” by Teece et al. (1997). They refer to “the firm’s ability to integrate, build and reconfigure internal and external competences to address rapidly changing environment” (ibid, p. 516). These “high-order capabilities” differ from “ordinary” or “substantive” capabilities which refer to the firm’s ability to solve problems (Winter, 2003, Zahra and al., 2006). There are various kind of dynamic as for example the dynamic capabilities to generate new ideas, to change the firm’s projects, to develop new scientific and technical knowledge so as to change the knowledge base of the firm, to change the ways of launching of new products etc. We largely focus here on the development of new scientific and technical knowledge and on the change of the knowledge base of the firm.

Technological capabilities and technological success are not nowadays considered as the results of the firms’ own resources but are the outcome of complex processes of collaboration and cooperation. To explain change and to improve the production theory, Von Tunzelmann and Wang (2007) propose the notion of “Dynamic interactive capabilities” to stress the role of interactions and of the different forms of learning both form consumers, suppliers and producers to explain the economic impacts of technology as well as the evolution of the firm. On this aspect, Cooperation, collaboration, open innovation strategies, scientific and technological networks are nowadays keys words in the literature. The mutation of the firm’s trajectory is expensive and risky. That is why it reinforces the trend toward the collaborative creation of knowledge capital (or open innovation strategy), which is confirmed in the recent literature (Chesbrough, 2003; Antonelli, 2005, Chesbrough, 2006, Gassman , 2006, Chesbrough et al., 2010) and involves various sectors, automotive (Ili et al. 2010) to the pharmacy (Yacoub and Laperche, 2010; Hughes and Wareham, 2010) or even to chemistry (Sieg et al., 2010), etc..

If we look more precisely at the literature on eco-innovation, the role of capabilities and of collaboration is also emphasized. To change the firm’s trajectory towards eco-innovation, the creation of new dynamic capabilities are thus necessary. A “natural-resource-based view of the firm” is thus, taking shape (Hart, 1995). Lin et al (2011) define green business innovation capabilities (GCICs) as “a green business innovation process wherein firms explicitly undertake capabilities to achieve higher green performance as well as commercial performance” (Lin and *al.*, p. 1840). In their aim to evaluate GBICs at the firm level, they

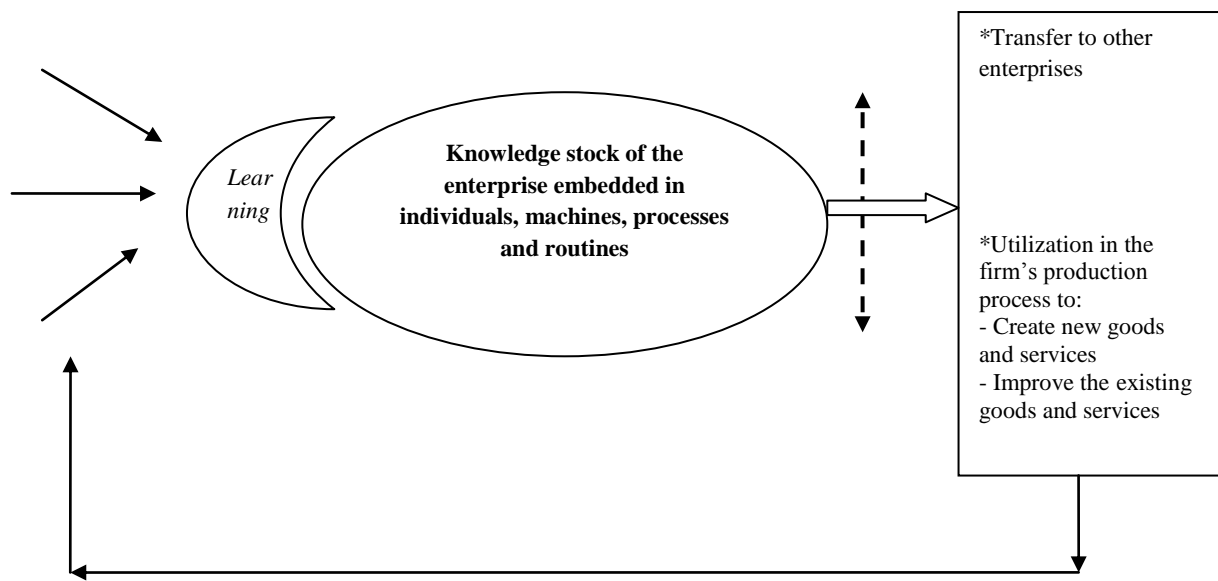
develop a framework made of 7 aspects – and 25 evaluation criteria–, including the definition of a green technological innovation strategy, the attitudes of workers towards change in their work routines, the ability of the firm to formulate green innovative projects, the development and protection of green knowledge, the communication capability, the ability to work with external partners and the management of business innovation. On the basis of a review of literature, Van Kleef and Roome (2007) compare the capabilities needed to develop innovation oriented towards competitiveness and those needed to develop innovation oriented towards sustainability. They show that these capabilities largely overlap, which is not surprising (as mentioned by the authors) as competitiveness is one part of the larger concept of sustainability. However, they put forward the importance given in the literature on green innovation to the communication and collaboration “with very diverse and culturally unfamiliar (and or local) networks of actors, on integrating their diverse perspective, criteria and information processing and decision styles” (Van Kleef and Roome, 2007, p. 45).

From what precedes the development of collaboration appears as very important for different reasons:

- the sharing of knowledge and thus the risks and the cost of innovation in a context of economic uncertainty (and even of crisis)
- the necessity to comply with the aims of the different stakeholders implied in eco-innovation strategies.

According to us, the learning process and the building of immaterial specific assets gathering internal and external resources is achieved by and lead to the construction of what we call the firm’s knowledge capital. “Knowledge capital” is defined as the set of information, knowledge and know-how produced, acquired, combined and systematized by the enterprise in order to create value. Studying the knowledge capital of a firm means analyzing the way the enterprise acquires and collects information on markets, produces knowledge alone or/and in collaboration – internal R & D, partnerships –, transforms it into knowledge, routines and know-how which are a source of specific advantages and uses that knowledge and information in a process of value creation. The building and the renewal of the knowledge capital appears as a tool to build new technological capabilities.

Figure 2. The ‘knowledge-capital’ (Laperche 2007)



—————> : Scientific and technical information feeding the knowledge stock of the enterprise

—————> : Utility and objectives of the knowledge-capital

- - - - -> : Diffusion of a part of the scientific and technical information constituting the knowledge-capital

Source : Laperche (2007)

Our enquiry showed that to face the crisis, firms put an important part of their R&D resources in the development of new technological paths, largely focused on eco-innovation. To do so, they have re-orientated and reorganized their knowledge capital in order to develop new scientific and technical capabilities. Collaborative strategies have been privileged to achieve this orientation, as explained in the following part.

2- Eco innovation strategy and evolution of firm's trajectories: engines and limits

2.1.1 The collaboration constitution of the Knowledge capital as an engine of change

According to our investigation, the economic crisis spreading to the whole economy in the middle of 2008 led to a slowdown of production activity of all firms but they however sought to maintain their R&D spending to remain competitive. R&D and more broadly innovation,

is "much needed" in a crisis because it is then more than ever the "lever of the Future" (interview ArcelorMittal). This future is mainly seen to be fuelled by eco-innovation which both appears as a necessity to face environmental damages and risks at the global level and as an opportunity to restart a new trend of growth in a Schumpeterian perspective (Schumpeter, 1947). To achieve this, the innovation management has evolved.

The firms of our enquiry have initiated a process of reorganization or restructuring of their knowledge capital. The crisis was for a number of them the opportunity to make a "catharsis", to sort between projects in order to focus on the most profitable and strategic (the clean technologies in particular). Moreover, they have developed their collaborative research that is now an essential component of strategies for building knowledge capital in industrial corporations. The accumulation of specific assets is an essential element in the ability of firms to change their trajectory, as we explained previously. And in a context of economic crisis, collaborative strategies are more and more popular because they allow access to specific skills as well as to share and thus reduce the costs of change. Thus, the collaborative constitution of the knowledge capital was reinforced at Renault, PSA, Valeo, Saint-Gobain, ArcelorMittal. However, when collaboration was applied for a long time and already was an essential element in the innovation strategy of the group, such as in the case of GE HealthCare, it simply continued. Companies collaborate at all stages of the innovation process (from design to the development of new goods and services) and with multiple partners. The objectives are diverse, we list them in Table 2.

Table 2. Partners of industrial firms, forms of objectives of the collaborations

Type de partners	Forms of collaboration	Objectives of the firm
Academic research	<ul style="list-style-type: none"> - Research programs - International and European tenders - Researchers mobility and phd funding - Licences 	<ul style="list-style-type: none"> - Access to an anticipated vision of the technological evolution and to new knowledge - Reduction of the risk and the cost of upstream research
Clients/ suppliers	<ul style="list-style-type: none"> - Alliances (with ou without capital participation) - Licences 	<ul style="list-style-type: none"> - Applied reaserch and co-development of products - Reduction of the risk and the cost of product development

Competitors	<ul style="list-style-type: none"> - Joint-ventures - International and European research programs 	<ul style="list-style-type: none"> - Conception of future technologies - Pre-competitive research - Reduction of the risk and the cost of pre-competitive research
Small innovative firms	<ul style="list-style-type: none"> - Financing, <i>spin off</i> and acquisition of start-up - Cooperation agreements within clusters - European and national research programs 	<ul style="list-style-type: none"> - Accesss to very specialised competences - Technological watch - Reduction of the risk and the cost of development

Source: authors, from the interviews

The collaborations with academic research were made possible because of institutional changes of the Universities, in the U.S.A first (Mowery et al. 2001, Vial and Etzkowitz, 2010), and then in the large majority of industrial countries. The commercialization of research, which can be defined as the process of transforming basic knowledge into marketable products, has indeed become the third mission of universities, alongside teaching and research.

These partnerships contribute to the creation of real "scientific and technical cooperation ecosystems" in the words of R&D director of Thales. This corporation creates strong partnerships between its teams and local academic research notably in the aim to reduce the amount of CO2 emitted by aircrafts as well as and their fuel consumption. Its laboratories are most often located on university campuses (such as that of Palaiseau –in the Paris area-, hosted on the campus of Polytechnic School, or that of Singapore which has a laboratory within the NTU - Nanyang Technological University). Saint-Gobain has installed within two of its research centers a CNRS (French national centre for scientific research) team. The group also developed a strategy of cooperation with the best of academic research around the world via the network SUN (Saint-Gobain University Network). This network of long-term partnerships (10/15 years) with institutions and top universities spread around the world based on two criteria: scientific excellence of the partner and its location in growing markets, ie where the group is interested in and can develop its activities. This network focuses on the upstream, ie on the understanding and improvement of knowledge rather than on product development which is in turn the subject of partnerships undertaken with small firms and start-up (through the NOVA program to which we will come back later). Through this network that extends throughout Europe, the United States, Japan, India and China, the

company seeks above all to accelerate R & D and to benefit from lower cost for basic research which it ultimately needs to strengthen its expertise in energy, environment and lighting in order to develop its autonomous house.

Car manufacturers are also developing strategic partnerships with academic research. Renault is thus engaged on the topic of drowsiness with medical schools, on electric batteries and motors with Supelec, Polytechnique, Centrale and the University of Amiens and on "sustainable mobility" with Paritech and the CEA (French Centre for atomic energy). At PSA, a long-term partnership (5 years minimum and extendable) in sensory and cognitive ergonomics allows the group to obtain the best technology at lower cost: a laboratory of the CNRS - Scientific Institute of Movement (Marseille)- has installed a team (4 to 5 researchers) in the "open laboratory" (driving simulator), within the center's research group in Velizy. Reciprocity of interest is ensured. The creation of such cooperation is viewed as a "progress" in the words of our interlocutor from PSA, which previously resorted to several spot contracts with engineering firms to meet some needs for technological innovation without being able to capitalize on the knowledge and know-how at the end of the agreement. Valeo has developed long term partnerships with many universities and colleges such as in France, the Ecole des Mines - Paris Tech and ESIGELEC for electronics.

Firms also cooperate with customers and suppliers, which generally are recognized as having an increasing role in product improvement and regarded as true partners. It is clear from empirical studies (Von Hippel, 2005) that, by sector, between 10 and 40% of customers (firms or individuals) engaged in the development or co-development with the producers to change the final product. This is usually the or one of the main clients. Similarly, suppliers are increasingly co-contractors in R & D. These collaborations are also a means to better understand these stakeholders' objectives, in a corporate social responsibility perspective.

Cooperation is also carried out with competitors. The companies then engage in co-competition which combine cooperation and competition strategies (Le Roy and Yami, 2010). While fiercely competing in the global market, companies cooperate in R & D. These collaborations most often take the form of joint ventures specializing in technologies for the future. They are particularly common between the two automakers met. This type of collaborative R&D is not new but has accelerated from 2008. The Economic interest group PSA / Renault, which is pre-competitive, aims to improve the engine and vehicle safety of both manufacturers. Another cooperation was initiated with Ford and Fiat for the development of an engine. OEMs are also working with each other and with companies other than

manufacturers. Valeo was thus associated with five partners (Michelin, Leroy Somer, Johnson Controls-Saft, GKN and Leoni, the last three are original equipment) for the development of plug-in systems for electric and hybrid vehicles in order to accelerate their launching in France and abroad. However, as explained by one of our interlocutor from Arcelor in a highly competitive and highly fragmented environment as that of steel, the constant search for competitive advantages lead to the absence of a direct cooperation between competitors. They however work together within large European programs which give them the possibility to finance their R&D in part on public funding.

All companies do not develop such **cooperation with small firms**. Those which develop them seek to integrate sophisticated technology and skills (or some that are totally out of their usual fields) within their knowledge capital. Valeo had developed such a startups fundraising but preferred to give it up to concentrate on other forms of partnerships. Saint-Gobain has been most heavily involved in this kind of cooperation. The company thus created a department in 2007, NOVA External Venturing, dedicated to the establishing of strategic partnerships between the group and start-ups worldwide. NOVA selects these based on their innovation, the quality of their proposal and possible synergies with Saint-Gobain. NOVA External Venturing particularly supports partnerships in the fields of energy, environment and lighting in the home. The three funding partners - NGEN Partners (USA), Emerald Technology Ventures (Switzerland) and 3E-Emertec Energy Environment-(France) are all specialized in clean technologies. Startups partners are located in the U.S. and Europe. This program has resulted in the signing of 25 development contracts with small innovative companies (after screening of 1000 projects and a tri / discussion in 100) in three years, twenty more are currently in the pipeline.

Collaboration is thus much need in the eco-innovation strategy, notably in a context of crisis, for the reasons invoked previously: sharing of knowledge and reduction of costs and risks, better understanding and integration of stakeholders perspectives and aims, so that to reach what we may call a “win-win-win” result : quicker feeding and with a shared cost of the innovator’s knowledge capital, integration of the stakeholders desires and positive environmental impacts (quicker diffusion of improved technology). However, the collaborative strategy is not always a way paved of roses and proves to be very costly.

2.1.2 Costs of changes

Despite a growing awareness of the negative impacts of the use of fossil fuel and related technologies, attempts to shift towards cleaner substitutes are still proving difficult. On the one hand, that is because hydrocarbon technologies have benefited from advantages resulting from increasing returns to adoption and economies of scale that make them cheaper, performing and user-friendly. On the other hand, green-techs that fail to win early adoption success have been locked-out from the market, unable to compete with the improved technology because of increasing returns. Moreover in a context of crisis, the purchasing power of the population may decrease which do not stimulate the demand for new green products. Firms try by themselves, through standards and marketing strategies to impose their products so that to “create” the demand and thus control the markets but they do not make it all due to the cost, difficulties and unproved profitability of eco-innovation (Laperche, Levratto, 2012). All the firms we interviewed stress the importance of environmental standards (created by the firms themselves or imposed by regulatory institutions)

If we focus on the development of new scientific and technical resources and capabilities, the cost of change towards eco-innovation is also reinforced by the very important expenditures that are needed to develop not only product innovations but also to encompass new services and a new organization of the activity. Despite the pooling of costs and risks and the acceleration of the innovation process enabled by collaborative research, the amounts of expenditures needed to develop new products, processes and services are still difficult to afford by the collaborating firms, especially in a context of economic recession.

Moreover, the shared costs implied by collaborative research do not exclude the existence of hidden costs that may increase the overall costs of change. Transaction costs (Williamson, 1975) may be related to the finding to the appropriate partner (for example an academic laboratory working on the same subject), to the negotiation of the contract (sharing of knowledge and related intellectual property rights problems) and to the contract monitoring (risk of cooptation, intellectual property rights conflicts). In our interviews, the R&D manager of Arcelor for example stressed the problems that have arisen with the CNRS (National Center for Scientific Research) regarding the sharing of intellectual property rights. GE healthcare mentioned its difficulties to find in France new partners (notably among start ups) to work with.

These costs of change cannot be all overcome by the managerial capabilities of communication and diffusion of information. In our interviews, the managers explained the importance of institutional support in order to reduce – if no overcome- this kind of costs.

2.1.3 Public policies as an essential support to the reorientation of Knowledge capital

We discussed above the growing relationship between universities and companies that allow them less costly access to to core competencies. In France from the mid-2000s, in response to decisions taken at European level in the Lisbon Strategy in 2000 and reaffirmed in 2008 to improve the competitiveness of enterprises, governments have become more involved in active support to the "technology transfer between public research and socio –economic actors". Different devices, which are intended to support the constitution and promote the re-orientation of knowledge capital in the future technologies have been introduced or improved: improvement of the Research Tax Credit (RTC), Project financing via the ANR (National Research Agency) and European R&D programs as well as the French cluster policy named “Pôles de compéttivité” (2004).

The RTC is considered and proved a real tool for helping firms to maintain their R&D budgets. Founded in 1983, it was amended by the Finance Act of 2004 and of 2008. Its purpose is to increase business competitiveness by lowering their research costs and development. In doing so it helps to improve the attractiveness of the French territory in R&D and serves as an argument to try to prevent the location in lower cost countries of their R&D centres. It currently consists of a tax credit of 30% of R&D expenses up to 100 million euros and 5% beyond this amount. In early 2009, to improve cash flow and support business investments that were undermined by the crisis, the tax administration has also committed to the anticipated repayment of the RTC. One advantage of the RTC is that it is not a targeted assistance but that it leaves firms free to choose their areas of investment. The RTC has allowed companies that were hit by the crisis in 2008-2009 (ArcelorMittal, PSA, Renault, Saint Gobain and Valeo) to maintain their spending on research and development, hire young doctors, explore new avenues of research and even to maintain a R&D centre in France.

For example, according to ArcelorMittal which was strongly affected by the crisis (fall in output of almost 50%; drop in steel prices since the 4th quarter 2008), the RTC has

contributed significantly to the continued R&D effort. Despite the crisis, the group was able to "allow risk-taking." For GE HC, the RTC has made possible the survival of the R&D center located in Ile de France, strongly challenged (due to much lower wages) by those of Hungary and India. Severely affected by the crisis in late 2008, the automotive sector has also benefited from additional public funding in 2009 (DGCIS, 2010). The French government signed a "automotive industry Pact" in February 2009 with the manufacturers to offset the immediate effects of the crisis but also to secure and prepare for the future of the industry. Among the measures taken, some are directly related to the development of clean vehicles. Loans (6.25 bn €) were granted to Renault and PSA so that they can "implement programs to develop new more environmentally friendly models." The plan "low-carbon vehicles" has been strengthened through the allocation of € 50 bn by ADEME and € 250 bn in soft loans managed by the DGCIS for specific projects of these vehicles and their equipment (batteries, ...).

Participating to national and European R&D programs is another way to maintain R&D effort and direct it to new themes, such as eco-innovation. Thus in 2008, Renault has teamed up to 104 collaborative projects partly financed by public funds through the ANR and other national organizations. It participates in 69 ANR projects in which it has invested 41 million euros (these projects have achieved 289 million euros in subsidies). It also engaged in 35 projects under the European Framework Programme 2007-2013 in the energy field in which it has invested 17 million euros (total grants: 432 million euros). Valeo has also obtained in 2009 a support of the French Environment and Energy Management Agency (6 million €) for the monitoring of two programs on the development of low-carbon vehicles: a mild hybrid project, a project of the vehicle thermal management system. ArcelorMittal was deeply involved in the ULCOS (Ultra-Low Carbon dioxide (CO₂) Steelmaking) consortium funded by the FP6. Expired end of 2010, it included all European steelmakers and other partners. The main drivers were ULCOS executives and engineers from ArcelorMittal. It consisted in benefiting from research funding support for research aiming to 50% reduction in CO₂ emissions per ton of steel produced. 70 "routes" were launched on this topic. 4 new technologies were developed and are being or are about to be tested by the group in France and Northern Europe. ArcelorMittal is also involved in the RFCS (Research Fund for Coal and Steel), a European program succeeding the ECSC (European Coal and Steel Community), launched in 1952 for 50 years. And also dedicated to upstream research (on iron ore, measuring instruments, metal tools, ...).

The French clusters named “Pôle de compétitivité” are an additional way to receive public funding (national, regional, local) and to reduce the transaction costs involved in the cooperation process. Established in France in 2005, they are based on a simple principle: government support for R & D benefit not only directly to businesses but also because of the dissemination of knowledge, to other companies via spillover effects. Targeted subsidies on collaborative research, particularly between industry and academia enable the cluster’s members to internalize the spillover effects and to avoid duplication of activities. Working with stakeholders, businesses have access to more fundamental research and thereby realize economies of scale. The establishment of clusters is therefore intended first to the acceleration of innovation production by boosting cross R & D processes, labs and training centers. Betting on the interdependence between the actors - the cluster responds to the figure of the "triple helix" (Etzkowitz and Leydesdorff, 1998). The involvement of groups in the clusters is thus an additional way to receive public assistance in cooperative R & D projects. All groups of our population are active members of the poles.

In the case of the Moveo’ Cluster dedicated to R&D in "Automobiles and public transport," members include manufacturers and suppliers that are part of our population. They work together and pilote the various thematic projects based on green technologies of this cluster. The project "low Co2 vehicles", whose purpose is the introduction of vehicles using the pull / electric propulsion and the development of interfaces of power supply (recharge for electric batteries, ..) is led by PSA Peugeot Citroën. The project "Vehicles Environmental Impacts " in charge of the identification and treatment of pollution sources and their impacts on the environment is controlled by Faurecia (OEM, a subsidiary of PSA). The project "energy storage systems", whose mission is to develop components and control and interface systems constituting the batteries and, more generally, any form of non-combustible energy storage for the electric and hybrid vehicles is controlled by Renault. The project "mechatronic systems" and "ICE Powertrain" whose mission is to reduce CO2 emissions are managed by Renault and Valeo. It is worth noting that Valeo is the corporation that has most invested in clusters while emitting the least reserve. As a whole, Valeo is the initiator of and participates in About 40 approved projects on themes related to energy, propulsion, mechatronics, software and complex systems. This type of participation, including in the governance of the poles, is considered very useful by the head of R&D group because "it creates the conditions for the emergence of partnerships with academic laboratories and with small business having complementary skills." Public funding is thus not an end in itself but it is an important

support. The System@tic cluster (working on software dominant systems) cited by several of our interlocutors is chaired by Thales, while Renault and Valeo are members of its executive committee. Among the five topics of this cluster, one dedicated to "the automotive and transportation." The Renault group is heavily involved in it through the project "geDRIVER" (Green and Efficient Driver). Saint-Gobain is itself engaged in a dozen of clusters with varied themes including AdvanCity (green technologies and sustainable cities) , Mov'eo, I-TRANS (transport systems) but also the European center of ceramics in Limoges (France). The very diverse results of the different French Pôles de compétitivité, their dispersion and their quite bureaucratic organization are nevertheless sources of problems, according to some enterprises like Renault or GE. Since the implementation of the Medicen cluster (innovative therapies and advanced technologies in healthcare) , GE HC serves on the Board but the group regrets that in practice no cooperation was developed with labs or companies. However, the company believes to benefit from its participation, notably in terms of image.

In a context of crisis and increased competition, resorting to public funds in their various modalities - tendering, participation in clusters and European programs, exceptional aid - is recognized as an effective means of maintaining their R & D effort and its reorientation. It is worth noting that they have simultaneously drawn on collaborative research to strengthen / build their knowledge capital.

CONCLUSION

Eco-innovation is now considered as a central element of industrial firms' strategies. To face the crisis and to position themselves on niches of the markets with high growth potential but also to satisfy the demand of various stakeholders, firms refocus their strategy and their organization towards the development of green products (goods and services) which imply organizational –but also many institutional changes. At the firm's level and dealing with technological change, we have emphasized the role of the development of new dynamic capabilities. The capabilities to collaborate with various partners for the building and re-orientation of the knowledge capital are central. As a matter of fact, in eco-innovation strategies, collaboration is a way to share the costs and risks of technological development and thus is a crucial vector of change of the firm's trajectory. It is also a way to comply with the aims and objectives of the various stakeholders implied in sustainable strategies of innovation. However, collaboration do not always reduce the cost of innovation since transaction costs may be the counterparts of the building of complex innovation networks.

Institutional intervention (arrangements, law, R&D and industrial programs, supply and demand incentives) is thus necessary to help firms overcome these hidden costs.

Our study is based on eight cases and as such cannot describe the behavior of all industrial corporations. However, most recent publication on the development of green technology tend to confirm our results. The 2010 Global innovation 1000 (Jaruzelski, Dehoff, 2010) points out for example that open innovation is one of the most crucial capabilities for innovative firms in good but also in hard times. Moreover quoting OECD (2009b), “in all likelihood, the crisis will accelerate the change already underway: (...) the increasing reliance on open innovation strategy that rely on partnerships and collaboration to share costs and risks”. Building upon this background, this study will continue to identify the capabilities for eco-innovation networks management in small and new firms as well as in bigger ones. Our aim will be to identify the role of firm size in the development and on the characteristics of these networking capabilities.

Does our study mean that collaboration capabilities are the key of success of eco-innovation strategy? We could answer positively if we remain at the firm’s level. At the marco level, one must not forget that firms act in an unforeseeable economic context, which evolution depends on financial considerations. Despite the fact that the firms try to maintain their R&D efforts so that to generate a boosting process on the supply side (new green goods and services) and on the demand side (marketing efforts), this may not be sufficient due to the economic uncertainty that contracts the economic activity.

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