Abstract

Electrification or hybridisation is the main focus for most car manufacturers today – however it implies large changes, both in terms of the vehicle itself (technology and integrated systems) and in terms of usage and business models. In literature on discontinuous innovation, learning is put forward as a crucial capability but there are few empirical studies on how this actually happens in firms. This paper aims at discussing different learning mechanisms used in the aim of developing capabilities related to electric and hybrid electric vehicles. It highlights that in this kind of broad innovation field, more advanced mechanisms might be needed for automotive firms aspiring to take the lead, such as market experiments and exploratory partnerships. It also argues that overall learning strategies are necessary to guide the many learning mechanisms activated. The paper contributes to an increased understanding of how automotive companies deal with innovations of a rather disruptive nature.

1. Introduction

The impact of automobiles on the natural environment is well known, and the reduction of this impact is a priority issue on every car manufacturer’s agenda. Reduction of CO2 is one of the main drivers in technology development and also in focus of aggressive regulations. There are several ways of reducing CO2 emissions from cars with combustion engines such as new types of fuels (bio-fuels), low consumption engines and driver behaviour. There are also more radical technology developments, such as electric or hybrid electric vehicles (EVs or HEVs). Toyota’s first large HEV project, the Prius, has substantially contributed to a large public and research interest (Magnusson and Berggren, 2001; Nonaka and Peltokorpi, 2006). However, it would be a mistake to restrict such innovations to their technological dimension. Electrification of the vehicle’s powertrain represents a very broad field of innovation, where for instance new marketing, technological and business model concepts need to be explored by the car manufacturers. How do car manufacturers build their capabilities in a situation that is potentially disruptive in so many dimensions?

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This paper aims at discussing some learning mechanisms that car manufacturers have used to develop their capabilities around EVs and HEVs. It highlights that in this kind of broad innovation field, new mechanisms for learning (instruments, tests, experiments) are being deployed in the automotive industry. It also argues that in the context of electrification, overall learning strategies are necessary to guide the many learning mechanisms activated. It contributes to an increased understanding of how automotive companies deal with disruptive innovation. It also responds to a call for more research on disruptive technology as such (Daneels, 2004). This paper is based on an interview study with different car manufacturers (six interviews), a case study of a HEV project at Volvo Cars (14 interviews) as well as industry documentation and secondary sources.

2. Theoretical framework

2.1 Discontinuous innovation and innovative capabilities

Innovation is often related to the degree of novelty; it can be described as something incremental (new), really new or radical (Garcia and Calantone, 2002) or as a continuum ranging from incremental change (doing things better) to radical change (doing new things) (Tidd et al., 2005). Other authors propose to distinguish between the degree of influence that the innovation has on existing products, where sustaining technologies are those improving the performance of a previously available product and disruptive technologies bring a different value proposition to the market (Christensen, 1997; Christensen and Overdorf, 2000). A complementary dimension concerns the degree of system integration, ranging from modular (component) innovation – where the linkages between core concepts and components remain unchanged – to architectural innovation where these linkages are ruptured (Henderson and Clark, 1990).

The capability of the firm is considered to be its ability to deploy the available resources as their main assets (Prahalad and Hamel, 1990). According to Christensen (1997), an organization’s capabilities are defined by its processes (methods for transforming inputs to higher value output) and its values (criterion used for decision-making). Leonard-Barton (1992) further describes the core capabilities of firms as the set of knowledge that provides competitive advantage. To avoid that core capabilities become core rigidities, a dynamic perspective on capabilities was introduced by Teece, Pisano and Shuen (1997) where the need to systematically revise and develop organizational capabilities is underlined (Helfat et al., 2007; Nonaka and Kenney, 1991). Previous research on radical or discontinuous innovation (e.g. Henderson and Clark, 1990; Christensen, 1997; Leifer et al., 2001) describes a process characterized by uncertainty and new knowledge areas where performance criteria rapidly change. For firms, there is a difficult trade-off between short term returns and long term capability building (Bartezzaghi et al., 1997) that has been described as the productivity paradox (Abernathy, 1978), exploration-exploitation (March, 1991) or the ambidextrous organization (Tushman and O’Reilly, 1996; 1997).

Innovative capability has been defined as “the internal driving energy to generate and explore radical, new ideas and concepts, to experiment with solutions for potential opportunity patterns detected in the market’s whitespace and to develop them into marketable and effective innovations” (Assink, 2006:219). Assink (2006) further argues that a way of developing this capability is to enhance the absorptive capacity, i.e. the capacity to recognize and understand external knowledge, assimilate and apply it internally (Cohen and Levinthal,
1990; Lane et al., 2006). Other authors have underlined the generative aspects of innovative capabilities where values are collectively recreated: “a collective capacity to permanently and simultaneously recreate new sources of value (products, concepts, patents, environmental values etc.) and competences (knowledge, know-how, professions etc.)”(Le Masson et al., 2006:21). Despite the theoretical discussions on innovative capabilities there are still few examples of how companies actually deal with innovations of a more radical nature and there is still a need to better understand how companies can prepare for and undertake such innovations.

2.2 Innovative capabilities and the role of learning

Previous research has shown that organizational learning is a critical capability for firms aiming at being innovative (Madhavan and Grover, 1998; Lynn et al, 1998). It may be defined as “the ways firms build, supplement and organize knowledge and routines around their activities and within their cultures, and adapt and develop organizational efficiency by improving the use of the broad skills of their workforce” (Dodgson, 1993:377). Hatchuel et al., (2002) underlines the need for management of learning by proposing a type of design-oriented organization meaning an “organization favourable to collective learning cycles, which… [is itself] conducive to this simultaneous regeneration of objects, skills and occupations (Hatchuel et al., 2002:18). They claim that knowledge management is closely linked to the organization of actions within the firm and that the company must constantly reconstruct its collective learning process in terms of ‘concept objects’ and ‘embryonic occupations’ whose ongoing development will perhaps – but not always, generate more routinized occupations and practices (Hatchuel et al., 2002:18). Learning is thus important in a dynamic capability view of the firm because resource endowments are ‘sticky’, at least in the short run, and because firms often lack the organizational capacity to develop new competences quickly (Teece et al., 1997). In this perspective, as competences and capabilities are normally rather difficult to replicate, learning is the fundamental process by which capacities are built.

The literature contrast two fundamental learning processes: “single loop learning” (Argyris, 1976) which mainly consist in problem solving where routines in the organization is refined within an existing “theory in use” (Argyris and Schön, 1996) or “dominant logic” (Prahalad and Bettis, 1986) of the firm and “double loop learning” which not only detect and solve problems but also change the values and norms through questioning the underlying values and norms which involves a change in the “theory in use” (Argyris 1976; 1977; Argyris and Schön, 1996).

Transposed to innovation management in organizations, “single loop” learning would consist in the introduction of incremental changes within a dominant design (Utterback, 1994) and the exploitation of existing competences. This can be achieved internally or by developing the “absorptive capacity” of the firm (Cohen and Levinthal, 1990; Lane et al., 2006) that “refers to one of the firm's fundamental learning processes: its ability to identify, assimilate and exploit knowledge from the environment” (Lane and al., 2006). Also other authors have stressed the link between absorptive capacity and the firm’s capability to learn (Willianer, 2007; Todorova and Durisin, 2007). By contrast, “double loop” learning would involve deeper changes in the knowledge and resource base of the organization. Innovative organizations are those that are able to explore, revise their routines and to mobilize new concepts and resources. In line with the design strategies proposed by Hatchuel, Le Masson and Weil (Hatchuel et al., 2005; Le Masson et al., 2006) this implies that a key-issue for companies is to combine their “absorptive capacities” with more “generative capacities”
(Elmquist, 2007). In a “double loop” approach of innovation, neither the solutions nor the performance criteria pre-exist from the start but are to be designed and developed during the innovation process.

A focus on learning is all the more important as the outcomes of innovation work are uncertain, and there are potential “spill-overs”, i.e. unexpected or unintended outcomes. This phenomenon is often considered out of focus for managers but in innovation management the spill-overs are a key issue from a learning perspective. The implementation of instruments or mechanisms through which “spill-overs” can be identified and may feed the innovation process back is an important managerial task. As people, knowledge and stories circulate in the organization and between organizations, learning is likely to occur beyond existing boundaries in an “open innovation” scenario (Chesbrough, 2003; Chesbrough et al., 2006). In this perspective, organizations shall not only learn within existing boundaries or projects, but also try to leverage on external knowledge.

Several authors have stressed that learning can be managed in a long-term perspective, through repeated innovations (see Penrose, 1960; Hatchuel et al., 2003) and through learning between projects (e.g. Maidique and Zirger, 1985; Rothwell and Gardinger, 1989, Cusumano and Nobeoka, 2000). Therefore, the innovation capability of the firm should not be measured within a project but need to be evaluated over a longer period of time within lineages of concepts and knowledge (Hatchuel et al., 2003) and on the capacity of firms to exploit spill-overs. In this managerial approach, the idea prevails that organizational learning is not a natural process but, on the contrary, it is a process that needs to be managed, designed and guided through the selection of appropriate mechanisms that maximize the opportunities of learning and increase the resource base of the company (see Tidd et al., 2005).

2.3 Learning mechanisms in the automotive industry

What are the known learning mechanisms designed to support the development of innovative capabilities in the automotive industry? Traditionally, researchers and companies have put efforts to design and implement new means to improve the performance of New Product Development (NPD) in terms of cost, deadlines and quality (e.g. Gupta and Wilemon, 1990). These efforts have been particularly fruitful in the automotive industry, which is a pioneering sector in the rationalization of NPD. New managerial techniques and principles - such as project management with heavyweight managers and cross-functional teams, co-development, platform management, concurrent engineering, etc. – new computer-based techniques – such as CAD, virtual prototyping, etc. – have been successfully implemented at a large scale by Japanese car manufacturers. Built together, these mechanisms are pieces of a broader framework, called the Japanese NPD model, that most competitors, inside and outside the automotive industry, have tried to replicate with different degrees of success (see Clark and Fujimoto, 1991, Cusumano and Nobeoka, 2000). Recent works have focused on “Front-loading” designating the strategy by which problems related to innovation can be anticipated and dealt with during the early phases of NPD (Thomke and Fujimoto, 2000, Thomke, 2003).

Despite their apparent simplicity, the mastering of these mechanisms is difficult, and the development of collective learning is not easy to achieve. Several empirical studies have stressed phenomena such as inertia, when new concepts and knowledge are not aligned with established routines (Willander, 2006), and organizational amnesia and competence-destroying as experts tend to focus on the achievement of short-term project targets rather than long-term functional competence development (Aggeri and Segrestin, 2007).
particular, as R&D in the automotive industry mainly consist of a small number of very large projects, transferring and reusing knowledge between projects has been shown to be difficult to organize. The completion of the project is the main driving force and once the delivery is done the teams tend to break up and move on, leading to frequent reinventing-of-the-wheel (Coombs and Hull, 1998). But collective learning is crucial to develop managerial and technical capabilities for the forthcoming projects. In terms of innovation capabilities it seems that the automotive industry is proficient in terms of incremental innovations but that the efficiency of the NPD model is nevertheless more questionable when it is to deal with more radical changes in terms of concepts or pieces of knowledge at stake, as argued also by Eisenhardt and Martin (2000).

Then, what kind of learning mechanisms are automotive firms using to support innovative projects? We propose to distinguish between five different mechanisms that have been identified in the literature. The first mechanism is technologically-driven and deals with opportunities opened by computer-based techniques; the three following mechanisms are management-oriented and deal with the management of innovation within or between organizations; the last mechanism is more market-oriented, dealing with the relationship between the corporation and its customers.

**Prototyping (virtual or physical)** – Different empirical studies have stressed how the use of new technologies like virtual prototyping and digital validation systems are likely to stimulate and intensify learning at the early phases of innovation processes. These experimental tools make it possible to speed up the detection of problems and validate alternative solutions at a very early stage, in line with front-loading strategies (Thomke and Fujimoto, 2000; Thomke, 2003). As in the software industries, early deliveries of prototypes can also stimulate interactions with users to define product specifications more effectively (MacCormack et al., 2001). The physical prototypes are classic learning mechanisms in the automotive industry as they can help testing a new concept in front of a public (clay models) or demonstrators (mock-ups) which are used in the auto industry to evaluate and/or demonstrate the performance of a concept to a large audience. Concept cars are sometimes officially launched to test ideas with a larger audience (Backman and Börjesson, 2007).

**Storytelling or Narratives** - In the organization literature, different works have stressed how learning from success or failure (Hamel and Prahalad, 1993) should be based on intended mechanisms like post-mortems or storytelling which can help revising routines and build a collective new sense-making (Weick, 1979) to develop a critical view on past projects (Levitt and March, 1988). Some published examples are to be found on the development of the Volvo XC90 (Bragd, 2002), the Renault Twingo (Midler, 1998) and the Laguna II (Aggeri and Segrestin, 2007).

**Organisational separation** - It is often suggested that more radical innovation projects should be organized separated from the NPD organization with dedicated teams, sometimes also referred to as “skunk works” (e.g. Galbraith 1982; Quinn, 1985; Peters, 1997; Gwynne, 1997; Sharma, 1999; O’Reilly and Tushman, 2004; Govindarajan and Trimble, 2005). For instance the Toyota Prius project worked physically separated from the rest of the organization, among others to be able to work independently (Itazaki, 1999). The skunk work approach is described as advantageous since it protects and culturally separates the project for the purpose of innovation, often operating in near-total secrecy with strong top-management support (Gwynne, 1997). Much focus lies on the culture and enthusiasm created in such a sub-
organization, based on a strong vision, autonomy, informal processes, collaboration and trust (Single and Spurgeon, 1996; Bommer et al., 2002).

Partnerships – Different works have demonstrated how partnering (building alliances, networks and inter-firm relationships) can be key-issues in the building of innovative capabilities (Segrestin, 2005). Collaborations with external partners, in both research and development projects, is a well known mechanism to both share risk, create economies of scale and learn (e.g. Kogut, 1988; Powell et al., 1996; Birkinshaw et al., 2007). The automotive industry is well known for close collaboration with its suppliers and also alliances such as the Renault-Nissan.

Customer involvement - Learning mechanisms are not limited to technology and managerial tools. Recent work has also stressed the importance of involving consumers in product development through lead-user involvement (Von Hippel, 1988) or toolkits used for innovation and mass customization (Piller & Walcher, 2006). In the automotive industry, customer reference groups are often used (e.g. Dahlsten, 2004), but customers are mostly included in early phases in the form of market data and in the late phases, for instance through customer clinics, focus groups (e.g. Dahlsten, 2004) and driving tests. This mechanism is gaining importance when the concepts introduced are so disruptive that a market experiment is necessary to give a value to disruptive concepts for which classical marketing tools are not adapted.

These five mechanisms for learning are all well known and widespread in the automotive industry. In this paper we will explore three innovative projects in the automotive industry and what learning mechanisms they deployed and discuss how these projects are related to the building of innovative capabilities in the companies.

3. The race for electrification in the automotive industry

Many recent innovations in the automotive industry, both in technological and marketing areas, are related to environmental issues. Labelled “eco-innovations”, these innovations raise new questions in terms of how innovative capabilities can be built. Before going into details about the learning mechanisms that may sustain such capabilities, the phenomenon of eco-innovation as such can be revisited: how to explain the recent blossom of innovations, some of which are quite disruptive? What are the drivers of the recent strategic attention to eco-innovations which, ten years ago, was mainly considered as a regulatory issue without any market value for customers?

3.1 Drivers for eco-innovation in automotive industry

It is commonplace to study the automotive industry as the archetype of a mature industrial sector built around a technological trajectory characterized by incremental and technological-driven innovations, within a dominant design. During more than a hundred years the propulsion has been based on the internal combustion engine (ICE). Former environmental innovations such as those related to recycling or to exhaust combustion technology were not disruptive since they consisted in “greening” the prevailing technology without changing the architecture or the key technological principles of the vehicle. Hybrid technologies and recent developments in tractionary batteries are potentially more disruptive since they might change both the technology and architecture.
For a long time, ecological innovation in the automotive industry has mainly remained a matter of technological development driven by public regulations. In this perspective, environmental innovation should not be regarded in terms of absolute costs but in terms of relative costs. A classical example is provided by Du Pont de Nemours who proactively promoted a regulation of CFC in the 80’s, despite higher production costs for substitutes, as a means to gain a larger market share than its competitors who tried to prevent such a regulation. More generally, the latter argument is consistent with different empirical and theoretical works that show the importance of standard setting in business competition (see Garud and Rappa, 1994) and, more generally, of studying the joint dynamics of innovation and institutionalization processes (Aggeri, 1999; Hargrave and Van de Ven, 2006).

The potential of eco-innovation for customers is an ongoing debate in the literature. Some authors argue that customers are increasingly interested in green products (e.g. Dagnoli, 1990) while others argue that there is no clear willingness to pay for the good of the environment (e.g Diekmann and Preisendörfer, 2003). Except general arguments about why environment ought to be a strategic long-term issue for companies, the key question here is how companies may conduct eco-innovation processes that combine the private good (private value for customers), the public good (reducing the environmental impact) and a sustained competitive advantage for the company (e.g. Porter and van der Linde, 1995; Sharma and Vredenburg, 1998). Previous research on eco-innovation in the automotive industry has mainly focused on the possibilities of encouraging such developments on an industry level, that is through taxes, incentives and legislation (e.g. Porter and van der Linde, 1995; Sharma and Vredenburg, 1998), but there is less focus on the company perspective. Some results have shown that despite an awareness of the negative externalities of the current technologies, inertia to change is prevalent (e.g. Willander, 2006). This is especially apparent since there is an inherent contradiction in the values put forward in sustainable performance criteria, such as low consumption, and the criteria traditionally associated with a car’s status such as powerful engines and large size (e.g. Luke, 2001).

Recent evolutions of the car market, characterized by a rapid decrease of big cars sales, reflect the urgency of developing more environmentally friendly cars. Three new drivers have increased the interest for climate related eco-innovations in the automotive industry. First, the acceleration of the public agenda with regards to climate change concerns – the anticipation of new regulations for CO2 emissions worldwide partly in combination with anticipated tax incentives with regards to vehicles with low CO2 emissions, as are already in place in for example France. However this variety of incentives systems and public choices is seen by large motor companies as an obstacle for the development of innovation. For instance, incentives strongly vary from a country to another with regards to diesel prices, to the promotion of electric vehicles or to the promotion of alternative fuels like natural gas or biogas. This heterogeneity may partly explain technological trajectories of car manufacturers. For instance, the strong focus on clean and efficient diesel engines by French car manufacturers relates probably to the fact that they are not addressing the US market, where diesel engines very seldom are used for passenger cars. Second, the brutal increase of oil prices has increased the car buyers’ concern about fuel consumption. Third, market competition is changing and first movers like Toyota have attracted the public eye and have received great media attention about their product innovations, like the Prius. This demonstration of how to actually combine a green, high status and performance image in one product has inspired competitors to outline and initiate their own hybridization strategies. All

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2 The forthcoming EU Directive on CO2 emissions will replace the voluntary agreement on CO2 emissions signed in 1998 whose targets will not be achieved by car manufacturers.
these elements have played an important role in the current race for eco-innovation that can be observed among car manufacturers.

3.2 Eco-innovation concepts related to electrification of the propulsion

Most eco-innovations in the automotive industry are related to the propulsion of the vehicle to improve fuel efficiency. This target is still firstly and foremost explored by incumbents through the improvement of the dominant design technology of ICE. Developments of turbo technologies for gasoline cars or injection technologies for diesels are illustrations of such incremental innovations that do not fundamentally change the identity of the car. Potentially more disruptive are eco-innovations related to new concepts such as EVs and HEVs. The electrification of the vehicle and its propulsion system provide an interesting alternative since it promises high energy efficiency in the vehicle as well as zero local emissions of pollutants.

Electric vehicles based on the use of an electric motor whose energy is supplied by a battery, is the most ancient and well-known concept. It has been seen as an alternative technological option to the internal combustion engine for more than a century. Beaume and Midler (2008) recall that the first electric vehicle was marketed in 1899 and more than 20 OEMs were operating in the automotive industry in 1902. However, it never became a mass product and the technology was progressively abandoned for marketing purposes and finally outperformed by the ICE technology.

Another technologically-driven concept, which has not yet turned into commercial application, deals with fuel cell technologies using hydrogen, which may be produced by different sources. Seen as the future of the vehicle by OEM’s like GM, remaining difficulties both in the technological and infrastructure sides (providing hydrogen at a large scale) may turn this concept into the range of “eternally emergent technologies” (Frery, 2000).

An intermediate solution between full electrification and full internal combustion is the HEV concept, illustrated by the Toyota Prius, which consists in supplementing the ICE by electric motors and batteries. Rather than being seen as radically different and competing technological options, different electrification or hybridisation concepts can be ranged according to different degrees of electrification of the powertrain, from almost fully depending on the ICE to all-electric propulsion.

4. Addressing electrification of the powertrain in different ways

In this section three different approaches to learning on EVs and HEVs will be briefly accounted for, via examples from Toyota, Volvo Cars and Renault. These examples have been selected because they highlight different learning mechanisms on how companies can build new competencies in this field.

4.1 Research method

Data has been collected using multiple methods. Data on Volvo Cars was collected through a case study research method (e.g. Eisenhardt, 1989). The case study is mainly based on data from 14 semi-structured interviews, lasting between one and two hours. To avoid or at least limit the bias of retrospective sense-making (Eisenhardt and Graebner, 2007), informants with different positions in relation to the project were selected; from directly involved and positive to quite distant and negative. Several hierarchical levels in the organization were represented,
from workshop staff via the project team to line managers and top management. Half of the informants are still employed by Volvo Cars, others have retired or work at other firms. Notes from each interview were submitted to the informants for review and approval. The main complement was the ‘project archive’ - a CD containing project documentation such as test reports, drawings, presentations, photos and press cuts. The data was analysed thematically, using a systematic combining approach (Dubois and Gadde, 2002) where intermediary analysis helped guide further data collection. The analysis also draws on knowledge from a number of other studies on product development and concept development at Volvo Cars which have provided the authors with in-depth contextual understanding of the practices in use in the organization (e.g. Backman et al., 2007).

Data on the Toyota project (Itazaki, 1999; Nonaka and Peltokorpi, 2006; Williander, 2007) and the Renault project (Kiviat, 2008; Scheer, 2008) are mainly based on secondary sources. A small interview study has also been conducted where two interviews at Renault and one at Toyota Europe provided additional data. Interviews with SAAB Automobile, Volvo Cars and Peugeot provided additional industry knowledge. The data from Toyota and Renault is thus not validated by us but will rather be used as examples to illustrate the differences in approaches used by the different companies. A list of interviews can be found in appendix 1.

4.2 The case of the Prius project at Toyota

The Prius hybrid project has played a key role in the formation of a lineage of hybrid vehicles at Toyota motor company. The considerable amount of investments that has been put on this concept at a time when incentives were still low is striking. The Prius hybrid has received much attention and there are many things to learn from how Toyota approached the field of hybrids (e.g. Itazaki, 1999; Magnusson and Berggren, 2001, Nonaka and Peltokorpi, 2006, Williander, 2007). If Toyota Prius is considered nowadays as a success, internal resource development and investments from Toyota shall not be underestimated. The vehicle was designed from scratch and it appears that this has been difficult to replicate by competitors. The knowledge and resource base of the company is considered as a specific asset that is distinctive resource from its competitors.

The project that led to the introduction of the Prius on the Japanese market in late 1997 was strongly supported by the top management (Itazaki, 1999). One of the reasons behind the ambitious and in several aspects probably quite risky project was management’s perceived need to challenge the organisation and avoid “the curse of success” (Nonaka and Peltokorpi, 2006:93). Among the factors contributing to a risky profile were the decision to develop all new hybrid technologies in-house (Itazaki, 1999) and the methodology to focus on technological viability, and only as this goal was achieved change to cost reduction (Magnusson and Berggren, 2001). A minimum of prototypes and the lack of back-up alternatives also contributed to the high level of risk. It was considered “an extreme challenge for the senior engineers” (Williander, 2007:208). The project management was situated in the “red carpet room” separated from the rest of the R&D organization. Simulation and tests were core issues in the project and test vehicles totalled five times longer distances than development of other new vehicles normally requires (Itazaki, 1999).

The first version of the Prius (Prius I) was launched in 1997 for the Japanese market only. It was a kind of “beta test” version, purposefully designed as a market experiment. The second version (Prius II) was launched worldwide in 2003 and benefited from the improvements based on the return of experiments of Prius I. In particular, the reliability of components was improved as well as the hybrid system (Toyota synergy drive) on which Toyota has registered more than 500 patents (Toyota website). The performance of the vehicle in terms of fuel
efficiency and acceleration was also considerably improved, reaching a level superior to the best diesel engines of the category.

The initial production volume for the Prius I was 1 000 vehicles per month (Nonaka and Peltokorpi, 2006) and has since then been increased in several steps. Towards the end of 2007 an accumulated total of over 800 000 Prius (I and II) vehicles had been delivered (GreenCarCongress, 2007). The commercial success of the Toyota Prius has played a crucial role in the emergence of a new “green” market segment and on the eco-innovation dynamics in the automotive sector — after an initial phase of scepticism, most of the large car manufacturers have launched R&D hybrid projects.

4.3 The case of the Desirée project at Volvo Cars

The Desirée project (Dual Hybrid Electric System for Increased Efficiency and Economy) at Volvo Cars started in October 1997 and involved approximately 20 persons from various departments. The objective was to develop two demonstration vehicles with substantially improved fuel efficiency that were to meet all regular emission and safety requirements and, apart from the powertrain, only contain standard components. It resulted in two demonstration vehicles 18 months later, using 40 percent less fuel than comparable cars. This remarkably high reduction was obtained through the introduction of a power-split hybrid propulsion system. No efforts were made to change the vehicle in other ways, for example by reducing the weight, streamline it to reduce air resistance or use low friction tyres. The technology demonstrated by the Desirée project was then further developed by the new owner Ford Motor Company and it is still used in the hybrid version of Ford Escape that was introduced to the market in 2004.

The Desirée project was mainly initiated to test and demonstrate a power-split technology developed by the Japanese automotive supplier Aisin. It was a bottom-up approach without a clear mandate from top management. Much work was carried out directly in the workshop, partly because of a very tight budget and time schedule. Volvo Cars had a relatively strong HEV knowledge base to build on as several mainly series hybrid vehicle projects already had been carried out. This fact in combination with a strong reliance on technology partners such as Aisin providing the power-split device, Varta providing the nickel metal hydride batteries and Bosch providing the engine control module, enabled the project to develop promising fully functional concept cars in only 18 months. Simulation and test driving were also very important activities in the project, not only because the technology was new to the firm but also as the involvement of managers and other stakeholders as test drivers was considered a method to gain support for further HEV activities.

Content with the prototype, Volvo Cars decided to show the Desirée vehicle at Geneva Motor Show in 1999 but in the change of ownership that followed ensuite, the project results were transferred to Ford, which took the lead of further development of the power-split hybrid technology. This resulted in the launch of the Ford Escape in hybrid version a few years later, but not in any hybrid Volvo vehicles. In recent years, Volvo Cars has launched a new hybrid centre, partly building on knowledge from the Desirée project and participate in several initiatives with partners and even competitors (such as the joint plug-in HEV project between SAAB, Volvo Cars and the Swedish energy company Vattenfall), but there are still no hybrid Volvo cars on the market.
4.4. The case of the Better Place project at Renault

The development of EVs has long struck against some “technological barriers”, among them: restricted autonomy and/or heavy batteries, lack of infrastructure to provide the energy for recharging the batteries, and the long time required for recharging the batteries. Despite strong incentives (California ZEV, national plans and public subsidies), these technological barriers have together with other factors contributed to the blocking of significant market change. Some have even described EV as an “eternally emergent technology” (Frery, 2000), an engineering dream, incapable of meeting market requirements.

However, recently car manufacturers have deeply revised their approach of EV development, inspired by Toyota and pushed by market change. Rather than aiming at a technological breakthrough for mass markets based on a “research-push” approach, some car manufacturers have started to experiment with more progressive learning approaches based on partnerships with energy providers and “market-pull” experiments in local markets confronted to specific usages. Renault provides a good example of such a strategic shift with their “Project Better Place” based on the concept of “quick exchangeability” for batteries (Beaume and Midler, 2008).

In January 2008 it was announced that Renault-Nissan had signed an agreement to begin mass-producing electric cars together with a project in Israel, the Better Place project. The aim is to develop electric cars that have a driving range of 100 km driving in the city and 160 km highway driving and have a 110 km/h top speed. Israel was chosen partly as 90% of Israelis drive less than 70 km per day and all major cities are within 150 km from each other. The battery is being developed by NEC to be available in 2011 (Scheer, 2008). Renault has announced that the goal is to mass produce and sell electric cars in Israel by 2011 and also in other countries in Europe by 2012 (Renault homepage, 10/04/08). In March 2008, it was also announced that the project had signed an agreement with Dong Electricity to develop a similar infrastructure in Denmark (Lampinen, 2008). The Better Place project was initiated by the entrepreneur Shai Agassi aiming at reducing oil dependency through building an electric vehicle infrastructure in Israel. The infrastructure is to be built on recharging points in the streets complemented by battery-swapping stations all over the country (Makeower et al, 2008). A pilot involving a few dozen cars will be launched during 2008 in Tel Aviv and a few hundred vehicles are expected to be on the road by 2009, with production scaled to the mass market by 2011. Early 2008, Israel slashed the tax rate on cars powered by electricity down to 10% in order to encourage consumers to buy such vehicles once they are available (Kiviat, 2008).

The Better Place project is a limited, initially small scale experiment very different from previous attempts with large scale public-private partnerships for electric vehicles in the 70’s in France (e.g Callon, 1980). Building a subscriber based ownership model this project is challenging one of the dominant logics of the car industry. A manager at Renault compared the Better Place project with the initiative Toyota took on the HEVs but said also that the uncertainty lies in the cost of batteries: [Asking people to buy an electric vehicle] “is like asking customers to buy fuel for the next ten years up front. We need another business model” (Interview Renault, 2008). Renault is part of the project for two reasons according to the interviewee, to learn on the technology but also to learn on the usage of the electrical car. The main role of the car company is the role of integration both for the physical product and the software – designing the best compromise between performance and consumption.
5. Developing innovation through learning mechanisms

Using these three examples we will revisit the learning mechanisms described in literature on the automotive industry and address how they contribute to the building of innovative capabilities.

5.1 Basic learning mechanisms

In terms of prototyping, simulations and tests were crucial parts of both the Desirée and the Prius project, partly as the technologies were new and several different components and subsystems had to work together. It was also stated that simulations contributed to the short development time in both cases. The Desirée project at Volvo Cars resulted in two vehicles for test driving and demonstration, and, as the car was selected for the Geneva Motor Show, it also became an official concept car. In the Better Place project, early prototypes have been rapidly developed by Renault to test its properties and set requirements for mass production. The Toyota Prius is a good example of a narrative that has spread throughout the industry - a recently translated book also tells the details of the development work (Itazaki, 1999). People in industry often use the Toyota case as a reference case for having done the good strategic choice in terms of the hybridization. Renault has a link on its webpage pointing at the Better Place project homepage where interested people can follow each step in the project. The project also seems to have a strong media strategy, launching press releases and keeping a blog on news and events (www.projectbetterplace.com). The Desirée project has a reputation internally at Volvo as a success story that confirms the technology proficiency of the company, but it is not a story that is known to a wider audience.

In the case of the Volvo HEV project, the skunk work profile contributed to a project with very limited administration and a tight project team. As the Desirée was used as a main message at the Geneva Motor Show in 1999, and as the team spent a lot of time involving managers and other stakeholders in the test driving of the demonstrators, the results were acknowledged by the rest of the organisation. It thus managed to avoid the risks often occurring when separating the more explorative activities from the core business, a set up that might lead to isolation and resistance against the ideas that are developed (Birkinshaw and Gibson, 2004; Moss Kanter, 2006). The Prius project had a strong top management support from the beginning and was kept separated from the regular R&D organization. The Renault project also has a strong support from top management and CEO Carlos Ghosn can be seen on a photo with entrepreneur Agassi on the project homepage.

Partnerships are handled differently in the three examples. In the Desirée case, the partnership with technology partners was a key to the project success. Aisin was the main partner, supplying transmission and motor drives, but the relations to Varta for the batteries and to Bosch for the engine control module were also critical. Toyota had a different approach as they developed all HEV technology in-house, convinced that this was the best learning strategy. In the Renault project, the partnership with the Israeli project has provided a strong platform for learning on both technology and customer uses. Furthermore, the success of the electric cars depends on the partnership with NEC on the battery technology.

Traditional customer involvement techniques, like customer clinics, focus groups, were not especially used in the case studied. A few end users were involved in the reviewing of the Desirée concept car in the final stage at the Geneva Motor show in 1999. In the Prius case, limited test driving was conducted in late stages of development whereas in the Project Better Place interactions are limited to prototype testing. It doesn’t mean that customer involvement is not relevant but rather that these traditional techniques were not adapted to the disruptive
nature of the innovation put into place which required other types of experimentation with customers (see next section).

5.2 Advanced learning mechanisms

Some additional learning mechanisms that are not so developed in literature on the automotive industry can also be noted in these cases. Some authors have argued that in a context of intensive innovation where the identity of the object itself has become unstable (Le Masson et al., 2006) companies are urged to redefine not only the product but also the values and the competencies of the firm to build innovative capabilities (Hatchuel et al., 2003). The high uncertainties (in all aspects; technology, market, customer preferences, regulations etc) make it difficult to develop all the needed competences in-house and companies are forced to renew also their learning processes based on controlled interactions with external partners (companies or customers).

A first advanced learning mechanism is market experimentation. Market experimentation means some controlled process of experimentation with real end consumers in order get feedback to improve the design of the product and or business concept. Market experimentation shall be distinguished from customer involvement or concept testing which intervenes at very early stages of the development process (concept testing) or at final stages, which in the latter case prevents from any feedback on the product design. In this perspective, one interesting aspect of the Toyota Prius project is that Toyota performed a full-scale market experiment using the Japanese market as a test before deciding if the technology would be exported to other countries (which it was, in a refined version some years later). Thus, the Prius I was not seen as an end in itself but rather a step in a broader lineage of product innovations. Similarly, the Better place project in Israel has been thought as a large-scale experimentation which is directed not only towards technology and related usage, but also towards the design of a new business model – redefining the ownership model. This emergence of new innovation models that are not based only on the search of technological breakthrough innovations in components (the battery technology particular) as it used to be in the past but aim at exploring new concepts that simultaneously try to address the technologies, the market and the supply of energy at stake is an interesting phenomenon. In the case of Toyota it is also clear that the brand has been transformed due to the success of the Prius. It seems these market experiments can be another way of learning in more innovative situations.

The deployment of exploratory partnerships is a second advanced mechanism. The term has been coined (Segrestin, 2005) to designate a phenomenon in which the partners’ interests and the common purpose are discovered in the course of action, instead of defined initially. The more exploratory the partnership is, the more reciprocal commitments and contractual arrangements have to be managed to guide the learning process (Segrestin, 2005). New forms of partnerships can also be found, where uncertainties are much higher than in traditional alliances and partnerships within the dominant design of ICE. For instance, in the Desirée project the initial agreement was very open, aiming at jointly trying the technology. The partnerships helped expanding the knowledge base and the innovative capabilities of the firm. The case of the Better Place is also a clear example of an exploratory partnership – in the initial stages Renault could not define in the initial stages what the outcome would look like, but they are developing the value to offer and reinventing ownership models and thus also their own role in the mobility system.

In Table 1 a summary of the basic and the more advanced learning mechanisms is presented.
Table 1. Basic and advanced learning mechanisms

<table>
<thead>
<tr>
<th>Project</th>
<th>Prototyping (virtual/physical)</th>
<th>Basic learning mechanisms</th>
<th>Advanced learning mechanisms</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Narratives</td>
<td>Skunk work</td>
</tr>
<tr>
<td>Desirée</td>
<td>Simulations, demonstrators, concept cars</td>
<td>Internal success story</td>
<td>Protected from top mgmt in early phases</td>
</tr>
<tr>
<td>Prius</td>
<td>Simulations</td>
<td>Reference case in industry</td>
<td>Supported by top mgmt, org separated</td>
</tr>
<tr>
<td>Better Place</td>
<td>Prototypes</td>
<td>Public site following development</td>
<td>Supported by top management</td>
</tr>
</tbody>
</table>

5.3 Building innovative capabilities in disruptive technology shifts

In literature, it is argued that learning is a critical part in innovation (e.g. Lynn et al., 1998) and that learning can be managed in a long-term perspective, through repeated innovations (see Penrose, 1960, Hatchuel et al., 2003) and through learning between projects (e.g. Maidique and Zirger, 1985; Rothwell and Gardinger, 1989). It has also been argued that to be innovative, companies need to manage learning strategies (Hatchuel et al., 2005). However, few studies have shown how companies work with learning in practice. The aim of this paper is to discuss how companies can build innovative capabilities in disruptive contexts through highlighting some of the mechanisms used in various projects. The analogue of the double loop learning (i.e. changing the underlying logic) is valuable in this context of electrification of the powertain since it is an innovation field where not only the technology is different but where there seem to be a destabilization also of the market, the customer usage and the business model.

The strong focus on developing new knowledge and using prototyping intensively by Toyota is consistent with their explicit ambition to learn as much as possible themselves instead of collaborating with external partners. Their experiments on the market also produced massive learning but was both resource intensive and risky. However, this strategy turned out to be highly successful and today, Toyota is the undisputed leader in the HEV market. Their heavy investment in HEV technologies has resulted in technologies that are now used in a portfolio of different products, all having a quite high profile. This reuse of HEV knowledge in a lineage of innovations (Le Masson et al., 20006) helps Toyota maintaining a dominating market position on a market that has been more or less created by Toyota. They also have close contact with the market through an elaborated market strategy, using ambassadors to promote the vehicle and hosting a strong web community, which has rewarded them with loyal customers (Interview Toyota, 2008). It has also been stated that the Prius project has generated a spill-over to the Toyota brand, rendering it a general improvement towards high-tech and clean-tech. It is not unlikely that this HEV learning strategy has also contributed to the growth of Toyota, now being close to over-taking GM as the world’s largest auto-maker.

Renault is a veteran in electrical vehicles, having launched their first EV in the seventies in partnership with EDF and the support of the French government and tested electric vehicles in
the 90’s within a partnership on intermodal mobility with the RATP (the operator of the subway in the Parisian region) and the city of St Quentin en Yvelines (the Praxitèle experience). The company has publicly stated that they will put a new generation of EV on the market by 2012 (Interview, Renault 2008). Using more limited resources (both financial and technological) than Toyota, Renault has opted for small-scale market experiments based on exploratory partnerships with suppliers and ventures with complementors. This joint knowledge development seems to be a way of developing their capabilities in the field in a cost-efficient and controlled way. The involvement in the Better Place project contributes, at this stage, to the positioning of Renault as a firm that engages in innovative ventures with a clear common good environmental dimension. In a longer term perspective it builds their knowledge not only on electric cars but also on the use and the potential business models to develop.

The Desirée project contributed to the launch of the Ford Escape hybrid, which is partly based on the Desirée project results. However, Volvo Cars did not build on the competences from the project for several years as Ford took lead on most hybrid development. In recent years, Volvo Cars have launched a new hybrid centre in collaboration with Ford and they claim that they can build on the competences that remain from the Desirée project, both in terms of electrical engines and power electronics. In 2007, Volvo presented a plug-in HEV concept car, but they have still not introduced any EV or HEV vehicles on the market.

The examples put forward in this article also illustrate the use of an extended range of learning mechanisms. The market for EV and HEV is not known to the companies (as they know the ICE market) and therefore there is a need to use learning mechanisms that generate this knowledge. Both Toyota and Renault use market experiments to learn on new usages and business models. These experiments have also helped repositioning their brands, something that influences also other companies in the industry. For instance, GM argues that their image loss in terms of reduced sales after the Prius launch were huge and the current testing of their plug-in hybrid Volt is partly driven by the fear of not developing the right knowledge – according to Bob Lutz “GM won't make that error again, even if it means losing money on initial Volt sales” (Detroit News, 2008). Recent launches of different types of eco-labels is another phenomena in this area – for instance, Renault launched their Eco2 label in May 2007 and Peugeot has a similar label called the Blue Lion. The labels signal green production, recyclable materials and low CO2-emission levels. For Renault it is a way of communicating with the customers, of helping them make a more informed choice when buying a car and to put forward the work on environment that they are doing (Interview Renault 2008). An interesting aspect of this is that the development of labels is a way of putting forward the performance criteria to be used for eco-cars and a way of experimenting with the brand.

Another learning mechanism that was identified in the examples was the exploratory partnerships – that is the collaboration with partners on issues that are being defined during the collaboration. This enables joint knowledge generation and could be seen both in the Desirée project and in the Better Place project. Another example in Sweden are so called distributed research centres that have emerged where competitors come together at a neutral platform to generate knowledge and come up with innovative concepts. For instance, Saab Automobile collaborates with Volvo Cars in three such HEV related centres: Electric machines, Battery technology and Hybrid systems (Interview, Saab Automobile). It seems that in a context such as the electrification of the propulsion in cars, learning mechanisms that support knowledge and concept generation become more critical when working within dominant design logics. This is also coherent with literature in how to build innovative capabilities.
The innovative capabilities of firms are built through their long term use of lineages of new concepts and knowledge (e.g. Hatchuel, 2003). Toyota has managed to apply this learning strategy successfully, exploiting spill-overs and applying new technology to families of products, for instance through introducing the Synergy Drive concept in a range of car models. Through an explicit learning strategy, the building of innovative capabilities can be managed. To get a deeper understanding it is important to highlight how different learning mechanisms are combined within a coherent design strategy and for what purpose they are mobilised. This paper argues that the use of different learning mechanisms has to be related to the design of an overall learning strategy to contribute to the building of innovative capabilities. This implies that to be able to explore this new area of EV or HEV vehicles, companies need to develop both long term learning strategies (how to develop knowledge to be able to launch a hybrid electric or pure electric vehicle) and the learning mechanisms that will help them reach their goals in a stepwise process of knowledge generation. This is in line with previous research on learning between R&D projects (e.g. Maidique and Zirger, 1985; Rothwell and Gardinger, 1989; Cusumano and Nobeoka, 2000).

6. Conclusion

This article set out to explore how car manufacturers build their capabilities in a situation of a potential disruptive technology shift through discussing some examples of how car manufacturers have used different learning mechanisms in their aim for developing their capabilities around EVs and HEVs. The electrification path in the automotive industry constitutes an interesting example since all companies are forced to revisit the knowledge areas that have been linked to the dominant design of the car for a very long time. Addressing a potentially disruptive innovation, such as the full electrification of the vehicle’s powertrain, has also led to the use of more advanced learning mechanisms in the industry, identified as market experiments and exploratory partnerships.

It seems that Toyota has managed to develop a learning strategy very early where they have invested heavily in generating all the knowledge in house, using both traditional and more advanced learning mechanisms. Other firms have used less resource intensive strategies, learning step-by-step with partners, such as in the Renault case and the Volvo Cars case, a strategy which has not been as successful. It seems that in a context of electrification, overall learning strategies are necessary to guide the many learning mechanisms that can be activated. Until a new dominant design of hybrid electric cars or pure electric cars is developed, the focus on knowledge generation remains crucial, as is the controlled development of the capabilities of the firms.
References


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*Garud and Rappa, 1994*


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Toyota homepage (www.toyota.com, accessed 10/04/08)


Appendix 1 - Interviews

Automotive firms

<table>
<thead>
<tr>
<th>Date</th>
<th>Company</th>
<th>Position</th>
</tr>
</thead>
<tbody>
<tr>
<td>April 2008</td>
<td>Toyota Europe</td>
<td>Marketing Manager</td>
</tr>
<tr>
<td>February 2008</td>
<td>SAAB Automobile</td>
<td>Senior R&amp;D Manager</td>
</tr>
<tr>
<td>February 2008</td>
<td>Volvo Cars</td>
<td>Marketing Manager</td>
</tr>
<tr>
<td>February 2008</td>
<td>Renault</td>
<td>Technology Manager</td>
</tr>
<tr>
<td>November 2007</td>
<td>Renault</td>
<td>Marketing Manager</td>
</tr>
<tr>
<td>July 2007</td>
<td>Peugeot</td>
<td>Strategy Manager</td>
</tr>
</tbody>
</table>

The Desiree case study

<table>
<thead>
<tr>
<th>Informant category</th>
<th>Number of interviews</th>
</tr>
</thead>
<tbody>
<tr>
<td>Desirée team member or leader</td>
<td>Five respondents</td>
</tr>
<tr>
<td>Manager at Volvo Cars</td>
<td>Seven respondents</td>
</tr>
<tr>
<td>HEV specialist at Volvo Cars not involved in Desirée</td>
<td>Two respondents</td>
</tr>
</tbody>
</table>