Managing learning in the automotive industry – the innovation race for electric vehicles

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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 of usage and business models. The literature on discontinuous innovation proposes learning as a crucial capability, but there are few empirical studies on how this actually happens in firms. This paper discusses the different learning mechanisms used to develop the capabilities related to Electric Vehicles (EVs) and Hybrid Electric Vehicles (HEVs). It highlights that in this kind of broad innovation field, more advanced mechanisms might be needed by automotive firms aspiring to be leaders, such as market experiments and exploratory partnerships. It also argues that overall learning strategies are necessary to guide the many learning mechanisms involved. The paper contributes to our understanding of how automotive companies deal with disruptive innovations.

Keywords: learning; innovation; innovative capabilities; hybrid electric vehicles; HEVs; eco-innovation; learning strategy.

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1 Introduction

The impact of automobiles on the natural environment is well known and the reduction of this impact is a priority for every car manufacturer. Reducing carbon dioxide (CO^2) emissions is one of the main drivers of technology developments and is the subject of aggressive regulations. There are several ways to reduce CO^2 emissions from cars with combustion engines, including new types of fuels (biofuels), lower consumption engines and better driver behaviour. There are also more radical technology developments, such as Electric Vehicles (EVs) or Hybrid Electric Vehicles (HEVs). Toyota's first large HEV project, the Prius, attracted wide public and research interest (Magnusson and Berggren, 2001; Nonaka and Peltokorpi, 2006). However, it would be a mistake to restrict these innovations to their technological dimension. The electrification of the vehicle's powertrain represents a very broad field of innovation where, for instance, car manufacturers need to explore new marketing, technological and business model concepts. How do car manufacturers and new mobility service providers build their capabilities in situations that are potentially disruptive in so many dimensions?

This paper aims to discuss some learning mechanisms that car manufacturers and their partners have used to develop their capabilities on EVs and HEVs. It highlights that in this broad innovation field, new mechanisms for learning (instruments, tests and experiments) are being deployed in the automotive industry. It 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. Furthermore, it responds to a call for more research on disruptive technology (Danneels, 2004). This paper is based on a study of car manufacturers (six interviews), a case study of an HEV project at Volvo Cars (14 interviews) and information from 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 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 have proposed distinguishing between the degrees of influence that innovation has on existing products, where sustaining technologies are those that improve the performance of previously available products and disruptive technologies bring a different value proposition to the market (Christensen, 1997; Christensen and Overdorf, 2000). A complementary dimension relates to 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 defined as its ability to deploy its available resources (Prahalad and Hamel, 1990). According to Christensen (1997), an organisation's capabilities are defined by its processes (methods for transforming inputs to higher-value outputs) and values (criteria used for decision making). Furthermore, Leonard-Barton (1992) described the core capabilities of firms as the set of knowledge that provides competitive advantage. To avoid that core capabilities turn into core rigidities, Teece *et al.*, (1997) introduced a dynamic perspective that underlines the need to systematically revise and develop organisational capabilities (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 characterised by uncertainty and new knowledge areas where the performance criteria rapidly change. For firms, there is a difficult tradeoff between short-term returns and long-term capability building (Bartezzaghi *et al.*, 1997), which has been described as the productivity paradox (Abernathy, 1978), exploration-exploitation (March, 1991) or the ambidextrous organisation (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, p.219)

The author further argued that one way to develop this capability is to enhance absorptive capacity, *i.e.*, the capacity to recognise and understand external knowledge, assimilate it 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, p.21). Despite the theoretical discussions on innovative capabilities, there are still few examples of how companies actually deal with more radical innovations and there is a need for a better understanding of how companies can prepare for and undertake such innovation.

2.2 Innovative capabilities and the role of learning

Previous research shows that organisational learning is a critical capability for firms aiming to be 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, p.377)

Hatchuel *et al.* (2002) underlined the need to manage learning by proposing a type of design-oriented organisation, which means an "organization favourable to collective learning cycles, which… [is itself] conducive to this simultaneous regeneration of objects, skills and occupations" (p.18). They also claimed that knowledge management is closely linked to the organisation of actions within the firm and that firms need to constantly reconstruct their collective learning processes in terms of 'concept objects' and 'embryonic occupations' whose ongoing development will perhaps – but not always – generate more routinised occupations and practices (Hatchuel *et al.*, 2002, p.18). Learning is, thus, important within the dynamic capability view of the firm because resource endowments are 'sticky' (at least in the short run) and because firms often lack the organisational 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 such capacities are built.

The literature contrasts two fundamental learning processes: "single-loop learning" (Argyris, 1976), which mainly consists of problem solving, during which organisational routines are refined within an existing "theory in use" (Argyris and Schön, 1996) or the "dominant logic" (Prahalad and Bettis, 1986) of the firm and "double-loop learning", which not only detects and solves problems, but also questions the underlying values and norms changing the "theory in use" (Argyris, 1976; 1977; Argyris and Schön, 1996).

Transposed to innovation management in organisations, single-loop learning would consist of 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 firm's "absorptive capacity" (Cohen and Levinthal, 1990; Lane *et al.*, 2006). Other authors have also stressed the link between absorptive capacity and the firm's capability to learn (Williander, 2007; Todorova and Durisin, 2007). In contrast, double-loop learning involves deeper changes in the organisation's knowledge and resource base. Innovative organisations are those that are able to explore, revise their routines and mobilise new concepts and resources. In line with the design strategies proposed by Hatchuel *et al.* (2005) and Le Masson *et al.* (2006), this implies that a key issue for companies is combining their absorptive capacities with more "generative capacities" (Elmquist, 2007). In a double-loop approach to innovation, neither the solutions nor the performance criteria are pre-existing, but need to be designed and developed during the innovation process.

A focus on learning is all the more important, as the outcomes of innovation activity are uncertain and there are potential 'spillovers', *i.e.*, unexpected or unintended outcomes. This phenomenon is often considered out of focus for managers, but in innovation management, spillovers are key from a learning perspective. The implementation of instruments or mechanisms through which spillovers can be identified and may be fed back through the innovation process is an important managerial task. As people, knowledge and stories circulate in and between organisations, in an 'open innovation' scenario, learning is likely to occur across and beyond existing boundaries (Chesbrough, 2003; Chesbrough *et al.*, 2006). In this perspective, organisations 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 learning among projects (*e.g.*, Maidique and Zirger, 1985; Rothwell and Gardiner, 1989; Cusumano and Nobeoka, 1998). Therefore, the firm's innovation capability should not be measured within a project, but needs to be evaluated over a longer period of time within lineages of concepts and knowledge (Hatchuel *et al.*, 2003) and based on the capacity to exploit spillovers. In this managerial approach, the idea is that organisational learning is not a natural process but, on the contrary, a process that needs to be managed, designed and guided through the selection of appropriate mechanisms that maximise learning opportunities and increase the resource base of the company (see Tidd *et al.*, 2005).

2.3 Learning mechanisms in the automotive industry

What are the learning mechanisms that support the development of innovative capabilities in the automotive industry? Traditionally, researchers and companies have expended effort on designing and implementing new ways to improve performance in 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 rationalisation 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.* – and new computer-based techniques – such as Computer-Aided Design (CAD), virtual prototyping, *etc.* – have been successfully implemented on a large scale by Japanese car manufacturers. Taken together, these mechanisms become a broader framework, called the Japanese NPD model, which companies inside and outside the automotive industry have tried to replicate with different degrees of success (see Clark and Fujimoto, 1991; Cusumano and Nobeoka, 2000). For instance, some research has focused on 'front loading', designating the strategy through 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 mastery of these mechanisms is difficult and the development of collective learning is similarly not straightforward. Several empirical studies stress that phenomena such as inertia (which occurs when new concepts and knowledge are not aligned with established routines) (Williander, 2006) and organisational amnesia destroy competence, as experts tend to focus on the achievement of short-term project targets rather than long-term functional competences development (Aggeri and Segrestin, 2007). In particular, as Research and Development (R&D) in the automotive industry consists mainly of a small number of very large projects, transferring and reusing knowledge between projects is difficult to organise. The completion of a project is one of the main driving forces, but once delivered, teams tend to disperse, leading to a frequent "reinvention of the wheel" (Coombs and Hull, 1998). But collective learning is crucial to develop managerial and technical capabilities for future projects. In terms of innovation capabilities, it seems that the automotive industry is proficient in terms of incremental innovations, but the efficiency of the NPD model is more questionable when related to more radical changes in terms of concepts or pieces of knowledge, as argued by Eisenhardt and Martin (2000).

What kind of learning mechanisms are automotive firms using to support innovative projects? We identified five different mechanisms in the literature. The first is technology-driven and deals with the opportunities opened by computer-based techniques; the next three mechanisms are management-oriented and deal with the management of innovation within and between organisations; the last is market-oriented, dealing with the relationship between corporations and their customers.

1 *Prototyping (virtual or physical)*

Several empirical studies have stressed how the use of new technologies such as virtual prototyping and digital validation systems is likely to stimulate and intensify learning at the early phases of the innovation process. These experimental tools make it possible to speed up the detection of problems and validate alternative solutions at a very early stage, which is in line with front-loading strategies (Thomke and Fujimoto, 2000; Thomke, 2003). As in the software industry, the early delivery of prototypes will stimulate interactions with users to define product specifications more effectively (MacCormack *et al.*, 2001). Physical prototypes are classic learning mechanisms in the automotive industry, as they help test new concepts in front of the public (clay models) or demonstrators (mock-ups) and 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 (Backman *et al.*, 2007).

2 *Storytelling or narratives*

In the organisation literature, several studies stress that learning from success or failure (Hamel and Prahalad, 1993) should be based on intended mechanisms such as post-mortems or storytelling, which help revise routines and build collective new sense making (Weick, 1979) to develop a critical view of past projects (Levitt and March, 1988). Some published examples are the development of the Volvo XC90 (Bragd, 2002), the Renault Twingo (Midler, 1998) and the Laguna II (Aggeri and Segrestin, 2007).

3 *Organisational separation*

It has often been suggested that more radical innovation projects should be organised separated from the NPD organisation, 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 was physically separate from the rest of the organisation (Itazaki, 1999). The skunk works approach is described as advantageous since it protects and culturally separates the innovative project, often operating in near-total secrecy with strong support from top management (Gwynne, 1997). The focus is strongly on the culture and enthusiasm created in such a suborganisation, based on a strong vision, autonomy, informal processes, collaboration and trust (Single and Spurgeon, 1996; Bommer *et al.*, 2002).

4 *Partnerships*

Several studies also demonstrate that partnering (building alliances, networks and interfirm relationships) is one of the keys to building innovative capabilities (Segrestin, 2005). Collaborations with external partners in R&D projects is a well-recognised mechanism that enables the sharing of risk, economies of scale and learning (*e.g.*, Kogut, 1988; Powell *et al.*, 1996; Birkinshaw *et al.*, 2007). The automotive industry is well known for its close collaboration with suppliers and for alliances such as in the case of cooperation between Renault and Nissan.

5 *Customer involvement*

Learning mechanisms are not limited to technology and managerial tools. Some scholars stress the importance of involving consumers in product development through lead user involvement (Von Hippel, 1988) or toolkits for innovation and mass customisation (Piller and Walcher, 2006). In the automotive industry, customer reference groups are often used (*e.g.*, Dahlsten, 2004); customers are mostly included in the early phases based on market data and, in later phases, through customer clinics, focus groups (*e.g.*, Dahlsten, 2004) and test drives. These mechanisms are especially important when the introduced concepts are so disruptive that a market experiment is necessary to prove the value of the concept which classical marketing tools are unable to achieve.

These five mechanisms for learning are widespread in the automotive industry. In this paper, we explore three innovative automotive industry projects and the learning mechanisms they deploy and discuss how these projects are related to the building of innovative capabilities in companies.

3 The race for electrification in the automotive industry

Many recent innovations in the automotive industry, in the areas of both technological and marketing, are related to environmental issues. Labelled 'eco-innovations', they raise new questions in terms of how innovative capabilities can be built. Before going into detail about the learning mechanisms that may sustain these capabilities, we look at the phenomenon of eco-innovation in terms of how to explain the recent explosion of innovations, some of which are quite disruptive. What are the drivers of the recent strategic attention on eco-innovations which was mainly seen ten years ago as a regulatory issue with no value for customers?

3.1 Drivers for eco-innovation in the automotive industry

It has become common to study the automotive industry as the archetype of a mature industrial sector built around a technological trajectory characterised by incremental and technologically driven innovations within a dominant design. For more than a hundred years, propulsion has been based on the Internal Combustion Engine (ICE). Earlier environmental innovations, such as those related to recycling or exhaust combustion technology, were not disruptive since they consisted of 'greening' the prevailing technology without changing the architecture or key technological principles of the vehicle. Hybrid technologies and recent developments in tractionary batteries are potentially more disruptive, since they could change both the technology and architecture.

For many years, ecological innovation in the automotive industry has been a matter of technological development driven by public regulations. In this perspective, environmental innovation should be regarded not in terms of absolute costs, but in terms of relative costs. A classic example is provided by Du Pont de Nemours, who proactively promoted the regulation of chlorofluorocarbons (CFC) in the 1980s despite the higher production costs for substitutes as a means to gain market share over its competitors, who tried to block this regulation. This is consistent with empirical and theoretical work that shows the importance of setting standards in business competition (see Garud and Rappa, 1994) and, more generally, of studying the joint dynamics of innovation and institutionalisation processes (Aggeri, 1999; Hargrave and Van de Ven, 2006).

The potential of eco-innovation for customers has been an ongoing debate in the literature for a while. Some authors argued that customers are increasingly interested in green products (*e.g.*, Dagnoli, 1990), while others maintained that there is no clear willingness to pay for improvements to the environment (*e.g.*, Diekmann and Preisendörfer, 2003). Apart from general arguments about why the environment ought to be a strategic long-term issue for companies, the key question here is how companies can conduct eco-innovation processes that combine aspects of private good (private value for customers) and public good (reducing the environmental impact) with 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 focuses mainly on the possibilities of encouraging such developments at the industry level, that is, through taxes, incentives and legislation (*e.g.*, Porter and van der Linde, 1995; Sharma and Vredenburg, 1998) and there has been less attention to the company perspective. Some results show that despite an awareness of the negative externalities of current technologies, inertia is prevalent (*e.g.*, Williander, 2006). This is especially apparent in the inherent contradiction in the values put on sustainable performance criteria such as low consumption and the criteria traditionally associated with a car's status such as a powerful engine and large size (*e.g.*, Luke, 2001).

Recent evolutions in the car market, characterised by a rapid decrease in the sales of large vehicles, reflect the urgency of developing more environmentally friendly cars. Interest in climate-related eco-innovations in the automotive industry have been spurred first by increased public concern over climate change in anticipation of the new global regulations for CO^2 emissions[1] in combination with anticipated tax incentives for low-emission cars, which are already in place, for instance, in France. However, this variety of incentive systems and public choice is regarded by large motor companies as an obstacle to the development of innovation. The incentives vary among countries in terms of the price of diesel fuel, promotion of EVs or promotion of alternative fuels such as natural gas or biogas. This probably explains the different technological trajectories of car manufacturers. For instance, it explains the strong focus on clean and efficient diesel engines by French car manufacturers – which are generally not produced for the US market, where diesel engines are seldom deployed in passenger cars. Second, the huge increase in oil prices has increased car buyers' concerns over fuel consumption. Third, market competition is changing and product innovations such as Toyota's Prius have received major media attention. This demonstration of how to combine an image of greenness, high status and performance in one product has motivated competitors to outline and initiate their own hybridisation strategies. All these elements play a role in the current race for eco-innovation among car manufacturers.

3.2 Eco-innovation concepts related to propulsion electrification

Most eco-innovations in the automotive industry are related to vehicle propulsion and improved fuel efficiency. This is being targeted mostly by improvements to the dominant ICE design technology. Developments of turbo technologies for gasoline cars or injection technologies for diesels are examples of incremental innovations that do not fundamentally change the car's identity. Potentially more disruptive are eco-innovations include new concepts such as EVs and HEVs. The electrification of vehicles and their propulsion systems provides interesting alternatives since it promises high energy efficiency in the vehicle, as well as zero polluting emissions.

EVs based on electric motors, whose energy is supplied by a battery, is the best known of these concepts. It has been seen as an alternative technological option to the ICE for more than a century. Beaume and Midler (2008) recalled that the first EV was marketed in 1899 and more than 20 Original Equipment Manufacturers (OEMs) were operating in the automotive industry in 1902. However, no EV ever entered mass production and the technology was progressively abandoned for marketing purposes, finally being outperformed by the ICE technology.

Another technologically-driven concept, which has not yet received commercial application, is the fuel cell technologies using hydrogen produced from different sources. Seen as the future for vehicles by OEMs such as GM, difficulties on the technological and infrastructure sides (providing hydrogen at a large scale) may render this concept an "eternally emergent" technology (Frery, 2000).

An intermediate solution between full electrification and full internal combustion is the HEV, illustrated by the Toyota Prius, which supplements the ICE with an electric motor and batteries. Rather than being a radically different and competing technological option, electrification or hybridisation concepts can be ranged according to the degree of electrification of the powertrain, from almost full (depending on the ICE) to fully electric propulsion.

4 Addressing the electrification of the powertrain in different ways

In this section, we discuss three approaches to learning on EVs and HEVs via examples from Toyota, Volvo Cars and Project Better Place. These examples have been selected because they highlight different learning mechanisms related to how companies can build new competencies in these fields.

4.1 Research method

Data were collected using multiple methods. Data on Volvo Cars were collected through case study research (*e.g.*, Eisenhardt, 1989). The case study involved 14 semi-structured interviews lasting between 1 to 2 h. To avoid or at least limit the bias of retrospective sense making (Eisenhardt and Graebner, 2007), informants in different positions in the project were selected, from direct and positive involvement to quite distant and negative involvement. Several hierarchical levels in the organisation 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, while others have retired or moved to other firms. The interview notes were submitted to informants for review and approval. The main source of complementary information was the 'project archive' – a CD containing project documentation such as test reports, drawings, presentations, photos and press releases. The data were analysed thematically using a systematic combined approach (Dubois and Gadde, 2002) in which intermediary analysis guided 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 provided the authors with an in-depth contextual understanding of the practices in use in the organisation (*e.g.*, Backman *et al.*, 2007).

Data on the Toyota project (Itazaki, 1999; Nonaka and Peltokorpi, 2006; Williander, 2007) and Project Better Place (Kiviat, 2008; Scheer, 2008) were mainly derived from secondary sources. A small interview study was conducted comprising two interviews at Renault and one at Toyota Europe to obtain additional data. Interviews at Saab Automobile, Volvo Cars and Peugeot provided additional industry knowledge. The data from Toyota and Project Better Place are, thus, not validated by us, but are used as examples to illustrate the different approaches used by different companies. A list of the interviews can be found in the Appendix.

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 the Toyota Motor Company (Toyota). The considerable investment in this concept at a time when incentives are still low is striking. The Prius hybrid project has received much attention and much can be learned from how Toyota approached the field of hybrids (*e.g.*, Itazaki, 1999; Magnusson and Berggren, 2001; Nonaka and Peltokorpi, 2006; Williander, 2007). The Toyota Prius can be considered a success, but the internal resources development and investments made by Toyota should not be underestimated. The vehicle was designed from scratch and it appears that competitors have difficulty in replicating it. The knowledge and resource base of the company is considered a specific asset and a resource that is distinctive among 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 the management's perceived need to challenge the organisation and avoid "the curse of success" (Nonaka and Peltokorpi, 2006, p.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 that focused on technological viability and changed to a focus on cost reduction only as this goal was achieved (Magnusson and Berggren, 2001). A minimum number of prototypes and the lack of back-up alternatives contributed to the level of risk. It was considered "an extreme challenge for the senior engineers" (Williander, 2007, p.208). The project management was situated in the 'red carpet room', separate from the rest of the R&D organisation. Simulations and tests were core issues in the project and the test vehicles covered five times longer distances than what the development of new vehicles normally requires (Itazaki, 1999).

The first version of the Prius (Prius I) was launched in 1997 only for the Japanese market. 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 feedback from Prius I. In particular, the reliability of components and the hybrid system (Toyota synergy drive) were improved, the latter having more than 500 registered patents related to it (Toyota webpage, 10 April 2008).[3] 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 in the same vehicle category.

The initial production volume for the Prius I was 1000 vehicles per month (Nonaka and Peltokorpi, 2006); this volume has been gradually increased. Towards the end of 2007, a 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 eco-innovation dynamics in the automotive sector: after an initial phase of scepticism, most large car manufacturers have initiated R&D hybrid projects.

4.3 The case of the Desirée project at Volvo Cars

The Dual Hybrid Electric System for Increased Efficiency and Economy (Desirée) project at Volvo Cars started in October 1997 with a team of 20 people from various departments in Volvo Cars. The objective was to develop two demonstration vehicles with substantially improved fuel efficiency that would meet current emissions and safety requirements and, apart from the powertrain, use standard components. Approximately 18 months later, two demonstration vehicles were introduced, both of which used 40%

less fuel than comparable cars. This high reduction was obtained through the introduction of a power-split hybrid propulsion system. No other changes such as, for instance, weight reduction, streamlining to reduce air resistance and low-friction tyres, were made. The technology was further developed by its new owner, the Ford Motor Company, and was incorporated in the hybrid version of Ford Escape that was introduced on the market in 2004.

The Desirée project was mainly aimed at testing and demonstrating a power-split technology developed by Japanese automotive supplier Aisin. It was a bottom-up approach conducted without a clear mandate from top management. Much of the work was carried out in the workshop, in part because of the very tight budget and time restrictions. Volvo Cars had a relatively strong HEV knowledge base on which to build and had conducted several other hybrid vehicle projects. This, combined with its strong reliance on technology partners such as Aisin (which provided the power-split device), Varta (which provided the nickel metal hydride batteries) and Bosch (which provided the engine control module) enabled the project to develop a fully functional concept car in only 18 months. Simulations and test drives were important components of the project, both because the technology was new to the firm and also because the involvement of other managers and stakeholders in testing was seen as a way to gain support for further HEV activities.

Due to its satisfaction with the prototype, Volvo Cars opted to show the Desirée vehicle at the 1999 Geneva Motor Show. Subsequent ownership changes resulted in the project results being transferred to Ford, which took the lead in further developing the power-split hybrid technology, resulting in the hybrid Ford Escape a few years later, but not any hybrid Volvo models. However, Volvo Cars has now launched a new hybrid centre, building on the knowledge from the Desirée project, and is participating in several initiatives with partners and competitors (*e.g.*, the joint plug-in HEV project involving Saab, Volvo Cars and the Swedish energy company Vattenfall), but there are no hybrid Volvo cars available on the market.

4.4 The case of Project Better Place

The development of EVs has encountered several ‘technological barriers’, including restricted autonomy and/or heavy batteries, the lack of infrastructure to provide energy for recharging the batteries and the length of time required for recharging. Despite strong incentives (California Zero-Emission-Vehicles (ZEV), national plans, public subsidies), these technological barriers together with other factors have contributed to blocking significant market change. Some have described EVs as an “eternally emergent technology” (Frery, 2000), an engineering dream incapable of meeting market requirements.

Rather than aiming at a technological breakthrough for mass markets based on a ‘research-push’ approach, another approach has recently emerged where the locus of innovation is more on the creation of a new business model based on open innovation. The pioneer of this new approach is ‘Project Better Place’, a venture-backed company located in California and founded in October 2007 by the former president of the electronic SAP corporation, Shai Agassi. Within two years, this company has invented a new business model for sustainable transportation services based on the development of an electric recharge grid to power specifically designed full electric vehicles. In this business model, EV owners pay to access a network of recharging spots, complemented by battery-swapping stations across the territory powered by renewable energy (Makeower *et al.*, 2008). For the first time, car ownership is separated from the requirement to own a battery. Project Better Place buys batteries and clean electricity and sells a sustainable mobility service (based on a price per km) to customers who subscribe to this service. To make this new business model actionable, ambitious private-public partnerships have been developed between car manufacturers, that design mass-market EVs, local authorities, that provide incentives and fund the recharging infrastructure, and local renewable energy suppliers, that provide clean energy.

In January 2008, Project Better Place, Renault-Nissan and the Israeli government announced that they committed to the widespread deployment of an electric recharging grid to power electric batteries by 2011. Renault-Nissan would supply the EVs and Project Better Place would construct and operate an electric charging grid across the entire country. By this time, an infrastructure of 500 000 recharging spots should be created over the territory. This project is part of a plan for oil independence by 2020, in which Israel heavily invests in renewable energies, especially solar power stations. Israel is also an ideal case for the use of EVs, since 90% of Israelis drive less than 70 km per day and all the major cities in Israel are within 150 km of each other. In this context, restricted autonomy is not a constraint anymore. Innovation efforts have been put on the development of a "rapid exchange" system (see Beaume and Midler, 2008). The aim is to develop full electric cars with a driving range of 100 km for city driving and 160 km for highway driving and a top speed of 110 km/h. An on-board computer system will indicate to the driver the remaining power supply and the nearest charging spot. For that purpose, Renault-Nissan is designing and building vehicles which will be equipped with a battery pack system that can be easily removed when depleted and replaced with a fully recharged pack.

Renault-Nissan was selected as a partner for the strong skills they have developed in EV and battery technology. NEC, who is a partner of Nissan, will develop a new lithium-ion battery for the project by 2011 (Scheer, 2008). On the Renault-Nissan side, according to the interviews we have conducted, the interest in the project is to learn about the technology, learn from real large-market experiments and learn about the potentials of this new business model.

Partners announced that a pilot project involving a few dozen cars will be launched in 2008 in Tel Aviv, with a few hundred vehicles expected to be on the road in 2009 and production scaled to the mass market by 2011. In early 2008, Israel slashed the tax on cars powered by electricity to 10% in order to encourage their purchase once they are made available (Kiviat, 2008).

In March 2008, it was announced that Project Better Place had signed a similar agreement in Denmark, the world leader in clean energy generation, with 20% installed capacity. Along with Renault-Nissan, who will begin marketing electric cars in Denmark in 2011, the partnership includes Danish Oil and National Gas Company (DONG), who secured a 103 million-euro equity in conjunction with Project Better Place (Lampinen, 2008). DONG will be the preferred supplier of renewable energy to the charging network. From January 2008 to January 2009, ambitious partnerships have been announced with the state of Hawaii, the Australian government, the state of California and Ontario province as part of plans to promote new sustainable mobility systems based on EVs. In these agreements, partnerships should be open to other automakers whose industrial and bargaining power is strong.

To summarise, the innovativeness of Project Better Place is not so much in technology, but primarily in a business model based on local public-private partnerships. In this respect, it differs from the technology-driven national policy that was promoted, for instance, in France in the 1970s for EVs (*e.g.*, Callon, 1980). In building a subscriber-based ownership model, this project challenges one of the dominant logics in the car industry.

5 Developing innovation through learning mechanisms

Using these three examples, we revisit the learning mechanisms described in the 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 to both Desirée and the Prius project, in part because the technologies were new and several different components and subsystems were required to work together. In both cases, simulations contributed to the short development time. The Desirée project at Volvo Cars resulted in two vehicles for test drives and demonstrations and once the model was selected for the Geneva Motor Show, it became an official concept car. In Project Better Place, early prototypes were developed at speed by Renault to test their properties and set the requirements for mass production.

The Toyota Prius is an example that has spread throughout the industry – a recently translated book describes its development (Itazaki, 1999). People in the industry frequently cite the Toyota case as a reference for good strategic choice in terms of hybridisation. Project Better Place maintains strong links with the media in the form of frequent press releases and a blog on news and events.[2] The Desirée project is considered a success within Volvo Cars and it confirms the technological 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 works profile contributed to a small administrative unit and a tight project team. As Desirée was displayed at the Geneva Motor Show in 1999 and as the team spent a lot of time involving managers and other stakeholders in test driving demonstration models, the results were acknowledged by the rest of the organisation. It thus avoided the risks related to isolation and resistance to the ideas developed when explorative activities are separated from the core business (Birkinshaw and Gibson, 2004; Moss Kanter, 2006). The Prius project had strong support from the top management from the beginning and was separate from the regular R&D organisation. Project Better Place also got strong support from the top management of the different partners involved.

The partnerships were handled differently in all three examples. In the Desirée case, cooperation with technology partners was essential to the project's success. Aisin was the main partner, supplying transmission and motor drives, but the relations with Varta for the batteries and Bosch for the engine control module were also critical. Toyota's approach was different, as they developed all HEV technology in-house because they believed that this was the best learning strategy. In Project Better Place, the partnership with the Israeli project is providing a strong platform for learning about both technology and customer uses. Furthermore, the success of EVs depends on the partnership with NEC on battery technology.

Traditional customer involvement techniques, such as customer clinics and focus groups, were not especially used in the studied cases. A few end users were involved in the review of the Desirée concept car in its final stage at the Geneva Motor show in 1999. In the Prius case, limited test driving was conducted in the late stages of development, whereas in Project Better Place, interactions were limited to prototype testing. This is not to imply that customer involvement is irrelevant, but rather that these traditional techniques were not appropriate for the disruptive nature of the innovation, which required other types of experimentation with customers (see next section).

5.2 Advanced learning mechanisms

Some of the learning mechanisms less developed in the literature on the automotive industry were present in these cases. Some authors argued that in a context of intensive innovation where the identity of the object has become unstable (Le Masson *et al.*, 2006), companies need to redefine not only the product, but also the values and 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 competences required in-house and companies are forced to renew their learning processes based on controlled interactions with external partners (companies or customers).

One such advanced learning mechanism is *market experimentation*. Market experimentation means some controlled experimentation with real end consumers to get feedback to improve the design of the product and/or business concept. Market experimentation can be distinguished from customer involvement or concept testing, which intervenes at the very early stages of the development process (concept testing) or in the final stages, where it cannot be used to be fed back to the product design. An interesting aspect of the Toyota Prius project is that Toyota performed full-scale market experimentation using the Japanese market as a testing ground before deciding whether the technology could be exported to other countries, which occurred in a refined version some years later. Thus, the Prius I was seen not as an end in itself, but rather as a stage in a broader lineage of product innovations. Similarly, Project Better Place in Israel is considered a large-scale experimentation directed towards technology and related usage, but also the design of a new business model that redefines the ownership model. This emergence of new innovation models, based not only on the search for technological breakthrough innovations in components (particularly battery technology) as in the past, but aimed at exploring new concepts which simultaneously try to address the technologies, market and supply of energy, 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 provide another way of learning in more innovative situations.

Table 1 The basic and advanced learning mechanisms in the three cases

	Basic learning mechanisms					Advanced learning mechanisms	
Project	*Prototyping (virtual/physical)*	*Narratives*	*Skunk work*	*Partnerships*	*Customer involvement*	*Market experiment*	*Exploratory partnerships*
Desirée	Simulations, demonstrators, concept cars	Internal success story	Protected from top management in early phases	Important partnerships with Aisin, Varta, Bosch	Only in the final stage – Geneva motor show	n/a	With supplier of core technologies
Prius	Simulations	Reference case in industry	Supported by top management, organisationally separated	Main development is internal	Limited test driving in a late stage	Japan as a test market. Development of Toyota's brand (environment, high technology)	n/a
Project Better Place	Prototypes	Public site following development	Supported by top management	Partnership with Project Better Place and NEC	Limited test with prototypes	Test market in Israel with new business model	Entrepreneurial approach with non-automotive actor New platform for design

The deployment of *exploratory partnerships* is another advanced mechanism. The term 'exploratory partnership' was coined by Segrestin (2005) to describe a phenomenon in which partners' interests and a common purpose are discovered through action, rather than being defined initially. The more exploratory the partnership, the more reciprocal commitments and contractual arrangements have to be managed to guide the learning process (Segrestin, 2005). New forms of partnerships can be found in which the uncertainties are much higher than in the 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 testing the technology. The partnerships helped expand the knowledge base and the innovative capabilities of the firm. The case of Project Better Place is also an example of an exploratory partnership – in the initial stage, neither Project Better Place nor Renault-Nissan or the Israeli government could define what the outcome would look like, but are developing value to offer and reinvent model ownership and, thus, their own role in the mobility system. Project Better Place was designed as a new 'product-service system' platform which serves as a template for new partnerships (USA, Australia, Denmark, *etc.*). In this perspective, replicating the concept is made possible thanks to the progressive definition of a set of rules based on four design principles: providing clean energy, building a dense network of recharging stations, building a rapid battery exchange system and creating a subscription business model. The setting of these basic design rules have apparently played an important role in the new interest of both public and private actors in EVs and innovative business models associated with this technology.

Table 1 presents a summary of the basic and advanced learning mechanisms.

5.3 Building innovative capabilities in disruptive technology shifts

The literature argues that learning is a critical part of innovation (*e.g.*, Lynn *et al.*, 1998) and that it can be managed in a long-term perspective through repeated innovations (see Penrose, 1960; Hatchuel *et al.*, 2003) and learning between projects (*e.g.*, Maidique and Zirger, 1985; Rothwell and Gardiner, 1989). It has 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 by highlighting some of the mechanisms used in projects. Double-loop learning (*i.e.*, changing the underlying logic) is valuable in the context of electrification of the powertrain, since it is an innovative field where the technology is different and where the market, customer usage and business model are disrupted.

The strong focus on developing new knowledge and the intensive prototyping of Toyota are consistent with its explicit ambition to learn as much as possible on its own without collaborating with external partners. Its experiments in the market resulted in huge learning, but were resource-intensive and risky. However, it has been a very successful strategy, making Toyota the undisputed leader in the HEV market. The reuse of HEV knowledge in a family of innovations (Le Masson *et al.*, 2006) is sustaining Toyota's dominating market position in a market that has been more or less created by the company. In an interview at Toyota, it was stated that the company has close contacts with the market through an elaborate strategy, which includes using its national ambassadors to promote its vehicles and by hosting a strong web community, which has resulted in a loyal customer base. The Prius project has generated a spillover to the Toyota brand, rendering it a general improvement in high technology and clean technology. It is likely that the HEV learning strategy has contributed to the growth of Toyota, which is close to overtaking GM as the world's largest auto maker.

Renault-Nissan is a veteran in EV manufacturing, having launched its first EV in the 1970s in partnership with EDF and with the support of the French government. It was involved in testing EVs in the 1990s within a partnership on intermodal mobility with the RATP (the operator of the Paris subway) and the city of St Quentin en Yvelines (the Praxitèle experience). According to our interviewee, the company has announced that it will introduce a new generation of EVs in the market in 2011. Based on more limited resources (both financial and technological) than Toyota, Renault-Nissan has opted for small-scale market experiments based on exploratory partnerships with suppliers and ventures with complementary actors. This joint development has provided a way to develop capabilities in the field in a cost-efficient and controlled way. Its involvement in Project Better Place is contributing to Renault-Nissan's reputation as a company that engages in innovative ventures with a clear environmental dimension. Over the longer term, it plans to build knowledge on its use and the potential business models required to develop EVs.

The Desirée project contributed to the launch of the Ford Escape hybrid. Volvo Cars did not build on its competences for several years, with Ford taking the lead on most hybrid developments. Volvo Cars has now launched a new hybrid centre in collaboration with Ford and claims to be able to build on the competences acquired in the Desirée project in terms of electrical engines and power electronics. In 2007, Volvo presented a plug-in HEV concept car, but has not introduced an EV or HEV vehicle into the market.

The examples in this article illustrate the use of an extended range of learning mechanisms. The market for EVs and HEVs is unfamiliar to the companies and, therefore, they need learning mechanisms to generate knowledge. Both Toyota and Renault-Nissan use market experiments to learn about new usages and business models. These experiments also help reposition their brands, which motivate other companies in the industry. For instance, GM's loss of image in terms of reduced sales after the Prius was launched was huge and the current testing of its plug-in hybrid Volt is partly driven by concerns related to 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). Launching different types of eco-labels is another phenomenon in this area – for instance, Renault launched its Eco2 label in May 2007 and Peugeot has a similar brand, the Blue Lion. The labels signal green production, recyclable materials and low CO^2 emission levels. In one of the interviews it was stated that Renault considers this labelling a way to communicate with customers, help them make more informed choices when buying cars and promote the work that they are doing in relation to the environment. The development of labels is also a way to promote the performance criteria to be applied to eco-cars and experiment with the brand.

Another learning mechanism identified in our cases is exploratory partnerships – that is, collaboration with partners on issues that are defined in the course of collaboration. This enables the generation of joint knowledge, exemplified in Desirée and Project Better Place. In Sweden, there is also the development of distributed research centres in which competitors work together on a neutral platform to generate knowledge and come up with innovative concepts. For instance, Saab Automobile is collaborating with Volvo Cars in three HEV-related centres: electric machines, battery technology and hybrid systems (Interview, Saab Automobile). It seems that in the electrification of the propulsion for cars, learning mechanisms that support knowledge and concept generation are more critical when working within dominant design logics. This is coherent with the literature on how to build innovative capabilities.

The innovative capabilities of firms are built through their long-term use of new concept and knowledge lineages (*e.g.*, Hatchuel *et al.*, 2003). Toyota has managed to apply this learning strategy successfully, exploiting spillovers and applying new technologies to families of products, for instance, by introducing the Synergy Drive concept in a range of car models. The building of innovative capabilities can be managed through the application of an explicit learning strategy. In order 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 needs to be related to the design of an overall learning strategy that contributes to the building of innovative capabilities. This implies that to be able to explore this new area of EVs or HEVs, companies need to develop both long-term learning strategies (how to develop knowledge to be able to launch an electric hybrid or a pure EV) 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 Gardiner, 1989; Cusumano and Nobeoka, 1998).

6 Conclusion

This article set out to explore how car manufacturers build capabilities in a context of a potential disruptive technology shift by discussing some examples of how car manufacturers have used different learning mechanisms in their bid to develop their capabilities around EVs and HEVs. The path to electrification in the automotive industry is interesting, since all the companies involved have been forced to revisit the knowledge areas linked to the dominant design of the car. 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 managed to develop a learning strategy very early and 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 in collaboration with partners, such as in Project Better Place and the Volvo Cars cases, a strategy that has not been as successful as Toyota's. It seems that in the context of electrification, overall learning strategies are necessary to guide the many learning mechanisms that can be activated. Until a new dominant design of HEVs or EVs is developed, the focus on knowledge generation and controlled development of firm capabilities will be crucial.

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Notes

1 The forthcoming EU Directive on CO^2 emissions will replace the voluntary agreement on CO^2 emissions signed in 1998, whose targets will not be achieved by car manufacturers.

2 www.projectbetterplace.com

3 Toyota webpage, www.toyota.com (Accessed 10 April 2008).

Appendix

Interviews

Automotive firms

Time of interview	*Automotive firm*	*Interviewee role*
April 2008	Toyota Europe	Marketing Manager
February 2008	Saab Automobile	Senior R&D Manager
February 2008	Volvo Cars	Marketing Manager
February 2008	Renault	Technology Manager
November 2007	Renault	Marketing Manager
July 2007	Peugeot	Strategy Manager

The Desirée case study

Informant category	*Number of interviews*
Desirée team member or leader	Five respondents
Manager at Volvo Cars	Seven respondents
HEV specialist at Volvo Cars not involved in Desirée	Two respondents