Portfolio management in double unknown situations: technological platformsand the role of cross-application managers

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Portfolio management in double unknown situations: technological platformsand the role of cross-application managers

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Abstract. This article investigates portfoliomanagement in double unknown situations. Double unknown refers toa situation in which the level of uncertainty is high and both technology and markets are as-yet-unknown. This situation can be an opportunityfor new discoveries, creation of new performance solutions and giving direction to portfolio structuring. The literature highlights that the double unknown situation is a prerequisite to designinggeneric technologies that are able to address many existing and emerging markets and create value across a broad range of applications. The purpose of this paper is to investigatethe initial phases of generic technology governance and associated portfolio structuring in multi-project firms.We studiedthree empirical contexts of portfolio structuring at the European Semiconductor provider STMicroelectronics. The results demonstrate that 1) portfolio management for generic technologies is highly transversal and comprises creating both modules to address market complementarities and the core element of a technological system – the platform and 2) the design of generic technologies requires "cross-application" managers who are able to supervise the interactions among innovative concepts developed in different business and research groups and who are responsible for structuring and managing technological and marketing exploration portfolios within the organizational structures of a company.

Introduction

Companies' innovative performance strongly depends on efficient portfolio structuring and its management. However, companies increasingly operate in novel and unknown environments, fundamentally modifying the logic of decision making and rendering the typical planning approaches inadequate. In these situations, companies must adopt more flexible approaches to incorporate learning and privilege interactions among projects and the corresponding environment.These significant changes in business environments and ever-growing competition are causing portfolio managers to cope with uncertainty by changing the strategic directions of portfolios, balancing and prioritizing projects differently.

The recent advances in portfolio management literature make it clearthat the dynamic environments and increasing complexity make risk management insufficient, and a high probability of unknown risks could cause companies to question an entire portfolio and even result in its failure (Geraldi, 2008, Olsson, 2008, Pender, 2001, Petit, 2012, Petit and Hobbs, 2010). Mullins and Sutherland (1998)demonstrated that firms operating in these environments require new practices to mitigate risks, manage uncertainties, and increase the likelihood of future success. Reflective learning, sensemaking, balancing to ensure flexibility of portfolios and decision-making are underlined as crucial whenworking with portfolios amid uncertainty (Olsson, 2006, Perminova et al., 2008, Petit, 2012).

While these approaches provide effective ways to examine and address uncertainty in portfolios, they generallytreat uncertainty as a problem to address or a challenge to overcome. However, unknowns can be seen as opportunities to design new alternatives to cope with and lower risks. By focusing on a framework for conceptualization of the relationship between ideation and project portfolio management,Heising (2012)showed that better organization of the initial stages of innovative portfolios and the connection between the operational phases of portfolio management and the fuzzy front end might increase companies' innovative performance. As Geraldi (2008) underlines through a study of multi-project firms on the edge of chaos, these firms must operate on the edge of chaos by bringing order tohigh-uncertainty situations.

Defined as unforeseeable uncertainty in research by Loch and colleagues (Loch, 2006, Loch et al., 2008), this situation is characterized by a team's lack of awareness of an event's existence or its probability of occurring. The difference between unforeseeable uncertainty and chaos is that in a situation of unforeseeable uncertainty, the team begins with reasonable assumptions and goals. In R&D contexts, this scenario often corresponds to a "double unknown" situation in which neither technologies nor markets are known. In a double unknown situation, the nature of the risks is unknown; alternatives have not yet been formulated, and thus, their values cannot be determined. Markets are considered unknown because the product features that could make them successful are initially unknown (O'Connor and Rice, 2012). Nevertheless, markets whose *ex ante* probability of existence is rather low can become important *ex post*. Technologies are unknown because while a variety of solutions might be designed for certain functions, none exists yet. In this situation, it remains unclear which emerging markets will succeed and which technologies will be more advantageous. These cases are often simply considered unmanageable, and the common approach is to wait until the unknowns are reduced.

In this paper, motivated by the importance of the early stages and pre-stages of portfolio existence, the idea is to profit from the double technological and market unknowns to create a portfolio that reduces these unknowns and to enable portfolio structuring and its effective management. By portfolio structuring, we refer to all the tasks involved in initially setting up a portfolio derived from an organization's strategy, such as evaluating proposals and selecting projects (Unger et al., 2012).How can portfolios bestructured in double unknown situations?

Maine and Garnsey (2006) have noted, in the case of advanced materials ventures, that the presence of technological and market uncertainties at early exploration stages offers opportunities for the creation of generic technologies, i.e., technological platforms that are able to address many emerging markets. Importing ideas from broad networks, creating environments for deep collaboration and technology-market matching processes are essential for the commercialization of generic technologies (Maine et al., 2014).The emergence of generic technology involves the exploration of both various nascent technical domains and many emerging markets (Baldwin and Woodard, 2009, Gawer, 2014). Although the societal importance of these pervasive technologies has been widely highlighted (Bresnahan and Trajtenberg, 1995, Keenan, 2003), the management of the initial stages of their development remains underexplored. However, this stage can be extremely challenging due to the high level of uncertainty, immaturity of technologies and markets, and difficulties in obtaining external financing, which often results in long development cycles. The exploration process involved in developing generic technology is often unclear. By designing a generic technology that is independent from any specific market requirements, we create a low-risk alternative that facilitates technology diffusion within various application domains. The creation of a portfolio that takes into account the logic of emerging generic technologies will offer a competitive advantage for a company that aims to design this technology and implement it across different markets, which requires effective multi-project management. Moreover, the actors and their specific competencies in developing generic technologies in the presence of multiple unknowns must be determined.

This paper aims to fill the gap between the technological platform and portfolio management literature amid high uncertainty by addressing the initial stages of platform development. **We examine the following research question: what is portfolio management for generic technologies, and how can a portfolio be structured under as-yet-unknown technologies and markets?**

The setting is the high-velocity semiconductor industry, which is constantly confronted with competition, rapidly-changing markets and rapid technological obsolescence, which together force the industry to explore both market and technological unknowns. For this investigation, a multiple qualitative case study approach (Yin, 2008) was used to provide new insights into the emerging phenomenon of portfolio management to address unknown risks.

This work demonstrates that portfolio structuring for generic technology comprises creating modules to address market complementarities and the core element of a technological system – the platform. The findings indicate that to account for generic technology's exploration in high uncertainty, portfolio management must be highly transversal. Portfolio managers in double unknown situations address multiple emerging technologies and markets and mustassemble portfolios based on generic technologies. The reasoning associated with the design of generic technologies requires significant scientific effort, and the governance of this design process appears critical for the successful design of generic technologies and execution of the portfolio. The transversal case analysis illustrates that the design of generic technologies requires a new managerial role, a "cross-application" manager, who is capable of creating innovative concepts developed in different business lines, creating interdependences and supporting balance within the project portfolio. The role of the cross-application manager appears to be critical for successful portfolio structuring and management to account for successful generic technology design.

Theoretical background

To guarantee a company's long-term survival, its renewal and organizational growth must be ensured. PMI (2013)defines a project portfolio as "a collection of projects or programs and other work that are grouped together to facilitate effective management of that work to meet strategic business objectives". Portfolio management enables strategic choices for a company and is crucial to prioritizing and selecting projects among various emerging options (Cooper et al., 1999, Olsson, 2007, Lycett et al., 2004). Portfolios are subject to different uncertainties that can influence future outcomes and change the course of action. To ensure the success of portfolios, managers must address the different levels of risks and uncertainties (Martinsuo, 2013, Perminova et al., 2008, Petit and Hobbs, 2010).The literature review presents current project portfolio management (PPM)practices in risks, uncertainty and unknowns.

Portfolio management amid risk

The literature on PPMconsiders risk management a crucial element to ensure portfolio success (Petit and Hobbs, 2010, Olsson, 2008, Lee, 2011).Using a sample of 134 firms,Teller and Kock (2012) illustrated the positive correlation between risk management quality, measured as risk transparency and risk coping capacity, and the success of a project portfolio.

The PPM perspective addresses the potential logic of risk mitigation (Sanchez et al., 2009, Olsson, 2008),focusing primarily onthe known-unknowns category of risks (Petit, 2012). Classical models of risk management propose that the likelihood of success is highly proportional to the initial technological and market uncertainties.

When uncertainties are low, the nature of technologies and markets and the associated project alternatives can be determined. A decision can be made in consideration of this riskwhen awhen a manager can list all the possible outcomes associated with a decision and assign a probability of occurrence to each outcome. Classical risk management techniques provide methods to help decision makers cope with these uncertainties (Chapman, 1990, Lipshitz and Strauss, 1997). Portfolio risk management incorporates risk management at the level of each product and the portfolio itself. Greater visibility for stakeholders and decision makers can be achieved by improving common portfolio risk management (Teller and Kock, 2012, Olsson, 2008). Petit and Hobbs (2010)indicated that the drivers of change go beyond those considered in the PMI classifications and are not yet contemplated by the PMI standard. In these situations, risk management is not sufficient for managing high uncertainty and complexity in portfolios in dynamic environments (Petit, 2012). Thus, portfolios are largely built when these risks are reduced. Though, organizations constantly cope with increasing levels of uncertainty, and to retain a leadership position in the market, they seek to innovate in environments that are unconventional for them.

Portfolio management amid uncertainty

Portfolios are subject touncertainty when project alternatives can be identified and when managing uncertainty consists of making the optimal choice between possible decisions and probable states of nature. Yet the outcome in this case is not fully known. The sources of uncertainty are numerous, including organizational complexity, external environmentsthat comprise technical andmarket uncertainties, emerging standards, regulations, the context of the operating company of the unit, and industry volatility. (Petit and Hobbs, 2010, Teller et al., 2012, Voss and Kock, 2013).

When uncertainty is high, probabilistic approaches are limited because the probabilities evolve during the process of exploration and cannot be correctly estimated initially(Loch, 2006). In this case, uncertainty reduction approaches are mobilized to reduce these uncertainties and more advanced approaches for portfolio risk management are required because the states of the environment are often impossible to predict and because probability-based risk management becomes irrelevant as a result of high market and technology volatility (Petit, 2012, Pender, 2001, Loch et al., 2008).

Choices made under uncertainty are often driven by the maximization of expected utility. Utility is a function of profit that comprises the value of benefits associated with each state of nature weighted by its probability and the utility of the decision itself. It aims to select the most promising alternatives (maximal utility) from the predefined list. This theory relies on various derived techniques to cope with uncertainty management (Savage, 1972, Raiffa, 1968). The economic return of a portfolio greatly depends on technological and commercial uncertainties (Verworn, 2009). Real-options theory is suggested to guide investment decisions under uncertainty (McGrath, 1997, Dixit and Pindyck, 1994, O'Connor, 2008) by estimating whether the option to invest in a new technology is worth pursuing or by determining how the learning process influences the option value. Real-options provides powerful tools that account for dynamic environments. For example, the real-options approach to project evaluation seeks to correct the deficiencies of traditional methods of valuation through the recognition that managerial flexibility can bring significant value to projects (Carlsson et al., 2007).

Nevertheless, real-options approaches are limited when addressing high uncertainty because the learning that is considered in these techniques is based on the distribution of subjective probabilities associated with the states of nature(Oriani and Sobrero, 2008). The learning process does not affect these states and the corresponding decisions, which is critical in unknown situations because new technological alternatives could emerge and new markets could be created during the exploration phase. Real-options approaches consider that the decisions and states of nature are independent. To apply real-options, a decision maker must know the project's potential, underlying assets, and needs based on the potential states of nature. Moreover, the estimated option value should indicate the reliable actions to take (Huchzermeier and Loch, 2001). In the case of exploration in high uncertainty, these conditions can rarely bemet. Additionally, new alternatives and unexpected results could emerge throughout the period of exploration.

Wouters et al. (2011)proposed a project portfolio option-value method that attempts to provide an overview of major challenges and key criteria of success for companies in the presence of many technological and marketing uncertainties and attempts to account for the interdependencies among projects in a portfolio. Visual tools attempt to facilitate interdependency management within a portfolio (Killen and Kjaer, 2012). A transparent risk management culture within organizations helps better reveal and manage interdependencies within various portfolio projects (Teller and Kock, 2012).

Various types of interdependencies are important to consider (Blau et al., 2004, Collyer and Warren, 2009). For example, Eilat et al. (2006) suggested resource interactions, benefit interactions and technical dependencies between projects. Archer and Ghasemzadeh (1999)addressed financial interdependencies. Additionally, Killen et al. (2009) underlined the importance of outcome dependences, which involve the re-use of the results within projects, including both technical and commercial aspects, and learning dependencies that lead to incorporating the capabilities and knowledge gained through various projects. The interdependencies between projects are more complex when addressing unknowns (Chien, 2002, Mikkola, 2001) but complex interdependent systems can be a source of breakthroughs(Fleming, 2012). By studying the management of four portfolios in two large multidivisional corporations,Petit and Hobbs (2010)examined PPM adapted for dynamic uncertain environments once a portfolio is selected. The authors demonstrated that the dynamic capabilities approach can be used to analyze the operational levels within an organization (Petit, 2012, Killen et al., 2012, Killen et al., 2008).

Portfolio management in double unknown situations

Portfolio structuring: coping with double unknown situations

In coping with uncertainty, PPM often considers that projects are already identified within the portfolio. However, when the exploration phase is confronted with unknown environments, markets are considered unknown because the product features that could make them successful are initially unrevealed (O'Connor and Rice, 2012). Technologies are unknown, which means that a variety of solutions might be designed, although none exists at the moment. This exploration of as-yet-undefined technologies and markets is precisely what is referred to as a double unknown situation. In this situation, it is ambiguous which emerging markets will succeed and which technological forms will be more advantageous. The identity of technology is not presumed, and future uses are not fixed (Gillier and Piat, 2011). In this situation, the projects in the portfolio are still undetermined.

Nevertheless, the initial stages of ideation are important for future portfolio success, and technological and market unknowns can be viewed as opportunities. By examining PPM relevance in uncertain and complex dynamic contexts,(Martinsuo, 2013) indicates that portfolios can be viewed as a means to open negotiations and to reconfigure and introduce flexibility into the decision-making process.Kock et al. (2011)underlined that technological innovativeness can increase the customer value of future products but also creates challenges for the innovating firm and its environment. Better organization of the fuzzy front end stages of project exploration contributes to the overall portfolio performance (Heising, 2012). The author noted thatthe existence of well-established literature on the ideation and fuzzy front end forms a singular project perspective; the link with a more operational phase of portfolio management is missing. Moreover, Meskendahl (2010) indicated that when applied to PPM, a firm's strategic orientation significantly influences its portfolio decisions and therefore the structure of the portfolio. The portfolio structuring in double unknown situations remain understudied,and their alignment with more mature project portfolios within an organization must be investigated. How, then, can we cope with double unknown situations and structure the relevant project portfolios?

Portfolio structuring and managementin technological contexts: generic technology design

The double unknown situation is not rare, and Maine and Garnsey (2006) have noted that the presence of technological and market uncertainties at early exploration stages offers opportunities for the creation of generic technologies, i.e., technological platforms that are able to address many emerging markets. The emergence of generic technologies involves the exploration of both various nascent technical domains and many emerging markets (Baldwin and Woodard, 2009, Gawer, 2014). Although the societal importance of these pervasive technologies has been widely highlighted (Bresnahan and Trajtenberg, 1995, Keenan, 2003), the management of the initial stages of theirdevelopment and of portfolio structuring remains underexplored.

Existing research has shown that the design ofgeneric technologies encompasses the architecture of a platform that allows the modularization of several market modules (Baldwin and Clark, 2000, Baldwin and Clark, 2006). As noted by Sawhney (1998), platform thinking should be driven by the definition of the common underlying technology –the core element of platform. The author demonstrated that firms must assess what is the core and what are the derivativesof the platform. The platform design becomes a strategic phase to define future firm direction.

For example, while building its PC platform, IBM outsourced the operating system and central processing unit to Microsoft and Intel and did not perceive these important components as a part of a core platform (Bresnahan and Greenstein, 1999, Gawer and Cusumano, 2002),

According to our knowledge, no prior studies have investigated how a portfolio can be structured and managed in this case. Previous studies on generic technologies have illustrated the challenges associated with their development; among them, Maine and Garnsey (2006)highlightaccess to complementary assets, capacity to finance the early design stages to demonstrate the value of generic technologies for multiple markets andthe importance to ensure efffective management and diffusion of generic technologies. We argue that better structuring and management of portfolios in double unknown situationsallows exploring multiple technological and market alternatives, accelerating the access to complementary assets and enabling the financing of the development states of early generic technologies.

Thus far, however, there has been little discussion of portfolio structuring and management in unknown environments. The importance of the creation of learning and interdependencies is well established, and the need for expertise to handle the process of unknown exploration is clear. However, the answer to the following question remains unclear:*What is portfolio management in double unknown situations for generic technology,and how can a portfolio be structuredunder as-yet-unknown technologies and markets to account for successful generic technology exploration?*

Methodology and data

Research design

The purpose of this work is to gain an understanding of PPM for generic technology design in highly uncertain environments. Given the newness of this research field and the lack of available knowledge, a qualitative research methodology is recommended (Yin, 2008).This methodology is appropriate in our context because we focus on exploring a phenomenon within an organizational context. The study is conducted within the semiconductor industry, an environment in which the probability of the existence of generic technology is high and uncertainties are multiple(Miyazaki, 1994, Olleros, 1986). This paper is based primarily on an in-depth empirical study at the largest European semiconductor company, STMicroelectronics (ST), and is part of a longitudinal multidisciplinary study of innovation practices at ST in collaboration with Mines ParisTech researchers.

Research field

Semiconductors are fundamental elements of all modern electronic systems and computers, such as smartphones, tablets, personal computers, consumer electronics, and telecommunication equipment. The growth in the demand for electronic components has drastically increased the demand for semiconductor devices leading to a creation of $300 billion industry (Source WSTS, accessed November 2014). To ensure growth, support demand and be at the leading edge of competition, industry players must be prepared for huge capital investment and R&D in rapidly changing technological generations. However, the risks are high, and companies seek ways to analyze the corresponding market structure and develop more reliable manufacturing strategies to secure their investments. As a result, the science-based semiconductor industry constantly looks for breakthrough innovations, and double unknown situations are common.

The relevance to the semiconductor industry of exploring breakthrough innovationshas been shown by various researchers (Cohen and Levinthal, 1989), particularly with respect to knowledge creation methods in science-based environments (Robinson et al., 2012, Le Masson et al., 2012a). Scholars have highlighted the challenging environment in the semiconductor industry and the high rate of innovative technology developments that target market creation (Teece, 1986, Dosi, 1982). The strong competition and rapidly changing environments that characterize the semiconductor industry lead to exploring not only new technologies, but also new functionalities and new products, while coping with the unknowns. It becomes clear that the pace of innovation in semiconductors is extremely high, and to develop successful innovation, companies such as ST must incorporate both market and technical dimensions, which places portfolio structuring as a key issue in dealing with double unknown situations. This industry is particularly relevant for our study, as it often has to engage in double unknown situation, and the pervasiveness of semiconductors' use makes them a prime example of generic technologies(Miyazaki, 1994; Olleros, 1986).

Multiple case study

The multiple case study approach is particularly useful inunderstanding the influence of variability of contextto experimentally validate findings and gain more generalresults(Eisenhardt, 1989). Multiple cases enable accounting for a more accurate level of abstraction and help achieve better generalizability. The different organizational contexts were selected to better reveal the phenomenon.

We conducted case studies of innovative technology development in multi-project contexts at ST. The following three identified cases offer different frameworks and units of analysis, which permits different perspectives on the research questions: **Case**1) portfolio structuring for projects issuing from innovation contests; **Case** 2)organized reflections on future portfolio structuring in a double unknown situation in the case of the ITRS "More than Moore" technology working group; and **Case**3) *ex-post* analysis of a research project portfolio. These three contexts represent different organizational settings and comprise various units of analysis (*Table 1*).

Because we lackeda theory of generic technologydesign to guide the case selection, we verified that each case aimed to design a new object – a technological platform as opposed to the existing specific technologies – and that a variety of participants were involved in the cases' elaboration. The cases were selected because 1) all were subject to double technological and market unknowns; and 2) allattempted to design generic technologies by profiting from double unknown situations and addressing multiple existing and emerging markets (Table 1).

Researchers' roles in portfolio investigation

The first author was engaged in the collaborative action research with a company from 2010 until 2013 (Adler et al., 2003). She was actively engaged in the study and collaborated with the practitioners. The fourth author is a company employee, and his involvement ensured privileged access to data collection and exploration. In Case 1, the fourth author's role was to support activities related to organizing the innovation contests. The first author's role varied in this case from purely observational activity to supporting participants' reflection and facilitating portfolio exploration issuing from ideas. In Case 1 the first and the fourth authors organized 20 semi-structured interviews (40h) and were engaged in the observation activity during the 4 workshops organized by ST for contests participants.In Case 2, the fourth author conducted the data collection. He attended 17 face-to-face meetings and 40 conference calls of the International Roadmap Community and is directly involved in the “More than Moore” initiation of the ITRS. In Case 3, the study was conducted *ex post* and the researcher role was to analyze the portfolios. In total 30 semi-structured interviews were conducted by the first author (30h). Observations were compared and synthesized between the first and fourth authors. The second and third authors were not directly involved in the empirical research conducted, and their participation allowed analyzing the data independently and ensured the establishment of cross-data observations.

Data collection and analyses

The information-gathering techniques used in this study were interviews, documentation,and observations during meetings or conferences. The interviews followed semi-structured, open-ended guidelines. To learn about each case study, we interviewed a variety of company representatives and external collaborators associated with each portfolio from a variety of functional perspectives, including senior management and project and portfolio managers, and experts with commercial, marketing, financial, technological, research, development, and operational backgrounds were involved and directly participated in executing, organizing, managing or decision-making roles within the portfolios.The backgrounds and experience of the interviewees varied within each case to ensure multiple sources of information (*Table 1*). Each interview lasted approximately 1-2 hours. The data from the interviews were transcribed, and a representative set was used to establish common themes. This set was obtained through a within-case analysis to reduce the data from each data setting, group the cases and ensure cross-case synthesis(Yin, 2003).

The internal validity and reliability of the chosen methodology were achieved through triangulation among the conducted case analysis, derived analysis and judgments of company representatives. Feedback was solicited from the interviewees on the cross-case analysis. This procedure enabled continuous involvement of the firm according to the guidelines of engaged scholarship (Van de Ven, 2007) and collaborative research (Shani et al., 2008). Overall, over a 3-year period, the authors had frequent access to case information and organized feedback sessions with company representatives. The cases were conducted separately over slightly different time periods. Comparative analysis was conducted after all the data were collected and grouped. To ensure visibility and gain further perspective on data analysis, steering committees were organized in which all the authors shared their insights with company representatives (as part of a longitudinal study with ST). The committee met every 3 months.

This involvement allowed for understanding of multiple sources of influence. In addition to the data collection, a review of secondary sources was conducted. These supporting documents included multiple sources of information (*Table 1*).

In the following sections, we briefly describe each case.

Case 1. Innovation challenge

An innovation contest called the "Business Innovation Process" was initially organized in 2009 by two geographical sites of STMicroelectronics in France (Crolles and Grenoble, which house more than 6,400 employees) located in the Rhone Alpes region, which is known as the "French Silicon Valley" in microelectronics and nanotechnology. The contest focused on transversality, ecosystem development and value for users and for ST on future innovative solutions to address several business areas. The process was launched with the following goal:

> *"to boost the Grenoble and Crolles sites' contribution to ST value creation through better innovation and better use of local clusters" (BIP, 2009b).*

The process involved phases of challenge initialization, idea generation, selection and idea development. The high number of ideas collected through each challenge (33, 60 and 110) resulted in 20 selected projects that were built through idea grouping and generalization (over a 3-year period).

Overall, of the 20 projects that issued from the contest, only the 4 that are still ongoing appear to be structured based on generic technology design. These projects seek to develop new technologies and orient them toward several emerging markets. The projects were used to form their own generic technology-based portfolios by creating new complementary projects.

Case 2. ITRS "More than Moore" technology working group

The ITRS aims to provide industry with roadmaps that "align" the priorities among the various actors responsible for transforming an idea into growth through innovation. In their study of the ITRS, Le Masson et al. (2012b) demonstrated the possibility of collectively managing the innovation capabilities of the ecosystem by creating roadmaps that are largely driven by the predictable range of technological change, which is known as Moore's Law. Technology working groups of the ITRS International Roadmap Community are responsible for creating their roadmaps according to future transistor generation and the challenges associated with scaling. They address uncertainty reduction for predefined technological domains (*i.e.*, system drivers, design, and other components).

The ITRS first noted the "More than Moore" trend in 2005. The "More than Moore" addresses situations in which the goal is no longer miniaturization; the exploration is exposed to various emerging markets and technologies that involve the management of various parameters. This trend demonstrates that the decoupling of the market and technology that is common in the semiconductor industry could no longer be supported; companies are now truly in double unknown situations, with many potential markets exhibiting high levels of uncertainty with regard to size, timing, and needs and with many potential technologies. In

2011, the European members of the committee wrote a “More than Moore” white paper that guided the ITRS community to identify those “More than Moore” technologies for which a roadmapping effort would be feasible and desirable (Arden et al., 2010). This committee seeks to “build the link between societal needs, markets and technologies well beyond the ITRS current practice, and is likely to require the involvement of many actors beyond the ITRS historical membership” (Arden et al., 2010). The white paper proposed to complement the usual technology push approach of the ITRS by sketchingthe broad “application scenario”. Technology building blocks that should be roadmapped “have to enable functionalities to account for several applications and markets (Cogez et al., 2013). The “More than Moore” technology working group attempts to build a transversal roadmap based on generic functions. These generic functions are precisely the common technology needs of various future markets, which can in turn be used as templates for companies dealing with portfolio structuring in double unknown situations.

Case 3. Research project portfolio

The portfolio of Ph.D. projects conducted within ST from 2002-2010 was considered for analysis. These projects are managed within the Technology R&D group. Overall, the data represent 405 thesis projects. The projects are classified according to the technological group ownership (similar to the technology working groups of the ITRS), in which each group owns its own portfolio. The analysis showed that the research groups primarily managed their project portfolios independently. Each research project lasts approximately 3-4 years, and the results are communicated within the groups and used to define goals for subsequent exploration. The available resources are shared within the groups.

Within the groups, the Advanced R&D group is largely responsible for the “More than Moore” project exploration. Its portfolio (4 groups of 10) directly incorporated market knowledge and thus resulted in faster market disruption. For example, the bipolar project portfolio (10 Ph.D. projects involved from 2002-2010) and the corresponding roadmap were driven both by the increase in the optical communications data rate and the emergence of applications at higher frequencies (Chevalier et al., 2007). The portfolio was structured along the bipolar technology adapted for millimeter-Wave applications. It is a technological platform based on a Heterojunction Bipolar Transistor (HBT), which has many advantages overComplementary Metal Oxide Semiconductor(CMOS) devices, such asits low noise factor, higher voltage and higher resistance for the same speed (for further details, see (Chevalier et al., 2007)). The co-exploration of technology and markets enabled the introduction of this technology to various markets, such as rapid download, optical communication, medical, and high-frequency markets. Aprevious study (Kokshagina et al., 2013) demonstrated that the technology behind this project was generic and that the portfolio was structured in order to support and introduce this technology to several market areas.

Insert Table 1 about here

Results:

Case descriptions: Portfolio structuring in double unknownsituation for generic technology

The case analysis enabled an examination of three cases structured around the portfolioestablishment for generic technologies. From the three cases, only portfolios seeking to operate in multiple environments were taken into consideration. For each case, we investigated how a double unknown situation was tackled, how the portfolio was structured to ensure the exploration of generic technology and how the interdependencies were defined.

In Case 1, the technologies mastered by the two sites involved in this contest were diverse. These technologies were developed by the central R&D groups that are responsible for specific technological development, Advanced R&D units that seek to explore immature and still-unknown technologies, external R&D centers that are involved in technological development with ST and R&D groups that are associated with each business unit independent of the general R&D. On the technology side, the contest allowed the open participation of any employee of these groups. Likewise, the wording regarding the targeted uses and markets allowed for a wide variety of solutions involving the open participation of all the business units and strategy and marketing units (*Table 2*). Hence, this process was clearly positioned in a situation of double unknowns (double technology and market exploration) and privileged open collaboration and learning. Case 2 was driven by the“More than Moore” concept to account for technologies that do not necessarily follow the CMOS miniaturization trends and thatrepresent a growing part of the total silicon-based semiconductor market. The sheer diversity of both those technologies and their potential applications render a roadmapping exercise very challenging. The heterogeneous integration of digital and non-digital functionalities into compact systems is one of the key drivers for a wide variety of application fields, such as communications, automotive, environmental control, healthcare, security, and entertainment.To maintain technological leadership, companies must then be prepared for breakthroughs in their expertise, architecture, and functionality and the chosen forms of business models. The role of the “More than Moore” technology working group is to structure the exploratory activity in double unknown situations to deliver innovative solutions to the markets. Through “More than Moore” technology working group creation, the exploration of highly innovative technology concepts in double unknown situations is encouraged.Similarly in Case 3, only portfolios that were well-positioned to address the “More than Moore” issue were chosen. For example, at ST, a micro-electro-mechanical-system (MEMS) started in 1996 when the MEMS Business Unit was created. This unit primarily analyzed the state of the art on the market. A project leader of MEMS development at ST,noted:

> *“It was 2000, and there was no market or any customers yet! We had to create them, so we started by looking at what already existed.”* (Internal ST Document)

The intentional exploration of double unknowns and the generic character of the semiconductor industry allowed ST to profit from these unknowns to design common platforms. These common platforms,based on technological building blocks that address generic functions,are common for several emerging applications and allow building market modules by reusing platform core. For example, inCase 1, a generic platform to develop“an active surface to simulate haptic touch sensations” was thought to maximize the number of targeted environments, including e-commerce applications, consumer back type keyboards for visually-impaired people, automotive applicationsgaming, and medical diagnosis through surface simulation using MEMS or piezoelectricity actuator (*Figure 1*). This platformwas developed from the initially submitted idea:

> *“Based on the material properties (tissue, wood, leather…), a MEMS actuator can simulate the surface of the object to the customer at home and help him to select and buy products online. This solution can be dedicated to medical applications, to establish diagnostics at distance, [to] e-commerce applications…”*.(BIP, 2009a)

The proposal was selected as a result of both its disruptive nature and its vast market potential. The resulting generic technology indicated the method of developing a platform that addressed generic functions independent of the environment and dissociated them from the adaptable modules that included specific functions. Furthermore, platform enrichment was organized through portfolio creation, which included the development of both interdependencies to address the development of market modules by reusing generic technology and management to ensure the deployment of market complementarities and generic core enrichment. The generic haptic technology yielded by this idea gave rise to a portfolio that currently comprises several research projects, collaborative projects with external research centers and industrial partners, and ongoing projects in BUs to develop commercial products. The generic portfolio was established to explore new unknown environments by acquiring the necessary knowledge and expertise (*Table 2*).

In Case 2 (*Figure 2*), a new technology working group for MEMS exploration was spun off of the Wireless technology working group (where only MEMS used for Radio Frequency filtering applications were discussed) in 2011. MEMS, micron-size devices that can sense or manipulate the physical world, are exceptionally diversified. MEMS encompass the process-based technologies used to fabricate tiny integrated devices and systems that incorporate functionalities from different physical domains into one device. MEMS revolutionized various existing product domains and created new ones by bringing together silicon-based microelectronics and micromachining technology (Bryzek, 1996).

MEMS technology became a hot topic in the industry in approximately 2006 with its introduction first in gaming consoles and later rapid expansion into mobile phones and other devices; however, MEMS makers were at first reluctant to work together toward a roadmap due to skepticism about decoupling technology and product; some experts argue that in MEMS, the technology is the product. They finally agreed, nevertheless, to meet around one common issue: the testing of their devices, for which they felt not enough research was being conducted, while this issue represented both a sizable proportion of their costs and a demand from their customers. Once this community was created around this common purpose, it was possible to introduce discussions about more general future needs, with several driving applications, such as tablets and smartphones. MEMS-based roadmaps comprise the generic platforms and specific projects to addresspicoprojectors, the electronic nose, microspeakers, ultrasound devices and other emerging products.

Throughout the cases 1 and 2, we observe that generic technology is designed for a range of emerging markets; it stimulates the creation of new applications andrevolutionizes existing ones. For example, the emergence of microfluidics in medical applications opens many possibilities for MEMS in drug delivery. Electronic nose applications that use MEMS principles are being developed for a wide range of healthcare and biomedical sectors and are revolutionizinghow this traditional sector operates (*Table 2*). To ensure wider applicability or flexibility of generic technology, the interdependencies need to be considered carefully.

Within the bipolar research portfolio inCase 3 (*Figure 3*), project interdependencies (especially learning interdependencies) and technological uncertainties are effectively managed.The purpose of Si-based Bipolarmicro-Wave technology is to combine the advantages of two types of transistors: the bipolar transistor for higher gain, higher switching speed, better noise performance, and low consumption and the CMOS transistor for higher density, better performance for logic operations, lower speed blocks, and control functions.

A high-frequency bipolar transistor with animproved back-end (Chevalier, 2007) was designed to address all the environmental constraints and succeed in several market applications with low adaptation costs (such as automotive radar, fast download applications, medical, non-invasive imaging, optical communication). The project team that worked on the bipolar technology reconstructed a sort of artificial market space with Wi-Fi to enable high device connectivity and a wider scope than the alternatives that facilitated technology adoption by derivative markets later. The generic technology design enables maximization of the list of functions by superposing several applications. Instead of fixing the set of market applications and organizing exploration by minimizing resources spent, the team inverted the reasoning by fixing the resources and maximizing the scope of the applications considered for platform building. Regarding the analysis of the Ph.D. projects, the bipolar portfolio consists of 10 projects (2002-2010).

This cluster, oriented toward generic technology exploration, aimed to mobilize the resources from all the other research teams and build interdependences with various business units and external partners to better position the portfolio in multiple markets. Once the platform core was designed,the projects were launched to optimize the technology and address the predefined market applications. For example, a projectstarted in 2005 aimed to “optimize the process of bipolar heterogeneous transistor for wireless communication and power amplification” and thus, built a module to ensure greater openness of the bipolar platform (Figure 3).

All the examined portfolios shareda common platform– generic technology – and aimed to structure their portfolios by ensuring platform reuse for emerging market applications.The value of flexibility was clearly inherent in generic technology. These three cases show that portfolio structuring is critical in ensuring the future core value, especially in the unknown exploration phase.

Portfolio management in double unknown: Toward cross-application management

The effect of cross-disciplinary exploration, exposure to unknown structures and the constant technology-market coordination process resulted in greater genericity in all of the analyzed cases. The multiple case analyses reveal that generic technology appears to succeed when managerial support is present and the transversal technological and market exploration is organized. For example, within the innovation process in Case 1, the project leaders who focused their attention on the generic functions succeeded in developing a generic platform for several markets. More important, the generic projects were the only ones that were considered successful within the context of these challenges (*Table 2*). Theinnovation contests played the role of innovation hubs or incubators to prioritize the collaboration of various business and R&D units. Thesecontests privileged the exploration of multiple emerging markets and new technologies by creating interdependencies and reducing unknowns. The exploration relevant to generic technology aimed to propose a solution that imposed the collaboration of several R&D groups to address the needs of several business units and stimulate the exploration of new markets. The proposals that resulted in platforms attempted to create complementary projects and organize portfolios to explore both the generic construct and its market modules. By pursuing generic technology design, the manager's role is to work on the generic aspects of the solution rather than prioritize specialization in more promising markets. For example, one of the potential customers was interested in using haptic technology for an eye-less keyboard application and haptic mouse that aimed to facilitate the adoption of the electronic devices by visually-impaired people or in conditions where access to the display was limited. If a manager chooses to address only these promising markets, then the transparency of a multi-touch capacitive solution required for smartphones and tablets would be difficult to even consider. In this case, the manager was able to design a portfolio in which functions specific to the market were managed in separate projects and in which the generic core was a common project that facilitated its reuse by the emerging market areas (*Table 2*). This manager, whom we propose to call the cross-application manager (CAM), was able to manage the links between the technological requirements and market needs (*Figure 1*). In contrast, a lack of collaboration within these roles and insufficient management of learning interdependencies might consequently lead to failure in generic technology exploration. Moreover, it is important to note the key role of the organizing committee, which did not seek to select the winner of the contest but privileged the accumulation of joint expertise in participants from different backgrounds. The committee privileged multi-market exploration and helped project leaders – future CAMs – build their network both internally and externally, and the team played the role of the interface among various technological and business groups. This team involved people from R&D, business units and strategic departments (an approximate total of 15 specialists) (*Table 2*).

In Case 2, the transversal collaboration within "More than Moore" and various technology working groups and the exposure to disruptive markets led the ITRS to structure a portfolio of potential "More than Moore" solutions. This portfolio presents the potential challenges that companies could meet and the directions that they could take to coordinate their scientific and development efforts. The idea of using generic functions and the incorporation of market ideas permit the committee to structure the effort toward the portfolio of generic technologies (*Figure 2*).

The coordinators of the "More than Moore" group play the role of CAMs within the ITRS community (*Table 2*). The existence of the technology working group "More than Moore" inCase 2 and its accomplishments, which were oriented toward the exploration of the double unknown, relies heavily on the involvement of its coordinator(s). CAMs privilege the construction of roadmaps in double unknowns based on the identification of generic functions (Cogez et al., 2013).CAMs'role is to search for existing knowledge gaps in the landscape of technologies and markets to define the direction of technological development and identify interdependencies that can be built to acquire generic technology. CAMs do not seek to reduce uncertainty by choosing a particular technological trajectory but aim to structure unknowns to privilege generic technology exploration. Their position within the ecosystem of the major players in the semiconductor industry facilitates their access to necessary information and enables them to test the relevance of their propositions. This case demonstrates that the highly coordinated activities of the individuals leading the "More than Moore" trend have increased the importance of this trend within the community. From its first mention in 2005, citationsof"More than Moore" reached 79 in 2011, and among 18 technology working groups within the ITRS, 11 cite "More than Moore". Additionally, a purely "More than Moore" -oriented group was created in 2011 for MEMS portfolio exploration.

Insert Figures 1, 2, 3 about here

In Case 3, there were groups that establishedspecific technology–market relationships. In this case, there was no need for transversal exploration toward the generic technologies; the idea was to reduce uncertainties and structure project portfoliosto attain higher benefits and increase the performance of the technological solution. Once the levels of uncertainty are higher, the technology in question islikelyto be generic, and the role of clusters for generic technology exploration will become advantageous. The presence of managers (the team coordinator and technology line managers) playing the role of CAMs enabled the company to buildan interface within various business and R&D units and position technologies as generic earlier, which in turn allowed for more rapid technology appropriation by the market through the construction of previous interdependencies. The portfolio organization of the R&D projects enabled effective exploration of the emerging market and technology spaces; it incorporated the clusters addressing unknowns, uncertainties and risks. The clusters addressing both unknown technologies and markets require the presence of CAMs to coordinate exploration toward the design of successful generic technology.

Exposure to unknown markets and technological structures provides an opportunity for CAMs to proceed toward generic technology development and build portfoliosto address multiple markets. Portfolio structuring for generic technology requires CAMs to seek transversal ideas to address several market areas (existing and new) and new original technological solutions that are flexible and robust to address several emerging markets. CAMs aim to explore a variety of market applications while reusing the existing technological competences and developing new competences with minimal costs of re-adaptation between future modules. Although these transversal projects offer solutions for several business units (such as bipolar portfolio in *Figure 3*), they often pose challenges in terms of investments for technology development, managerial responsibility, technology ownership, and time to market. For example, business unitsmust decide how they will share the costs of platform development and which remaining costs they must pay for market complementarities. To ensure platform adaption by the various markets, CAMs must manage these organizational risks.

A common observationacrosscases exhibit that the successful implementation of generic technologies requires multiple roles to guide the technology and market exploration phases and their propagation, appropriation, communication, and management.Together these results show the similar nature ofCAM's role that consists in coordinating the exploration between various technological and market groups to identify the opportunities within a portfolio and createbalanced portfolios. The CAM must be able to mobilize technical experts to assess the technological character to estimate whether the emerging technology has the potential to address emerging market needs. The CAM definesgeneric technologies and organizes their exploration such that they are able to attract market functionality and stimulate further market exploration (*Table 2).*

Insert Table 2 about here

Discussion and conclusion

The goal of this paper is to investigate how portfolios can be structured in double technological and market unknown situations by exploring the possibility of developing generic technologies and portfolio management for generic technologies.

Toward portfolio structuring in unknown situations

The importance of the ideation or fuzzyfront end phases to the more operational phase of portfolio management is stressed by the literature (Heising, 2012, Geraldi, 2008, Ozcan and Eisenhardt, 2009). This paper introduces an effective method of originating high-performing portfolios within a company challenged by high uncertainty and a dynamic environment. Despite the challenges associated with environments with high uncertainty and high velocity common to high-tech industries, such as semiconductors (Cohen and Levinthal, 1989), this work shows that it is possible to account for portfolio management in unknown environments through the design of generic technology that creates interdependencies within technologies and markets and that structures a portfolio to explore this technology and its market derivatives. Companies that engage in the exploration of generic technologies naturally link their portfolios with their strategic orientations. Our results indicate that it is possible to structure portfolios based on generic technologies that structure unknowns instead of simply reducing them.

The economic success of a portfolio depends on its commercial and market success (Shenhar et al., 2001). To account for successful exploration, it was demonstrated that in unknown situations, management of both uncertainty and interdependency is crucial. In double unknown situations, the existence of multiple emerging market signals and technological alternatives appear as prerequisitesfor the design of generic technologiesto build portfolios across the emerging generic core. Project portfolios for generic technologies resolve unknowns by enhancing cooperation among technological, market, and strategic research units and thus create synergies within portfolios (Loch, 2008, Cooper et al., 2001). Once a portfolio is structured, it resolves unknowns by structuring the exploration space. This mode of structuring portfolios around generic coreand modules ensures the successful resolution of unknownsbecause the unknowns that are relevant to this particular challenge are resolved. The earlier efforts in portfolio organization enabled reducing unknowns and accounting for higher genericity.The mode proposed in this paper certainly poses new questions; however, for that particular situation, the unknowns are reduced due to portfolio structuring and new interdependencies created based on generic technologies.

The opportunity to design platforms and develop new platform-based portfolios helps companies ensure product variety and reduce complexity within product lines (Pruett and Thomas, 2008). This paper shows that the projects that attempt to design generic technologies enable the organization and structuring of portfolios under contexts of high uncertainty. The generic project is the core of a portfolio and must ensure its independence from the set of possible specific projects (such as specific market applications) and create interdependencies with the emerging markets. The generic platform must be attractive for multiple markets and stimulate their creation.

Resource limitations require an organization to strategically allocate resources to a subset of possible projects (Dickinson et al., 2001). Portfolio design based on generic technologies is helpful for building more balanced portfolios.The portfoliostructuring for generic technologies that is examined in this case can help balance the levels of promise and interdependency of a platform owner and its derivatives, where the latter can exist in projects both within and outside the company. This portfolio is balanced by the constant resource interdependencies created during the portfolio structuring (Meskendahl, 2010, Killen et al., 2008). Additionally, platform development ensures that firms can access external resources by opening up the platform and attracting complementary innovators within a supportive ecosystem. The possibility of incorporating new projects over time signals the flexibility and easier adaptation of a portfolio in the face of new challenges (Olsson, 2006). As a result, long-term strategic and less risky application-specific projects are balanced within these portfolios. Thesecontributionsare rooted in the economic and organizational aspects of platform-based organizations (Baldwin and Woodard, 2009, Gawer, 2014) and ensure the efficient combination of contributions from multiple project perspectives.

Cross-application manager and corresponding organizational structures

These results indicate the existence of an actor(s) who has the expertise to identify missing technologies and markets and construct interdependencies. We refer to this actor as a cross-application manager – an actor who is able to ensure interaction between the innovative concepts developed in different business and research lines. This role requires specialized capabilities to transversally invest in different fields to ensure cross-application character for generic technologies, demonstrate the external uncertainties, stimulate the environment and ensure the learning process in situations involving unknowns (absent in the state of the art and characterized as knowledge gaps).

The three casesdiscussed in this paper jointly show the relevance of this actor in different situations and exhibit different forms of generic technology-based portfolios.

The figure of the CAM supports the changes in both markets and technological exploration and the operating conditions that are directly linked with the innovation capabilities of organizations. To ensure successful management of generic technologies, the cross-application manager must control a totality of the knowledge structure.

The platform leader and his role comprise the interaction with a large number of complementarities that occupy peripheral positions (Gawer, 2010). Similar to the platform leader, the role of the CAM comprises the interdependencies that accumulate to further promote the portfolio that is designed as a result of the platform. However, in addition to the duties of platform leader, the CAM role also involves generic core identification and building. The CAM's role is to ensure platform insertion into both existing markets that can generate profit in the short term and emerging markets to ensure long-term growth for generic technology. Through the process of unknown exploration, this actor permits the coordination of exploration activities within an organization. When coordinating portfolio structuring in the context of unknowns, the CAM encounters double difficulty because potential value is difficult to estimate due to the rapidly changing industrial environment and high volatility.

This study reveals that the CAM is responsible for 1) managing explorations in multiple technology and market areas simultaneously in a double unknown context; 2) knowing the functional structure of emerging and existing markets within various business units and their existing technological portfolios; 3) evaluating external and internal R&D technological portfolios and revealing the character of technologies while identifying knowledge voids; and

4) identifying opportunities for generic technology development. Due to the specificity of the function of the CAM in conducting the reasoning in unknown situations, it appears important to distinguish this role from those already existing, such as champions, brokers, boundary spanners, and heavyweight project leaders (Wheelwright and Clark, 1992, Hargadon, 1998, Keller & Holland, 1975, …)because of the nature of his exploration in double unknowns. However, these roles are not contradictory. For example, similarly to boundary spanners, the CAM ensures effective monitoring of the environment and performs boundary-spanning activity to link organizational structures (Keller and Holland, 1975), although the CAM's specificity lies in the portfolio structuring based on generic technologies design. CAMs ensure knowledge brokering from where it is known to where it is unknown by spanning multiple markets and technologies and searching to engage in interdependent activities that enable innovation (Hargadon, 1998). A CAM may proceed as a knowledge broker once a genericity is designed and interdependencies are structured as activities within a portfolio. However, the specific competences that differ from knowledge broker functions are required to successfully structure portfolios based on generic technologies in unknown situations.A parallel situation involves a heavyweight project leader introduced by (Wheelwright and Clark 1992). Heavyweight leaders (similar to CAMs) must ensure access to a variety ofexpertise across the organization, support a variety of functional organizations, stimulate and facilitate communications across functions (as in the example of heavyweight leader Scott Shamlin of HP). Like the heavy weight project leader, CAMs are addressing the cross-organizational challenges of large firms. However, CAMs' objective is different: they explore unknowns, aim to "mutate" the existing ecosystem by defining generic technologies, ensure their innovative design across different functions that exist internally and externally and structure the portfolio based on the emerging generic technology and organizational capabilities.

This figure may be challenging to identify, and the necessary level of expertise is difficult to achieve without relevant experience; however, this role appears necessary in designing generic technology and structuring portfolios. The cases show that the Cross-Application Manager is not necessarily one actor but can be a structure or a team (as in Cases 2 and 3).

Further research and implications

The work on innovative research portfolio management can lead to new tools and frameworks for companies confronting technical challenges of increasing complexity in addition to shorter product life cycles. This environment forces firms to rely on R&D as a source of strategy, and companies are inclined to evaluate their technologies from a portfolio perspective in which a set or sub-set of R&D projects are evaluated together in relation to one another. This research creates new perspectives for management of high levels of uncertainty in the process of exploring emerging industrial sectors (Rothwell and Gardiner, 1989). Although the results from these three cases studies in the semiconductor industry do not establish definite principles for how portfolios should be organized in double unknown situations, this article suggests a way of structuring high-performing portfolios based on generic technology. Portfolios structured around generic technology require continuous coordination and exploitation (Müller et al., 2008). Addressing the importance of high uncertainty and many unknowns, this work providesthe important insight that practitioners should address unknowns as opportunities to meet strategic objectives (Martinsuo, 2013, Olsson, 2006, Perminova et al., 2008, Petit, 2012, Olsson, 2008).

This research demonstrates the importance of the cross-application manager in structuring and guiding portfolios of generic technologies. This study contributes to examining the link between the organizational structures and necessary competences for portfolio organization to account for PPM in unknown environments. The empirical understanding of the issues of generic technology exploration in highly uncertain; dynamic environments and the associated role of management were added to the interdisciplinary PPM context. This research provides a new perspective on the strategic management of innovation through portfolio structuring.

Generally, the literature confirms the interest in developing generic technologies (Youtie et al., 2008, Maine and Garnsey, 2006). However, methods of organizing the development of generic radical technologies and associated management techniques remain understudied. In terms of the contribution to the literature, the paper addresses the issue of designing generic technologies to provide insights into portfolio organization to account for genericity and define the importance of the managerial role (defined here as the cross-application manager) in accounting for generic technologydesign. However, this research is limited to the empirical context of the semiconductor industry. The findings must be verified in the larger context and within various industries. The sample size should be increased, and the effect of the presence of generic technology on the success of the overall portfolio must be quantified. The conditions in which a company shouldpursuegeneric technology exploration within a portfolio and organize its exploration in the context of unknowns remain to be identified.

Finally, our findings bring new perspectives on creating high-performing portfolios built on generic technologies. High variety in portfolios often implies higher costs and greater resources required. By building portfoliosingeneric technologies in double unknown situations, a firm can ensure variety by leveraging the emerging platform. This research provides important insights into the governance of double unknown situations and clarifies the capability of actors in coordinating exploration and portfolio structuring for multi-project firms when both technology and markets are unknown.

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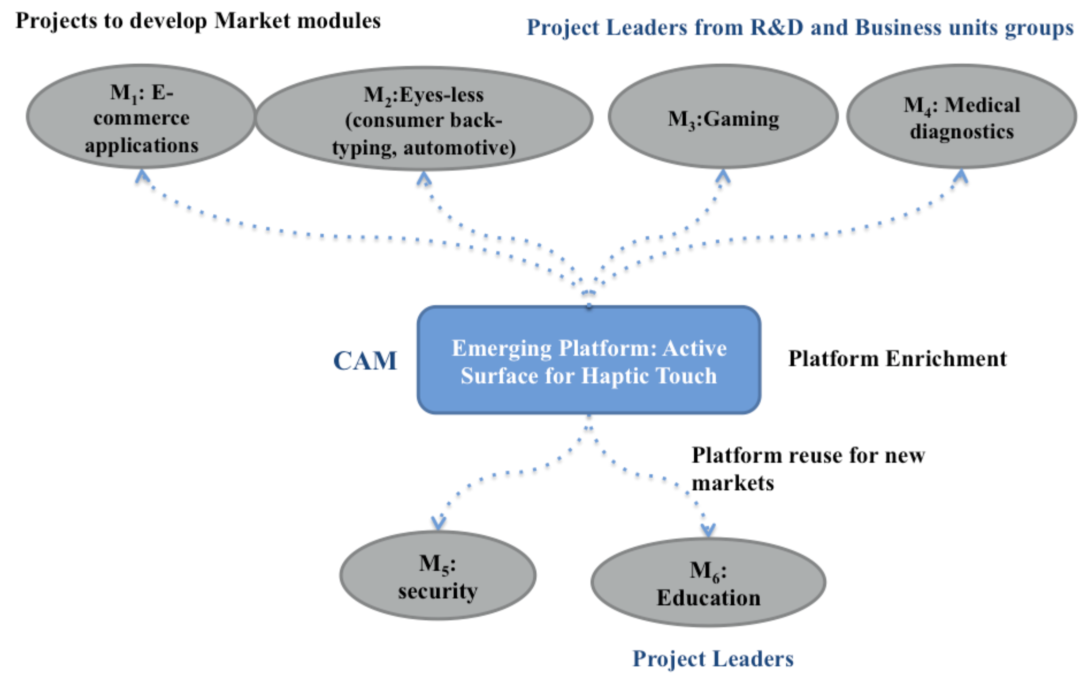

Figure 1 Example of generic portfolio structuring in Case 1: Haptic technological platform

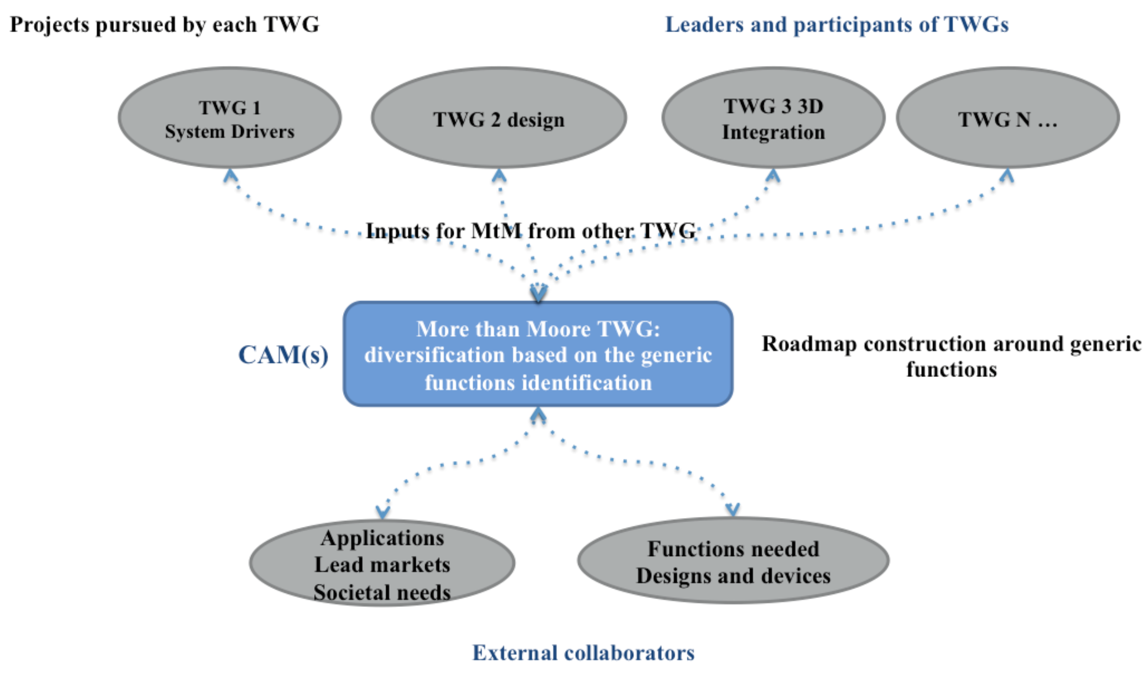

Figure 2 Generic roadmap establishment in Case 2: More than Moore ITRS technology working group

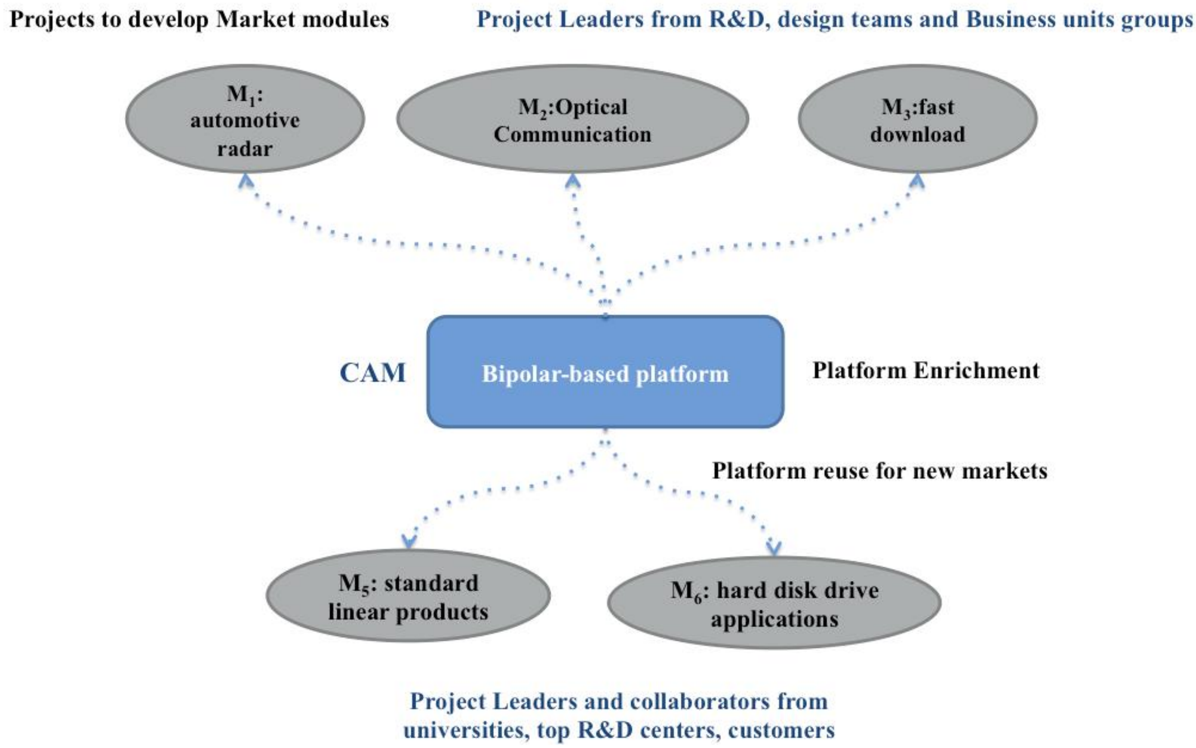

Figure 3Example of generic portfolio structuring in Case 3: Bipolar-based platform

Table 1 Data description and units of analysis

	Case 1	**Case 2**	**Case 3**
Description	Open Innovation Contests – Business Innovation Process (3 consequent innovation challenges)	International Technology Roadmap for Semiconductors (ITRS) technology working group "More than Moore"	*Ex-post* analysis of a research project portfolio
Time period	2009-2012	2005-2013	2003-2010
Type of project	Innovation exploration projects accepted after the idea collection phase – 20 potential portfolios in 3 years from 221 ideas submitted	Working group composed of actors from various semiconductor companies (Intel, NXP, and STMicroelectronics)	10 research project clusters (~400 research projects)
Unit of analysis – technological platform and emerging portfolios	**Example of one portfolio**: 3DTouch platform based on active surface to elaborate haptic touch	**Example**: Generic functions identified for future platforms structuring – MEMS-based roadmap	**Example:** Bipolar technology addressing RF-based multiple markets
Organizational entities involved	Business units, and strategy, marketing, and R&D groups	Companies' representatives and "More than Mooretechnology working group leaders	R&D groups
Participants	- Participants involved in the three contests from ST's Grenoble and Crolles sites, including specialists from marketing and technical backgrounds and strategic and operational units, internal and external participants (interns and university students involved in ideation) - Organizing committee	ITRS members included specialists from different companies (mostly R&D directors, innovation directors): - Technology working group leaders - Technology working group participants	400 research projects (each project was 3 years in duration): - 1 industrial Ph.D. candidate per project - at least two responsible at the company: project leader and R&D group - General R&D program managers and Technology line managers
Primary data sources	- 20 semi-structured interviews (40 h) - Observational activity of 16 (64 h) workshops named "Growing seeds" to facilitate generic technology exploration and promote technology adoption throughout the	- 17 face-to-face meetings - 40 conference calls	- 30 semi-structured interviews (30 h)

	company, 4 workshops by contest		
Interviewees	- Members of the decision-making board (2 Chairmen – companies' Vice Presidents; 2 members – Business Units' managers; and 2 sponsors – directors of ST's Grenoble and Crolles sites) - Members of the organizing committee – 8 interviewees from R&D and Business Units - Leaders of 3 ideas selected – 3 interviewees (including 3D Touch project) -3 participants of 3DTouch Team	- Members of International Roadmap Committee (steering committee of ITRS) participated in 17 face-to-face meetings and 40 conference calls - steering committee has twotofour members from each sponsoring region (Europe, Japan, Korea, Taiwan, and the U.S.A.). Its mission is to provide guidance/coordination for the technology working group leaders	- Technology line managers responsible for each project cluster – 5 - R&D team managers - 6 - R&D specialists of Bipolar project portfolio – 4 from device development teams and 3 from design team - Ph.D. candidates in bipolar team – 4 - Collaborating laboratories – 2 - Business Units – 2 persons from automotive and interface groups (interested in bipolar-based technology) - R&D financial structure – 1 person - Project and program management office – 2specialists - 1 Intellectual property management specialist
Supporting documents	Internal press releases, innovation week programs, flyers, the three databases associated with idea collection for each contest, evaluation committee assessment reports, presentations of selected ideas at various milestones, mail, and survey results	ITRS conference calls of International Roadmap Committee (steering committee of ITRS) since 2005 (the fourth author attended), working documents of several specialized working groups of the ITRS, and publicly available documents	Internal database of document workflow for each thesis project (including annual reports, project description, final document and resume presentation) and description of associated collaborative projects if Ph.D. students were part of a more global European and international program

Table 2 Generic Technology-driven portfolio and the role of Cross-application manager

	Case 1	**Case 2**	**Case 3**
Context – double unknown exploration			
Technological complexity: High variety of Technological domains	Optical sensors, Image processing techniques, Communication technology, Haptic Technology, 3D, RFID, sensors, MEMS, Radars …	Accelerometers and gyroscopes, microphones, and RF MEMS, including resonators, varactors, and switches…	Etching, Lithography, MEMS, 3D Integration, Bipolar, FD-SOI…
High variety of application domains	Consumer, Medical, Entertainment, Automotive domains, Gaming, Security, Retail, Navigation…	Medical, Automotive. Energy, Lighting, Security, Transport&Mobility, Communication…	Consumer, Medical, Entertainment, Automotive domains, Gaming, Security, Energy, Lighting…
	Portfolio structure: generic technology and associated modules		
Example of emerging platform	Platform based on active surface to elaborate haptic touch	MEMS technology-driven platform	Bipolar technology-driven platform based on heterojunction bipolar transistor
Example of portfolio structuring	Specific projects based on: - developing market complementarities, such as E-books, educational, social networks, gaming solutions, gesture learning and object customization, security were added - further enrichment of the generic platform - developing specific functions to address a list of market applications	Specific projects are based on: - developing accelerometers and gyroscopes, microphones, and RF MEMS, including resonators, varactors, and switches by building on the platform - to address optical filters, picoprojectors, the electronic nose, microspeakers, ultrasound devices and other emerging products	Specific projects based on: - developing market complementarities for high-frequency applications, such as targeting high-frequency applications: optical communications up to 100 Gb/s, automotive radar sensors at 77 GHz, wireless communications at 60 GHz, high-speed instrumentation, non-invasive imaging (medical and security) – enriching the platform itself
Result	4 generic technology-driven portfolios led to successful generic portfolio creation	Generic technology-driven roadmaps to constitute platforms (generic function) and ensure the creation of variety of product families	4 generic technology-driven portfolios led to successful generic portfolio creation
Portfolio structure	Formulation and execution of projects built on a specified set of generic technological platforms		

Interdependencies	High resource and technical interdependencies because of the common platform and resources		
Managerial role: Cross-application manager (CAM)			
CAM	Platform owners became CAMs progressively	Coordinator of technology working group "More than Moore"	Technological leaders and technology line managers
Role of CAM	- Ensure technological development of platforms and platform modules through project structuring and reuse - Manage balance, resource allocation and coherence of portfolio	- Hold group together – pursue exploration of generic functions for both technologies and key application domains	- Ensure coordination among R&D groups to constitute a platform - Establish collaboration with multiple Business Units - Manage balance, resource allocation and coherence of portfolio