INNOVATION, MODULARITY, AND LEARNING: AN INVESTIGATION OF THE ANTECEDENTS, DIMENSIONS, AND CONSEQUENCES OF MODULAR APPROACHES TO INNOVATION AND LEARNING

Dissertation

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Abstract

Modularity makes complexity manageable. Modularity theory maintains that modular architectures lead to both a higher efficiency through offering multiple product variants and a higher strategic flexibility through innovation. Furthermore, theories on modular design propose that a modular product design influences directly the organizational knowledge and structure creating modular organizational and knowledge architectures. There is little direct evidence, however, on how firms manage the different types of modular architectures to achieve the expected advantages.

In the dissertation, I seek to clarify whether and how firms address the challenges of dynamic markets with modularity of products, organizational processes, organizational structures, and knowledge, and how these choices affect their strategic flexibility. I build on and extend theorizing on learning and innovation. I review research and theorizing on learning with a focus on routines and absorptive capacity. Routines hinder learning within organizations. Firms without an absorptive capacity fail to learn from other firms. Modular strategies may provide a solution to the problems of rigid routines and help develop the required absorptive capacity. Furthermore, I discuss a review of research and theorizing on innovation, in which I present arguments on the behaviour of firms in dynamic markets, on failure to innovate, and on approaches to solve the innovation problems. Finally, I elaborate on theories and research on modularity, which represents a key approach to managing innovation. I draw on theories of modularity, learning and innovation to build the hypotheses.

I find that firms do match the market dynamics with modularity strategies. However, firms do not manage simultaneously modular architectures on product, organizational, and knowledge level and often fail in their flexibility quest. Only firms

that develop a higher order capability in mixing and matching simultaneously organizational process modularity and knowledge modularity succeed to innovate faster both at components and at architectural level.

The research project contributes to theorizing on learning, innovation, and modularity. Firms in dynamic markets innovate faster if they adopt modular strategies. Modular strategies, however, solve the innovation problems only under a specific approach to the management of the knowledge and processes. I term this specific approach 'mixed modularity' and argue that it represents a dynamic capability of the firm.

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INTRODUCTION: RESEARCH QUESTION AND MOTIVATION

Management of modular architectures is an area of intense interest both to scholars and practitioners (Baldwin and Clark, 2000; Garud and Kumaraswamy, 1995; Langlois, 1997; Schilling, 2000). In increasingly dynamic markets modularity of products offers to managers the possibility to exploit economies of scale and scope and to enhance product variety to meet heterogeneous customer needs (Garud and Kumaraswamy, 1995; Gawer and Cusumano, 2002; Wheelwright and Clark, 1992; Tu et al., 2004). Moreover, in theories on modular architectures, modularity of products, organizations, and knowledge promises an increased pace of learning both at component and architectural level through coupling modular product designs with modular organization designs (Baldwin and Clark, 1997; Sanchez and Mahoney, 1996; Schilling, 2000).

In this paper, we investigate whether different types of modularity have impact on flexibility of firms in markets with varying dynamics. I study the existence and the outcomes of firms' capability to manage modularity of multiple dimensions: how companies with modular strategies mix and match not only product components, but also product modularity, organizational modularity, and knowledge modularity to cope with the dynamics of their markets. I create a path model of the antecedents, types, and outcomes of modular strategies of firms, which I test in a large-scale cross sectional study (see Figure 1).

Insert Figure 1 around here

Theories on modular management of product, organization, and knowledge distinguish between a first- and a second-order effect of modularity (Sanchez, 1995, 1997; Sanchez and Mahoney, 1996). The former refers to the increases in flexibility through manufacturing multiple products from few components, the latter comprises of the gains in flexibility through faster component and architectural innovation. While Sanchez and Mahoney (1996) argue that modular designs are beneficial for both component and architectural innovation, empirical studies offer contradicting findings and divergent implications. Drawing on case studies of the stereo component and the microcomputer industries, Langlois and Robertson (1992) provide evidence on the positive impact of external product modularity, i.e. networks of producers of a modular product, on the rate of innovation of components. However, they find out that the rate of innovation of architectural knowledge is actually slower in systems with external product modularity. Chesbrough and Kusunoki (1999) advance the investigation with the evidence that internal product modularity has also the disadvantage of inducing myopic learning which limits architectural level learning. Based on a case study in the aero engine industry, Brusoni, Prencipe, and Pavitt (2000) conclude that product modularity may harm component innovation if knowledge boundaries are allowed to become too narrow. In a large-scale study of the home appliance industry, Worren et al. (2002) find that product modularity has an impact on enhancing the number of variants of a product, but does not influence the pace of innovation. Surprisingly, they find that modularity of organizational structures and processes has no impact on strategic flexibility. In sum, the literature so far abounds in contradicting theoretical arguments and empirical findings on the outcomes of different types of modularity. Few studies have empirically linked the different types of modular architectures of a company with the different types of expected advantages in the setting of dynamic markets.

While prior research has considered the types of modular architectures separately, I attempt to contribute to a better understanding on the interdependencies between the types of modular architectures and the links between modularity and the expected outcomes. We build directly on general theories on modularity proposed by Schilling (2000) and Sanchez and Mahoney (1996) as well as on the influential empirical study of Worren et al. (2002). In addition, I draw on theories and research on learning and innovation. I advance the investigation on modularity and flexibility of Worren and his colleagues (2002) with the missing external product modularity, defined as networks of producers of components (Langlois and Robertson, 1992; Schilling, 2000) and knowledge modularity, defined as loosely coupled systems of knowledge components (Sanchez and Mahoney, 1996). I test for the expected existence of a multidimensional construct of overall firm modularity. Research efforts have been constrained to several industries, like computer industry, automotives, and home appliances, which seem to be a favourable setting for modular strategies. There is a gap in the research stream on the relevance of the modularity strategy in a cross-sectional sample of industries.

The dissertation is structured as follows. First, I review theories and research on learning, innovation, and modularity. Second, I provide definitions of the constructs and build the hypotheses drawing on the background theories on modular designs, innovation, learning, and knowledge boundaries of the firm. Third, I discuss the method, the context of the study, and the instrument development. By means of a second order Confirmatory Factor Analysis, I test the validity of a model of overall multidimensional modular capability, consisting of the five types of modular architectures. Using a path analysis with latent variables, Structural Equation Modelling, I assess the model of modular architectures and their outcomes. Finally, I discuss the findings and the avenues for future research.

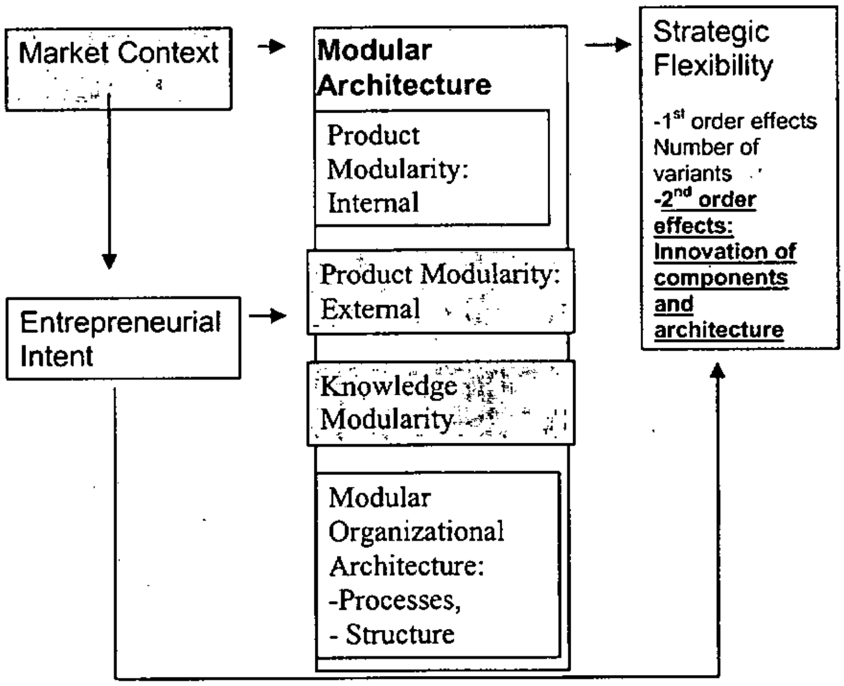

Figure 1: Theoretical model

THEORETICAL BACKGROUND: LEARNING THEORIES AND RESEARCH

Organizational learning figures prominently in a wide array of research programs (Argote et al., 2003; Cho and Pucik, 2005; Hatch and Dyer, 2004; Tippins and Sohi, 2003). While the empirical research on the phenomenon increases dramatically, scholars are challenged by critiques on ambiguities in the theoretical foundation of their research (e.g. Foss, 1996, 2003; Hargadon and Fanelli, 2002; King and Zeithaml, 2003). To improve the basis for knowledge accumulation, learning theorists work on better definitions of learning, understanding of the learning processes on and between multiple levels in organizations, and of measurement of learning (Argote and Ophir, 2002; Crossan et al., 1999; Crossan and Bedrow, 2003; Edmondson, 2002; Ingram, 2002; Schulz, 2002; King and Zeithaml, 2003).

Learning, routines, and organizational knowledge

Theorizing on intraorganizational learning focuses on learning and the organizational knowledge embedded in routines. Levitt and March (1988) define learning as "encoding inferences from history into routines that guide behavior" (Levitt and March, 1988: 319). Schulz (2002) emphasizes that this focus on routines allows scholars to claim a supra-individual basis of organizational learning. However, learning scholars have paid less attention so far to the definition of the concept of routines on the individual, groups and organizational levels and to the measures of the tacit and informal aspects of routines.

The idea that organizations know differs from the approach to analysis of knowledge at the organizational level. Scholars reason that organizational knowledge is held by individuals but cannot be reduced to the simple sum of the knowledge of the individuals (Kogut and Zander, 1992; Blackler, 1993; Weick and Roberts, 1993; Spender, 1996). The observation that employee turnover does not change the action patterns in the organization seems a convincing evidence of the fact that organizations know more than the simple sum of individual knowledge or the shared part of individual knowledge. Both individuals and collectives have knowledge-based identities (Spender, 1996). The organizational knowledge is understood as higher order organizational principles and becomes manifest by the regularities with which members cooperate in the social community of the firm (Kogut and Zander, 1992). Routines provide the basis for coordination in the organization (Blackler, 1993; Grandori, 2001). Thus, the regular patterns of action in groups, defined as routines, express the higher order organizing principles of cooperation, defined as organizational knowledge. Routines are one of the expressions of organizational knowledge (Blackler, 1993).

Routines embed knowledge in the organization (Foss, 2003). Badaracco (1991) distinguishes between 'migratory' knowledge in the individuals, who may leave, and organization's 'embedded' knowledge in routines, networks, etc. The idea of organizational knowledge implies that it is permanently embedded in the organization and an attention to action (Blackler, 1993; Spender, 1996). Representations of the routinized action patterns are maintained in the organization in several forms: in the memories of individuals for their respective roles and part of the pattern; in physical artifacts, such as tools, special arrangements, written codes of standard operating procedures, organizational structure, formal practices or computer systems; in locally and globally shared language forms such as shared meanings, formalized oral codes or 'war stories' (Cohen et al., 1996; Weick, 1979; Argote and Darr, 2000). Therefore, a change in the routines as one of the representations of organizational knowledge is corresponds to a change in the organizational knowledge. Students of organizational knowledge envision the firm as a system of knowing activity (Blackler, 1993; Grant, 1996).

Routines by definition refer to the recurring patterns of activities, which have been learned by an organization (Cohen et al., 1996). To change the organizational knowledge, organizations learn and the routines are the retention mechanisms in learning on organizational level (Weick and Quinn, 1999). The retentive capacity of the firm (Szulanski, 1996, 2000) influences the acquisition of new knowledge. The concept of retentive capacity is related to the under-researched notion of 'unlearning' (Bettis and Prahalad, 1995; Nystrom and Starbuck, 1984). Action patterns persist and old action patterns can impede the embedding of new knowledge in the organization. Understanding how organizational learning can be impeded on different levels allows better management of the processes of organizational learning (Edmonson, 2001).

The new attention to the group level of analysis of cognitive processes of organization enlarges the understanding of the ways organizations learn and organizational knowledge changes or resists change (Brown and Duguid, 1991; Gibson, 2001; Edmonson, 2001). Learning occurs in communities of practice and routines are embedded in them (Brown and Duguid, 1991; Galunic and Rodan, 1996; Cohen et al., 1996). Cognitive processes on group level differ from individual cognitive processes (Gibson, 2000). Therefore, researchers in social cognition explore the phenomenon of 'transactive memory' (Moreland et al., 1996; Moreland, 2000), which relates to the distributed nature of organizational knowledge embedded in routines.

The discussion of the relation between organizational knowledge and routines makes possible the addition of the theoretical and empirical contributions on organizational knowledge and on organizational learning to the investigation of modularity and innovation.

Scholars of routines advance research and theorizing on routines in two competing and diverging streams. Evolutionary scholars, who believe in the stability of routines, define routines as the organizational level counterpart of individual skills (Cohen et al., 1996; Nelson and Winter, 1982; Winter, 2000, 2003). Nelson and Winter (1982) use the metaphors of individual skills, organizational memory, and organizational truce to define routines. Routines are multiactor patterns of behavior, which are neither stored in the mind of a single individual nor explicit and easy to articulate. They are stable and highly independent from the will of the individual, that is, independent of agency. Performative scholars conceptualize and study routines as the interaction of abstract ideas about routines in the minds of the individual performer of routine and the actual action of an individual performer of a routine at a specific moment (Feldman, 2000, 2003; Feldman and Pentland, 2003). Performative scholars argue that both the ostensive and the performative parts are influenced by agency and are therefore mutable and flexible. Thus, in a learning setting, routines may store knowledge and act as a stable knowledge repository as the evolutionary scholars predict or they may be too unstable to allow for learning to take place as the performative scholars attempt to demonstrate. It is clear that the debate cannot be solved without adopting a common understanding of routines as a starting point. The debates between the evolutionary and the performative scholars seem to blur our understanding of what routines are and how they function on individual and organizational level.

Learning and absorptive capacity

Theorizing on interorganizational learning emphasizes the importance of absorptive capacity (Ingram, 2002). Still absorptive capacity relates to the knowledge boundaries of the firm and the knowledge modularity of the firm. Theorizing on modularity has not considered the implications of modular knowledge and organizational structures for the development and deployment of absorptive capacity.

Cohen and Levinthal (1989, 1990) introduce the term absorptive capacity to label the capabilities of the firm to innovate and, thus, to be dynamic. The absorptive capacity consists of the capabilities to recognize the value of new knowledge, to assimilate it, and to apply it to commercial ends. It depends on the knowledge source and prior knowledge, it is conditioned on the appropriability regimes, and it influences the innovative performance of the firm. I suggest a summary of Cohen and Levinthal's theorizing on the components, antecedents, contingencies, and outcomes of absorptive capacity in figure 2.

Zahra and George (2002) review the literature on knowledge absorption and conceptualize absorptive capacity as a dynamic capability. This conceptualization, they argue, enables them to provide a new model of the components, antecedents, contingencies, and outcomes of absorptive capacity (see Figure 3). Comparing the new model in figure 3 with the original model in figure 2, I can distinguish what Zahra and George (2002) accomplished. The scholars substitute the component recognizing the value with acquisition and relocate the influence of the contingency variable appropriability regimes. They add the concepts of transformation, activation triggers and social integration mechanisms. They split absorptive capacity into potential absorptive capacity and realized absorptive capacity.

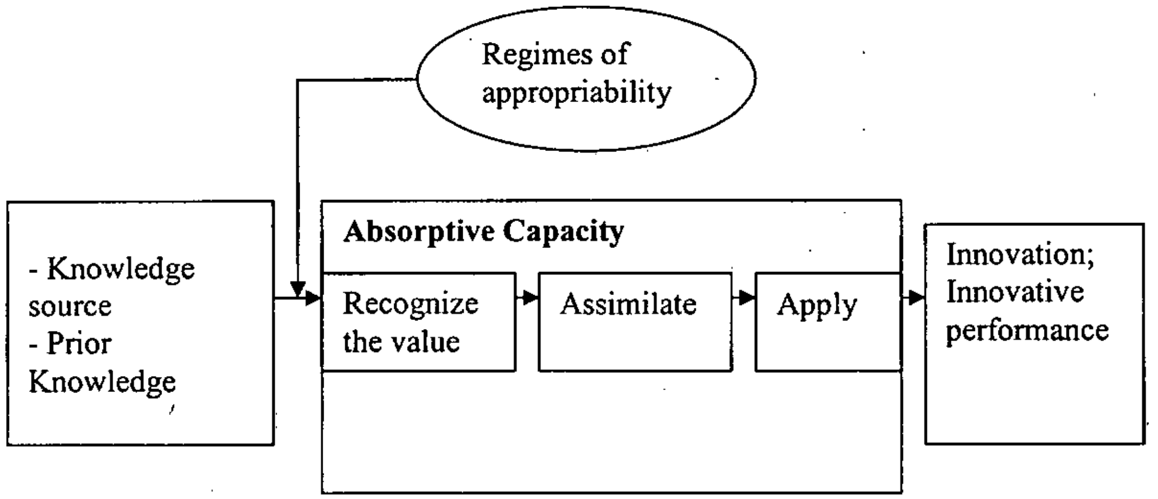

Figure 2: Cohen and Levinthal (1990): model of absorptive capacity

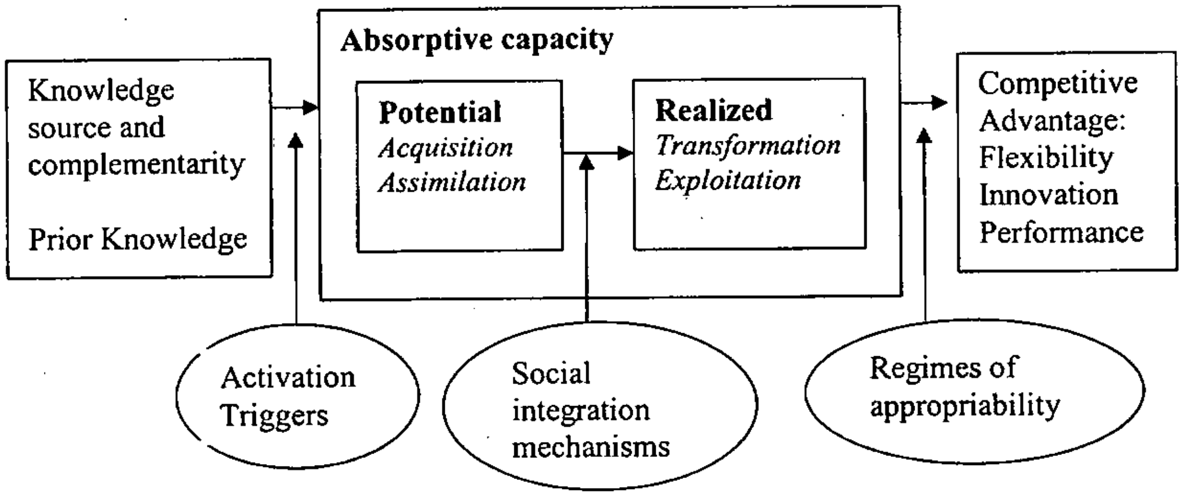

Figure 3: Zahra and George (2002) The new model of absorptive capacity

To understand external product modularity and knowledge modularity I use the theories on absorptive capacity and interorganizational learning. Zahra and George's model is clearly rooted in Cohen and Levinthal's contribution even though they refer to it only three times and label it merely as "the most widely cited definitions of ACAP [absorptive capacity]" (Zahra and George, 2002: 186). Zahra and George build systematically on Cohen and Levinthal's original contribution. Still absorptive capacity relates to the knowledge boundaries of the firm and the knowledge modularity of the firm. Theorizing on modularity has not considered the implications of modular knowledge and organizational structures for the development and deployment of absorptive capacity.

THEORETICAL BACKGROUND: INNOVATION THEORIES AND RESEARCH

Innovation and the dynamics of the environment

The capability to be flexible is critical for the firm in order to sustain its competitive advantage in the current dramatically shifting competitive environment (Nelson and Winter, 1982; Grant, 1996; Teece et al. 1997; Henderson and Clark, 1990). Therefore, the most recent work on the resource based view of the firm has focused on the connection between innovation and market dynamics (Iansiti and Clark, 1994; Eisenhardt and Martin, 2000, Helfat and Raubitschek, 2000). To study why some firms can sustain competitive advantage in situation of rapid and unpredictable change, discussions on the model of the change, that is how rapid and unpredictable the market dynamics is, and about the interaction between the change of environment and the knowledge base of the firm become part of each contribution of the stream.

Effective patterns of innovation management vary depending on the market dynamism (Eisenhardt and Martin, 2000). Three models of innovation have been discussed in the resource based research, which have been based on ideas and evidence from organizational development and other related or unrelated theories. The models of continuous change and of punctuated equilibrium have been in the foreground of academic interest. The third model of the innovation based on the mechanisms of complex systems will not be used in this paper, because it denies the possibility of any control of the system. What happens with the capabilities during the creative phase of chaos is unpredictable and they are left to themselves (Stacey, 1995).

Many firms compete by changing continuously and the ability to change continuously is a critical factor for the success of the firm (Brown and Eisenhardt, 1997).

Firms have to capture continuously shifting opportunities by constantly altering their capabilities (D'Aveni, 1994, Eisenhardt and Tabrizi, 1995; Galunic and Eisenhardt, 1996, Burgelman 1994, Chakravarthy, 1982). Dynamic firms limit their routines to the minimum (without eliminating them which leads to chaos), experiment with products and look in the future (Eisenhardt and Brown, 1997). The changes through multiple product innovation are frequent and small, based on the existing competencies of the firm. So they are typical incremental changes. Through innovating routines, firms anticipate the dangers of creative destruction and co-evolve smoothly with the environment. Moreover, there is no need to change radically and match organizational practices to the opportunities of a radical technological innovation of a competitor. No need for risky and episodic change comes from the market to challenge the forecasts of the futurist, the limited routines and the experimented prototypes, built through existing competencies.

In the model of punctuated equilibrium, there are long periods of stability and short bursts of radical change that fundamentally alter the industry (Tushman and Rosenkopf, 1992; Gersick, 1994). During the period of stability firms are constrained to incremental changes by their deep structures. During a revolutionary change the deep structure must be dismantled leaving the system first in disorder. The relationship between the two modes is explained by the construct of highly durable underlying structures, the "deep structures" (Gersick, 1994). These structures consist of patterns of activities, so the construct implicitly relates to the routines and capabilities of the firm. An external change can lead to a need of change of the deep structure and, thus, to a revolutionary change, but it cannot cause it. A failure of the deep structure can cause the revolutionary change of the firm. So a failure of the capabilities of the firm is directly connected to the idea of radical change. This combination of the two models of change resembles the model of Nelson and Winter (1982) about evolution through the mechanisms of rule-guided evolution and the mechanisms of search. The firm possesses routines and rules, maybe dynamic capabilities, which guide it to change successfully together with the environment. By failure of current routines and rules, a search for new routines is initiated. The empiric evidence of the technological discontinuities provides evidence of the presence of both periods of continuous change and the bursts of revolutionary change (Tushman and Anderson, 1986, Henderson and Clark 1990, Christensen and Bower, 1996).

The way in which a firm responds to a change in the market depends on the type of change and on influence of change on the capabilities of the firm. The important point is whether the change leads to an enhancing of the present capabilities of the firm or destroys the present capabilities. Researchers investigate the link between the type of change of environment and its influence on the capabilities of the firm. Technological change has been considered to be the 'natural laboratory' for studying the change of the firm (Helfat, 2000). The assumption that technology is the central force shaping the environmental conditions does not deny the existence of other factors which account for the dynamics of the markets and firms at present.

The relationship between environmental change, triggered by technological innovation of competitors or discontinuous changes in customer, and change in organizational capabilities introduced by Tushman and Anderson (1986) represents the basis for the discussion of the effects of sustaining versus discontinuous change on organizations. According to Tushman and Anderson (1986) environmental change can be competence-destroying and competence-enhancing. Competence destroying change breaks the rules and is associated with discontinuous and radical change of the environment. The new technology or customer preferences fundamentally alter the set of relevant competencies. They disrupt the industry structure and seem to break the basis of the dominating position of the established firms (Tidd et al., 2001; Christensen and Bower, 1996; Tushman and Anderson, 1986; Mensh, 1979) Continuous change, on the contrary, is ensured through competence-enhancing discontinuities, which build on existing skills and knowledge and, thus, are incremental (Brown and Eisenhardt, 1997; D'Aveni, 1994, Eisenhardt and Tabrizi, 1995; Galunic and Eisenhardt, 1996, Burgelman 1994, Chakravarthy, 1997). While radical innovation is clearly competence destroying and incremental innovation builds on the existing competencies, architectural innovation can be both competence-enhancing and competence-destroying (Henderson and Clark, 1990). It links the established components in a new way. The failure of leading firms by this type of innovation results from the embeddedness of architectural knowledge in structure and information processing procedures.

Tushman and Anderson (1986) emphasize that the effects of non-technological discontinuities must also be examined to understand more profoundly how firms and markets change. However, the focus on technology allows a more direct insight on the links between capabilities and change and a focused accumulation of empirical evidence and theoretical insights. New product and process development is the most visible arena where the need for innovation challenges the current capabilities of the firm (Leonard-Barton, 1992). In fact, Christensen and Bower (1996) define technology as "the processes by which an organization transforms labor, capital, material, and information, into products and services". Hence, technology is the organizational processes of the firm, that is its capabilities, and a change in technology requires directly and obviously a change in processes.

I consider the relationship between change in technology and change in organizational capabilities introduced by Tushman and Anderson (1986) to be a fundamental insight on the change of firm's capabilities and basic by discussing the rigidity of firm's routines. According to them change can be reasoned in terms of competence-destroying and competence-enhancing change of technology and, therefore, of environment. Competence destroying change is associated with radical episodic change of the environment. The new technology fundamentally alters the set of relevant competencies. They disrupt the industry structure and seem to break the basis of the dominating position of the established firms (Mensh, 1979; Tushman and Anderson, 1986) Continuous change, on the contrary, is ensured through competence-enhancing discontinuities, which build on existing skills and knowledge and, thus, are incremental. While radical innovation is clearly competence destroying and incremental innovation builds on the existing competencies, architectural innovation can be both competence-enhancing and competence-destroying (Henderson and Clark, 1990). It links the established components in a new way. The failure of leading firms by this type of innovation results from the embeddedness of architectural knowledge in structure and information processing procedures. The changes in architectural knowledge are difficult to be recognized by the firms and hard to be corrected. Firms fail, because they are constrained by prior capabilities.

Attempts at explaining the failure of leading firms to change in more detail have been the study of Tripsas and Gavetti (2000) on the problems of changing managerial cognition and the study of Christensen and Bower (1997) on handicapping resource dependence on customers and failure of leading firms. While the first study simply complemented the insights on the difficulty to change old routine, the second study seemed to have convincingly falsified the hypothesis that firms fail by radical or architectural change because their competencies become obsolete. However, a peripheral observation and an unexplainable by-result of the study of Christensen and Bower (1997) seem to only confirm the link between failure of firms and the rigidity of routines by the radical and architectural change. The study found that the leading firms had the capabilities to do the radical innovation, because there were individuals inside them who proposed a prototype of the revolutionary product. These prototypes were not accepted because of the resource allocation processes in the organization. Firstly, resource allocation processes are in themselves capability. Secondly, the authors rightly observe that there was a conflict between the individual competencies, which were enough for the radical innovation, on the one hand, and the organizational processes and capabilities, on the other. Therefore, the leading firm's old routines stopped the change. In addition, Christensen and Bower (1996) found that leading firms succeeded to be radically innovative only when they separated the unit with the radical innovating product from the mainstream organization. An explanation could be that in the new independent unit the old capabilities did not hinder the innovative processes. Their explanation that the mainstream organization lost their present customers, because their incremental innovations suffers by allocating the resources to revolutionary products, is another possible explanation. However, the reasons for and the sign of the difference in the amount of investment for the spin off and the investment for internal development shall be explored.

In a review of research on organizational change and development Weick (1999) contrasts radical and continuous change and the ideal organizations for each type of change. He concludes that conceptualization of inertia underlies the choice to consider a change as episodic or continuous. According to this review both change starts because of failure to adapt and change never starts because it never stops. Therefore, dynamic capabilities have to function both to enable the firm to sustain it performance in moments of radical change, when inertia counteracts adaptation, and to allow a firm to change continuously and incrementally. Recent work on organizational change suggests, however, that to understand organizational change is to understand organizational inertia (Gersick, 1991; Goia, 1992; Tushman and Rosenkopf, 1992; Pfeiffer, 1997). Therefore, to understand the change of capabilities I have to focus on the rigidity of capabilities. The evolution of the firm occurs through three mechanisms: rule guided adaptation, search and selection (Nelson and Winter, 1982). In the search of new routines, good routines can be found. However, building new capabilities does not necessarily mean that they will replace the old and rigid ones. So the firms fail and they are selected by the environment based both on their ability to 'find' new capabilities and to deal with rigidity.

Helfat (2000) uses the model of the evolutionary theory to analyze the adaptation versus rigidity in firm's behaviour with the underlying assumption that they both result from firm's routines. She reasons on the factors which influence the extend of change in an activity in terms of the rule-guided, the search and the selection effects of the evolutionary theory. However, the search mechanism, which is essential by competence-destroying change, is not explored with respect to the removing of the existing routines, but only with regard to finding viable new routines. Rigidity of decision rules is mentioned to stem from uncertainty and time-consumption of the search without further elaboration. Therefore, the contributions on rigidity versus adaptation of firm's behaviour can be complemented by trying to reason why the removing of existing routines is so difficult.

Mismatch between firm's behavior and environmental dynamics

Strategic management researchers challenge the basic assumption of population ecology that only the initial conditions determine firm's capabilities and that firm's performance depends exclusively on the selective forces of the environment (Hannan and Freeman, 1989). The results of Cockburn, Henderson and Stern (2000) show that both the starting conditions and the responses of firms affect the rate of adoption of technology and, thus, their change and performance. The resource-based researchers do not fail to consider the constraining influence of the 'starting conditions' and history on firm's behaviour and introduce the notion of 'path dependence' of firm's capabilities (Brown and Einsenhardt, 1997; Teece and al. 1997). The recognition that the repertoire of firm's routines constrains its future behavior is closely linked to the empirically observed phenomenon of incumbent inertia (Leonard-Barton, 1992; Teece et al. 1997; Tushman and Anderson, 1986). The idea of innovation through creative destruction (Schumpeter, 1942) suggests a possible approach to the problems of incumbent's inertia. Untangling the origins of the rigidity could provide the insights of how this creative destruction functions. So far several empiric studies address the issue trying to detect what in capabilities does not change and how it stops change (Tripsas and Gavetti, 2000; Klepper and Simon, 2000). Leonard-Barton (1992) found that some dimensions of capabilities are difficult to change and, thus, decrease the overall ease of change. The value dimension of capabilities changes very slowly because it is closely bound to culture and culture changes slowly over time. Managerial cognition and satisficing in learning can also stop change (Tripsas and Gavetti, 2000; Winter, 2000). The investigation of the sources of rigidity can benefit from using as a starting point the logic of the change process by radical change and the insights on the intrinsic characteristics of capabilities.

Capabilities are the organizational processes that make firm's skills and resources work together (Dietrix and Cool, 1989; Amit and Shoemaker, 1993; Prahalad and Hamel 1990; Grant, 1991, 1996). Firm's capabilities as repetitive patterns of behavior are the firm's routines (Nelson and Winter, 1982; Grant, 1991). Though several authors discuss the tacitness, complexity, link to the knowledge base of the firm and other characteristics of the firm's routines(Kogut and Zander, 1992; Grant, 1991, 1996), the original analogy of Nelson and Winter (1982) between firm's capabilities and individual skills provides a clear lens to uncover the two major particularities of firm's routines that make them hard to correct. I maintain that firm's routines resist change because they are largely tacit and because reside in informal networks.

Failure to innovate

Current competitive battles take place not on the level of positions of product and processes, but on the higher level of the ability of a firm to change its products and processes to match a highly dynamic environment, to innovate (Collis, 1994; Teece et al., 1997; Brown and Eisenhardt, 1997; Langlois, 2003). Thus, the innovative behavior of the firm becomes a key issue of research. In this section, I discuss the concept of innovation, which has been so far more or less broadly defined, the interest in failure to innovate and my choice of focus on large mature firms. Then, I review the literature on failure to innovate by large firms based on a classification of innovative behaviors in two groups: problems in behaviors related to the possibility as a first component of innovation and in behaviors related to reflection and change of action as the second component of innovation.

The *innovation* literature considers the processes of creation, development and implementation of new ideas or behaviors such as new products and processes (Damanpour, 1991; Brown and Eisenhardtt, 1995; Daneels, 2002). Hit, Hoskinsson and Nixon (1993) make a clear distinction between innovation and invention and, thus, exclude the process of creation of ideas, namely invention, from the domain of innovation. This distinction is made clear by Freeman (1982, pp. 7) when he noted that: "an *invention* is an idea, a sketch or model for a new or improved device, product, process or system" whereas "an *innovation* in the economic sense is accomplished only with the first *commercial* transaction involving the new product, process, system or device…". In contrast, Kanter (1988, pp. 170) defines innovation as the "creation and exploitation of new ideas" and Van den Ven (1986) includes in the notion of innovation both the development and implementation of new ideas. A further approach to the concept of innovation relates it to the potential of generating and exploitation a new action embedded in the organizational knowledge, termed 'possibility', while the modification of the actions and knowledge of organization that are required to implement an innovation are distinguished as learning, termed as 'action' (Hargadon and Fanelli, 2002). This knowledge-based perspective recognizes the dynamics of the process of innovation and develops the idea of a dynamic reciprocal relationship between generation of novel action through generation, encoding of the novel actions in existing routines through learning, and the influence of adopted actions on the possibility for future action. The 'potential' reflects the latent knowledge in individuals from the organization, while 'the action' expresses the empirical knowledge of the organization, held in physical and social artifacts. The process of improving the organizational action because of better knowledge and understanding has been also defined as organizational learning (Fiol and Huff, 1992; Miner and Mezias, 1996). Learning entails an iterative process of action and reflection (Edmondson, 2002). Argote and Orphir (2002) argue that organization learn when its actions are modified as a result of the experience that foster reflection on new knowledge or insight. Thus, change in action results from behaviors that foster new insights.

To clarify the origins of failure of new products or processes, I use the discussion on invention, innovation and learning to adopt a modified definition of innovation. Since the interrelated processes of creation of new ideas and their development and implementation through learning determine the results of the innovative efforts of the firm, I suggest a notion of innovation, which consists of three concepts: 'potential', defined as the latent knowledge, represented by the individually held schemata, 'reflection', which includes the behaviors that involve the creation of novel ideas, based on the latent knowledge and empirical knowledge (Edmondson, 2002) and 'action', which refers to the behaviors that promote the test or implementation of a new idea (Hargadon and Fanelli, 2002). Low performing new products or processes may result from failure in any of the three components of innovation.

The interest in organizational *failure* proliferates first within the research stream of organizational ecology (Hannan and Freeman, 1989). Evolutionary inquiry studies the selection processes of organization in order to investigate how the pace and path of strategic change influence the results of competitive battles in terms of survival (Barnett and Burgelman, 1996). Studies on failure report findings that support the assumption of evolutionary scholars of lack of historical efficiency (Caroll et al., 1996; Ingram, 1996; Singh and Mitchell, 1996; Makadok and Walker, 1996). For example, selection among retail banks did not depend on the choice of strategy and structure, but on the historical path of competition (Barnett and Hansen, 1996). Scholars that are interested in failure of organization to innovate add evidence about why efforts to create the 'ideal organization' following the predictions about successful innovative behavior may fail (Dougherty and Hardy, 1996). To avoid a sample-selection bias, scholars of failure to innovate investigate both the best and the failures (Henderson and Clark, 1990; Dougherty and Heller, 1994; Cockburn et al., 2000; Tripsas and Gavetti, 2000; Langlois and Steinmueller, 2000).

Failure to innovate has been studied both with regard to *established large firms* and new firms (Henderson, 1999). The research on the question on whether large or new firms are more likely to win the innovative battles provides mixed evidence (Tripsas, 2002). I focus on the failure of large firms for three main reasons. First, failure to innovate seems to be one of the main factors to endanger the survival of large firms. Liability of obsolescence arguments suggest that firms are largely inertial and tend to become increasingly misaligned with environment (Brudel and Shussel, 1990; Fichman and Levinthal, 1991). Scholars explore the firm-level contingencies which explain why some firms exhibit liability of obsolescence while other old organizations tend to be favored by the selection processes (Baum, 1996; Ranger-Moore, 1997; Henderson, 1999;... article). Second, a very large proportion of the R&D resources continue to be expended by established large corporations (Ahuja and Lampert, 2001). Therefore, managing the constraints on innovative efforts in large companies can potentially lead to increase in the value, created by innovative efforts. Third, recent research in the stream of innovation and technology management on failure of incumbents seem to stick into investigating causal factors which seem to have the same common cause: problems with the change of action patterns. The evidence suggests that large firms are hampered by their initial capabilities (Helfat, 2000).). If capabilities are defined as ensemble of routines (e.g., Cohen et al., 1996) and organizational knowledge is expressed in the regularities by which members cooperate (Kogut and Zander, 1992), then the question is how the routines resist change and stop organizational learning.

Problems to innovate in mature firms with routine operations have generated considerable interest as early as Burns and Stalker (1961) and Kanter (1983). Existing practices are considered inert (Hannan and Freeman, 1984), rigid (Leonard-Barton, 1992), even "hostile" (Burgelman, 1983; Dougherty, 1990; Meyer, 1982). Recent empirical studies collaborate this phenomenon and show that firms continue to use their information processing assets and their routines in the face of radical change, because they do not notice that they are obsolete, because it is more costly to develop new assets, and/or because organizational change is difficult to execute (Henderson, 1993;

Henderson and Clark, 1990; Tushman et al., 1997). Established firms need to link their activities of product innovation to the existing institutionalized practices and power structures. Dougherty and Heller (1994) identify and analyze types of illegitimacy, because of lack of fit between product innovation activities and taken for granted activities in established firms. Furthermore, innovators may lack the power to make the connection between existing organizational practices and new practices and fail to gain access to the organizational resources, collaborative structures and processes, and strategic support (Dougherty and Hardy, 1996; Noda and Bower, 1996).

The organizational explanations which Hill and Rothaermel (2003) summarize the state-of- the-art sources of inflexibility of incumbents seem all to be related to problems of changing the current action patterns. It becomes even clearer if I group as (1) inertia of current action patterns as structures of formalized bureaucracies and of current competence-based knowledge structures embodied in routine activities, (2) stability of the current action patterns as a distribution of power, and (3) stability of current action patterns from the institutionalization of current practices. Thus, these factors predict problems in innovation efforts of large mature firms in the cases in which the current action patterns have to be modified and all of them point to the role of routines as more or less formal structures of knowledge, institutionalized activities, and power.

A review of the literature on failure to innovate in large firms groups the studies in three categories, based on the definition of innovation as 'potential', 'reflection' and 'action' (see Table 1). I observe that there are a lower number of studies in the area of 'action' than in the areas of "reflection" and "potential". At the same time the reflection seems to be investigated mainly with regard to managers and less with regard to the cognitive processes of individuals and groups of individuals within the firm. The implementation of modular strategies is one of the main possibilities for 'action'. Thus research on modularity fills a gap in the research on innovation.

Innovation phase	Author	*Findings*
Reflection	**Tripsas and Gavetti, 2000**	**managerial cognitive representations and product innovation evolution of capabilities and organizational inertia**
Reflection and Action	**Henderson and Clark, 1990**	**architectural innovation**
Reflection	**Garud and Rappa, 1994**	**management cognition and intertia**
Reflection	**Barr, Stimpert, and Huff, 1992**	**management cognition and inertia**
Reflection	**Brown and Eisenhardt, 1998**	**management cognition and inertia**
Reflection	**Zyglidopoulus, 1999**	**management cognition and inertia**
Reflection	**Gavetti and Levinthal, 2000**	**management cognition and inertia**
Reflection	**Christensen and Bower, 1996**	**disruptive technology: new niche and new customers**
Reflection	**Christensen and Overdorf, 2000**	**disruptive technology and customer orientation**
Reflection	**Christensen and Rosenbloom, 1995**	**new niches and new customers; co-opetitors' capabilities: value networks**
Reflection and Action	**Gilbert and Bower, 2002**	**strategic process and resource allocation**
Reflection and Action	**Dougherty, 1994**	**dissonance with the established system of institutions**
Reflection	**Dougherty and Hardy, 1996**	**political configurations and resource allocation**

Reflection	**Noda and Collis, 2001**	**top management commitment**
Reflection	**Noda and Bower, 1996**	**top management commitment**
Reflection	**Sorensen and Stuart, 2000**	**embeddedness and innovation**
Reflection	**Hoskisson, Hitt, and Hill, 1993**	**managerial incentives and innovation**
Potential	**Singh, 1986**	**resource allocation and innovation success**
Potential	**Tripsas, 1997**	**complementary assets**
Potential	**Dosi, 1982**	**Firms develop technologies which use there existing complementary assets**
Potential	**Mitchell, 1989**	**complementary assets**
Potential	**Teece, 1986**	**complementary assets**
Potential	**Helfat, 2000**	
Potential	**Afua and Bahram, 1995**	**Innovation destroys co-opetitors capabilities**
Potential	**Kanter, 1988**	**Innovation, creativity and resources**
Potential	**Hlavacek and Thompson, 1973**	**structures and strategy hostile to creativity**
Potential	**Dougherty, 1990**	**organizational structure and product innovation**
Potential and reflection	**Burgelman, 1983**	**product innovation and strategic processes**
Potential and Action	**Dougherty, 1992**	**thought worlds' of departments: reflection of organizational members**
Potential	**Leonard-Barton, 1992**	**Old capabilities act as rigidities**
Potential and reflection	**Ahuja and Lampert, 2001**	**learning traps**
Action	**Tushman and Anderson, 1986**	**Management of a competence destroying technology**

Action	Teece and Pisano, 1994	Dynamic capabilities as solution to the innovation problems
Action	Sanchez and Mahoney, 1996	Modularity as solution to The innovation problems
Action	Tushman et al. 1997	Ambidextrous organization as a solution to the innovation problems

Table 1: Components of innovation: Review of literature on innovation and failure to innovate (1980-2002)

Dynamic capabilities as a solution to the problems of innovation

Dynamic capabilities allow firms to change (Teece et al., 1997, Pisano 1994, Grant, 1996, Henderson and Cockburn, 1994, Eisenhardt and Martin 2000). They enable firms to build new products and new capabilities. Teece, Pisano and Shuen (1997) provided the concept of dynamic capabilities and stressed the importance of further theoretical and empirical work to help understand "how firms get to be good, why and how they improve and why they sometimes decline". The evolutionary theory stream contributes to the understanding of how firms and their capabilities evolve and enlarges the insights on the dynamic capabilities of the firm (Winter and Nelson, 1982; Helfat and Raubitschek, 2000; Raff, 2000). The concept of dynamic capabilities as well as the resource-based view have been criticized for being vague, tautological and lacking empirical support (Williamson, 1999; Priem and Butler, 2000). Firms can and do change. So some kind of dynamic capabilities exist. But, what dynamic capabilities are and how exactly they function have to be further clarified. This becomes a fundamental question in the capabilities research streams.

Research on dynamic capabilities found that by continuous change dynamic capabilities are linked to semi-structures, links through time and sequenced steps (Brown and Eisenhardt, 1997) Continuous change builds on the existing competencies of the firm. By radical change or change of the architectural capabilities completely new knowledge is needed. Moreover, some of what the firm knows may be not useful any more and can actually handicap the firm (Henderson and Clark, 1990; Tushman and Anderson, 1986). Radical change is, thus, competence destroying. Established firms have been found to have serious problems in adapting their capabilities and to fail by radical change. (Cockburn et al. 2000, Tripsas and Gavetti 2000, Langlois and Steinmueller 2000). The empirical evidence suggests that they are hampered by their initial capabilities, accumulated knowledge based and path dependent cognition (Helfat, 2000). Prior competencies and history endanger the adaptability of established firms by radical change and the term "creative destruction" was imported to define how dynamic capabilities function in this case (Pavitt, 2002). The tension between adaptability and rigidity of routines challenges the researchers (Lewin,1951, O'Toole, 1995,.Weick, 1999, Helfat 2000). An empirical study on new product development projects by Leonard-Barton (1992) explicitly dealt with the creative and destructive effects of capabilities. However, the contributions on the difficulty of change of capabilities are limited (Helfat, 2000). Moreover, this research uses the continuous change model (Galunic and Eisenhardt, 1996; Brown and Eisenhardt, 1997; Helfat and Raubitschek, 2000). The substantial empirical evidence on the failures of established firms to change capabilities by competence destroying change provides an incentive to investigate the problem. It is important to know not only how capabilities emerge, evolve and change, but also how capabilities do not change and in this way stop change. The surviving of established firms by radical change has been explored so far only with regard to the elements of dynamic capabilities connected with the capability to build new competencies through integrative capacity and geographical distribution of R&D centres (Iansiti and Clark, 1994; Tripsas, 1997).

Designing ambidextrous organization as a solution to the innovation problems

The concept of ambidextrous organizations has been proposed to describe organizations which succeed both in incremental and radical innovation. However, the phenomenon of ambidextrous organizations has been understudied and the concept remains underdeveloped. There is little direct empirical evidence on whether ambidextrous organizations exist.

Theory on Ambidextrous organizations maintains that ambidextrous organizations innovate successfully both in case of evolutionary and revolutionary change (Tushman and O'Reilly, 1996). "The structure of ambidextrous organizations allows cross-fertilization among units while preventing cross-contamination (O'Reilly and Tushman, 2004: 78)". There are numerous examples of firms want to be ambidextrous, but fail in putting together in one organization the required contradictory organizational architectures for both types of change (e.g. Christensen, 1997; Cooper and Schendel, 1976; Henderson and Clark, 1990; Majumadar, 1982; Tushman and Anderson, 1986; Utterback, 1994). There is little direct evidence on how the structure and the culture of the ambidextrous organization can be kept separate to prevent cross contamination and integrated to allow cross fertilization at the same time.

Prior theorizing on ambidextrous organizations has focused on the integrating role of managers and has assumed that managers can recognize the type of innovation and its implications for the organizational processes and structures (O'Reilly and Tushman, 2004; Tushman et al., 1997). However, the uncertainty inherent in innovation can hinder the efforts of managers to differentiate between types of innovation and their effect on organizational architectrures a priori (Knight, 1921; Lane and Maxfield, 2005). Prior theorizing on ambidextrous organizations has focused on organizations where the explorative and exploitative units can be completely separated and has assumed that in all product markets and industries the exploitative projects will not influence the explorative projects (Gilbert and Bower, 2002; O'Reilly and Tushman, 2004).

In the broader picture of research on innovation and organization, I observe the troubling lack of empirical evidence on the organizational aspects of doing simultaneously successful incremental and radical innovation. Researchers often investigate incremental and radical innovation in separate research programs. Researchers on innovation have investigated the structure and culture of organizations which excel in incremental change (Burgelman, 1994; Galunic and Eisenhardt, 1996; Chakravarthy, 1982; Brown and Eisenhardt, 1997; Helfat and Raubitschek, 2000) and of organizations which outperform competitors in radical change (Christensen and Overdorf, 2000; Cockburn et al., 2000; Tripsas and Gavetti, 2000; Langlois and Steinmueller, 2000). Incremental change occurs in centralized structures with highly standardized processes (Utterback and Abernathy, 1975). Semi-structures, sequential steps through experimentation and links in time encourage continuous incremental change in high-velocity markets (Brown and Eisenhardt, 1997). Radical innovation must be performed in a separate unit, which is not burdened by the path dependencies of old structures and ways of doing things, and must be later integrated to replace the obsolete traditional businesses (Christensen and Bower, 1996; Christensen and Overdorf, 2000; Gilbert and Bower, 2002).

Modularity as a solution to innovation problems

Studies of product innovation consistently point out to a high level of failure to progress from original idea to a successful product in the marketplace. Actual figures of failure rate range from 30% to as high as 95% (Crawford, 1990). By innovation, organizations are faced with a risky and uncertain process (Tidd et al., 2001). Theorizing and research on modularity suggest that modular designs of products, organizations, and knowledge platforms increase the flexibility of the firm (Sanchez and Mahoney, 1996; Shilling, 2000). Sanchez and Mahoney (1996) argue that modular designs can increase the rate of both incremental and architectural innovation efforts. I study modularity, because it may speed up learning and provide a solution to problems of matching organizational and market dynamics.

CONCEPTUAL BACKGROND AND RESEARCH HYPOTHESES

I develop a holistic model, which captures the antecedents, components, and strategic outcomes of modularity. The theoretical model is depicted in figure 1 (pp. 10). In the next subsections I first define the concepts of market dynamics, types of modularity, strategic flexibility and strategic intent. Then, drawing on theorizing and research on modularity, learning, and innovation, I build the research hypotheses.

Market Dynamics

I distinguish between three factors which can characterize the level of market dynamics: competitive intensity, customer uncertainty, and technological opportunities. In theorizing and research on modularity, there is no common agreement on which features of the market determine the adoption of modular designs. While Staudenmayer et al. (2005) emphasize the competitive dynamics, Tu et al. (2004) focus exclusively on customer uncertainty. In their study of modularity in the home appliance industry, Worren et al. (2001) define market dynamics as the speed of change of both customer preferences and competitors' products. I add the dimension of technological opportunities, in order to incorporate the key variable in the environment which determines the shifts between modular and integrated designs (Chesbrough and Kusunoki, 1999). Similarly, Schilling (2000) argues that speed of technological change must be considered as an antecedent of modularity and proposes that it increases the modularity of products. In our model I build on prior research and study simultaneously all three antecedents of modularity: customer uncertainty, competitive intensity, and technological opportunity. I test whether they represent the dimensions of a higher level concept of market dynamics, and investigate the relationships between the three antecedents and the level of adoption of modular strategies by firms.

Types of Modularity

In the General Theory on Modularity, Modularity is defined as "the degree to which a system's components can be separated and recombined" (Schilling, 2000). Modularity refers not only to the extent of coupling of components, but also to the existence of architectural rules, which define how components are combined in an overall system. Baldwin and Clark (2000) argue that modularity is "a structural means of achieving functional integration in complex systems". They discuss three features of modularity: (1) modules are distinct parts of a larger system, (2) modules are independent of one another, and (3) modules function as an integrated, seamless whole. In the definitions of each type of modular architectures I build on the corresponding definitions of this type of modularity in the literature and on the common definition of modularity, proposed by Baldwin and Clark (2000). In the discussion of each type of modularity, I define the concept based on Baldwin and Clark's three core features of modularity.

Internal and External Product Modularity

The increasing modularity of products in emerging high-technology industries leads to the emergence of the concept of modularity in management sciences (Langlois and Robertson, 1992; Sanchez, 1995; Ulrich, 1995). In the further extensions of the concept to cover also organizational and knowledge systems, the distinctive features of modular systems in general correspond to the distinctive features of modular products (Schilling, 2000). Designers in the computer industry partition products in logical blocks that can be developed separately and in a parallel way by different organizational units or by different organizations. Then, the same organization or another organization integrates the blocks into a system following predetermined rules of the design (Baldwin and Clark, 1997). Depending on whether all of these activities take place within the same organization (Worren et al, 2002) or whether they are distributed in a network of different organizations (Langlois and Robertson, 1992; Schilling, 2000), I distinguish between internal and external product modularity. The concept of interfirm modularity (Baldwin and Clark, 2000; Langlois and Robertson, 1992; Schilling, 2000; Stauden mayer et al., 2005) is synonymous in our understanding to external product modularity, because it refers to the settings where different firms are responsible for the designing and manufacturing of various subsystems of a product. I prefer to use the term external product modularity to emphasize the focus on the product level of analysis. The distinction between internal and external modularity in our model allows us to study the effect of market dynamics on different modular architectures and to disentangle the sources of strategic flexibility.

Organizational Modularity

The modularity scholars argue that modularization of products requires and enables new kinds of organizational structures and processes (Baldwin and Clark, 2000; Sanchez and Mahoney, 1996; Sanchez, 2004). Organizational structures and processes like physical products are decomposed in separate components which can be developed in a parallel way within specific parameters and which can be frequently reconfigured. Like in physical products the interfaces between the building components of the organization in terms of processes or units are specified by means of the overall design rules of the system. The architectural knowledge in the design rules specifies the parameters of the components and the interfaces and flows between them and allow the organization to function as an integrated whole (Sanchez and Mahoney, 1996). Worren et al. (2002) distinguish between modularity of organizational structure and organizational processes in their theorizing and empirical research. The standardized structure of modular product interfaces and components can provide the basis for the coordination and development of loosely coupled organizational structures (Sanchez and Mahoney, 1996). In modular organizational structures, small component development and manufacturing units can function autonomously and innovate concurrently under the coordination of the product architecture. Process modularity is based on process standardization, which allows processes to be added, removed, or rearranged to created different process configurations (Cooper, 1999; Feitzinger and Lee, 1997). I include both concepts in our model to replicate and advance Worren et al.'s (2002) investigation of the antecedents and consequences of the two different types of organizational modularity.

Knowledge Modularity

In the study of modular strategies the study of modular designs of the knowledge structures and coordination in organizations gains in importance (Brusoni and Prencipe, 2001; Sanchez and Mahoney, 1996). Managers can apply a modular design also to the knowledge structures of the organizations. However, knowledge modularity has not been explicitly defined in prior research. Modularity encompasses all "techniques for dividing effort and knowledge... [that] ... are fundamental to the creation of highly complex manmade things" (Baldwin and Clark, 2000: 5). Knowledge becomes decomposed into knowledge about the components which is then integrated into an overall knowledge system. The successful integration of knowledge components enables firms to remain competitive in dynamic markets (Grant, 1996). I can distinguish between internal and external knowledge modularity. The concept of internal knowledge modularity, however, cannot be meaningfully separated from the concept of organizational process modularity. Internally organizational knowledge resides in organizational routines and processes and internal organizational knowledge cannot be conceptually different from organizational processes (Dietrix and Cool, 1989; Amit and Shoemaker, 1993; Kogut and Zander, 1992; Winter, 2003). To avoid tautology and contamination, I incorporate in our model only the concept for external knowledge modularity. Firms deploy and use knowledge components from different sources like alliances, collaboration projects, and joint ventures with other organizations (Ingram, 2002; Zahra and Nielsen, 2002). Each of the knowledge components can be developed separately and in a parallel way and then integrated into a smoothly functioning knowledge system (Brusoni and Prencipe, 2001). Thus, our concept of knowledge modularity, has a theoretical meaning consistent with the three core features, which distinguish modular systems from integrated systems (Baldwin and Clark, 1997).

Types of Strategic Flexibility

Strategic flexibility denotes the ability of firm to develop multiple variants of products and to innovate in order to match the changes in the consumer tastes, competitor's moves, and technological opportunities (Sanchez, 1995, 1998, 2000; Worren et al., 2001). Strategic flexibility means the ability to do new things quickly (Shillling and Steensma, 2001). The concept is similar to the concepts of organizational flexibility (Volberda, 1996) and adaptive capacity (Astley and Brahm, 1989), but it differs in its narrower focus on strategic product variation and innovation. The strategic flexibility of the firm determines its performance. Cho and Pucik (2005) provide empirical evidence that flexibility in terms innovativeness increases profitability and growth. Sanchez and Mahoney (1996) distinguish between three types of strategic flexibility: strategic flexibility through multiple product variants, strategic flexibility through component innovation, and strategic flexibility through architectural innovation. Theorizing on modularity proposes there are different effects of modularity on the three different types of strategic flexibility. Yet only Worren et al. (2002) attempt to study the three types of strategic flexibility simultaneously. They show that only strategic flexibility in terms of number of product variants is predicted by internal modularity of products. In order to gauge differences in the effect of modular designs on flexibility, I incorporate all three types of strategic flexibility in our model.

Strategic Intent

Drawing on prior research on modularity, I included in our model the concept of entrepreneurial strategic intent (Worren et al., 2002). Companies with strategic plans to develop new technologies, to enter new markets, or to improve their product development processes are more likely to adopt modular designs. Moreover, companies with entrepreneurial strategic intent are more likely to be flexible through other strategies besides modular designs. I wanted to control for the variation between companies with different strategic intents in order to improve our power to detect effects of modularity on strategic flexibility. In addition, I wanted to embed in our research a replication of the study of Worren et al. (2002) and to investigate how companies choose modularity in planning their strategies (Sanchez and Heene, 1996).

Research Hypotheses

The impact of market dynamism on modularity management

Increasing technological complexity and heterogeneity of consumer demands drive firms to adopt modular designs in order to improve their flexibility and performance (Baldwin and Clark, 2000; Schilling, 2000; Tu et al., 2004). In the literature on modularity there is an extensive discussion on the relationship between market dynamics and modularity. Initially scholars develop theories on modularity of products from observations of the phenomenon in a set of specific industries. However, they argue that companies in all industries will benefit from using modular strategies if they are facing dynamic markets (Sanchez, 1995). Nadler and Tushman (1999) propose that modular organizational forms will enable firms to compete successfully in rapidly changing environments. Modularity of products, organizations and knowledge may help firms to match the dynamics of their markets.

High customer dynamics and competitive intensity makes it beneficial for firms to adopt modular strategies consistently across all the accumulated research findings (Langlois and Robertson, 1992; Worren et al., 2002; Schilling and Steensma, 2001; Tu et al. 2004). Conversely, several research contributions show that some aspects of the technological dynamics may actually counteract the drive to modular strategies in some situations (Chesbrough and Kusunoki, 1999; Ernst, 2005; Sorenson, 2003). Ernst (2005) provides evidence that in the fast moving environment of the semi-conductor industry, firms are reluctant to adopt a single modular architecture, because of the threat of disruptive technological architectures from their competitors. With a high dynamics of markets, the stabilization of interfaces and parameters may limit the ability of the firm to react the moves of the competitors. Indeed, firms which use modular architectures in markets with emerging technologies may fall in modularity traps. Chesbrough and Kusunoki (1999) argue that firms must switch between modularity and integration to answer shifts in the market dynamics from the settings of emerging technology to the settings of dominant designs and via versa in order to avoid modularity traps. In the context of emerging technologies the market dynamics is higher and the threat of emergence of a disruptive technology in a competitive firm is higher. In the settings with industry standards and low opportunities for disruptive technological change firms are more likely to adopt modularity (Shilling and Steensma, 2001). The concept of technological opportunities in our model captures specifically the aspects of market dynamics related to opportunities for major changes in the technology. Therefore, I expect that firms will adopt increasing modular strategies in markets with opportunities for technological breakthroughs and will reduce their modularity in markets with dominant design and opportunities for only minor technological changes. I expect that the three types of the market dynamics, customer uncertainty, competitive intensity, and technological opportunity, will represent the dimensions of one overall multidimensional concept of market dynamics.

Up till now the evidence on the impact of market dynamics on the different types of modularity comes from separate research projects. Tu et al. (2004) investigate the impact of market dynamics on organizational structure and organizational process modularity. In markets with consumer and technology uncertainty, the firms, which adopt modular manufacturing practices, are able to cope better with the increasing demands for individually customized products (Tu et al., 2004). Schilling and Steensma (2001) propose and test a model on antecedents and contingencies of external product modularity. They concluded that the market context in terms of consumer heterogeneity, competitive intensity, and speed of technological change increases the level of the external product modularity of a firm. In the study of modularity in the home appliance industry, Worren et al. (2001) provide evidence on the positive relationship between competitive and customer pressures and internal product modularity as well as modularity of organizational structures and processes. The impact of market dynamics on knowledge modularity has also been studied separately. To stay competitive in dynamic markets firms outsource not only components of their products, but also components of their knowledge (Quinn, 2000). Knowledge integration of the different internal and external knowledge components into a smoothly functioning knowledge system determines the success of the firm in developing new products in an innovation-based competition (Grant, 1996; Zahra and Nielsen, 2002). Market dynamics increases the efforts of the firm to use, develop, and integrate different knowledge components. Summarizing the fragments of research on market dynamics and type of modularity, I expect that market dynamics motivates firms to adopt internal product modularity, external product modularity, organizational process modularity, organizational structure modularity, and knowledge modularity. Therefore, I hypothesize:

> *Hypothesis 1a:* Firms in more dynamic markets are more likely to employ internal modularity of products.
>
> *Hypothesis 1b:* Firms in more dynamic markets are more likely to employ external modularity of products.

Hypothesis 1c and 1d: Firms in more dynamic markets are more likely to employ modularity of organizational structures and organizational processes.

Hypothesis 1e: Firms in more dynamic markets are more likely to employ modularity of knowledge.

The impact of Modularity types on Strategic Flexibility

The central argument of theories on modularity puts forward that modularity increases the flexibility of the firm (Sanchez and Mahoney, 1996; Schilling, 2000). Modular designs are likely to generate three types of advantages: high number of product variants, faster component innovation, and faster architectural innovation. The modularization of products, organizations, and knowledge enables a firm to create a high number of product variants and to achieve mass costumization through the recombination of the standard components (Langlois and Robertson, 1992; Sanchez, 1995, 2004; Tu et al., 2004). In a study of the home appliance industry Worren et al. (2002) show that modular product architectures increase product variety. They find that modularity of organizational structure and processes has no significant effect on product variety. In contrast, Tu et al. (2004) provide empirical evidence that companies with both modular products and organizations create a wider range of end products to meet specific customer needs and thus have higher mass customization capabilities. They argue that the modularity of organizational processes and structures is the necessary complement to modularity of product. Modularity based manufacturing practices, which influence the number of product variants, consist of a whole set of actions including processes and structure. In a study of modularity strategies Sanchez (2004) explores the mechanisms through which modular product architectures increase product variety and innovation. He concludes that modular products which are supported by modular process architectures achieve higher dynamic efficiency, because this strategic approach reduces further the complexity of the managerial task and gives the organization a greater flexibility to undertake a larger number or a greater variety of new product development projects. I expect that firms which implement modular designs of products, structures, processes, and knowledge, achieve higher flexibility in terms of a larger number of product variants.

Hypothesis 2a: Firms with higher internal modularity of products are likely to have higher number of products variants.

Hypothesis 2b: Firms with higher external modularity of products are likely to have higher number of product variants.

Hypothesis 2c and 2d: Firms with modularity of organizational structures (2c) or organizational processes (2d) are likely to have higher number of product variants.

Hypothesis 2e: Firms with higher modularity of knowledge are likely to have higher number of product variants.

Modular systems are important in increasing the flexibility of the firm, because they allow parallel innovation of components and thus increase the speed of component level innovation (Langlois and Robertson, 1992; Garud and Kumaraswamy, 1995). The disaggregation of large hierarchical organizations into loosely coupled production arrangements allows faster learning through parallel experimentation and creates real options (Baldwin and Clark, 1997; Schilling, 2000). Because the interfaces between product components in a modular system are fully specified, the modularization of products allows innovation of components to be carried out concurrently and autonomously by different teams in the organization (Sanchez and Mahoney, 1996). Not only internal product modularity, but also external product modularity influences innovation. Outsourcing innovations allows companies to lower innovation costs and risks while increasing the pace of innovation (Quinn, 2000). Thus, external product modularity will increase the speed of innovation.

In order to create faster superior modules, managers must redesign their organizations too. Managers can speed up the innovation in the design of the individual modules by splitting the work among small autonomous organizational units, each responsible for a different component (Baldwin and Clark, 1997). In modular organizational structures, managers reorganize teams more rapidly and link them to the necessary tasks in response to changes in the market. Galunic and Eisenhardt (2001) investigate modular organizational structures and conceptualize "dynamic communities" as modules of organizational units, which have distinctive resources, responsibilities, and capabilities, and which can be easily reconfigured to adapt to changing environment. Standardization, codification, and partitioning of processes and knowledge allow more rapid leveraging of resources inside the organization and across the organizational boundaries (Zander and Kogut, 1995; Zahra and Nielsen, 2001). Processes and knowledge can be transferred more easily and can be applied to a wider range of tasks. Thus, modularity of organizational processes and knowledge increases the flexibility of the firm. While firms develop knowledge about some specialized components of the modular product, they can use the modular architecture to source knowledge through networks of firms (Sanchez and Mahoney, 1996). Firms which integrate knowledge from different external and internal sources increase the speed of commercialization of new technologies (Zahra and Nielson, 2002). Brusoni and Prencipe (2001) argue that the increase in innovation through knowledge and organizational modularity may not be the automatic result of product modularity and may require the development of specific capabilities for managing knowledge and organizational modularity. Firms may fail at component innovation if they increase knowledge modularity and fail to retain technological knowledge about some outsourced components (Gambardella and Torrisi, 1998; Prencipe, 1997). Organizations must maintain or have access to technological capabilities related to the outsourced components in order to deal with the imbalances of the uneven rates of change in component techniques. Thus, I expect that knowledge modularity will influence the innovation of components, but I cannot predict the direction of the effect of knowledge modularity on speed of innovation of components based on the conflicting evidence in prior research. I expect that the successful implementation of the other types of modularity, i.e. product modularity, organizational modularity, and knowledge modularity, is likely to increase the flexibility of the firm in terms of speed of component innovation. I hypothesize that:

Hypothesis 3a: Firms with higher internal modularity of products are likely to have higher Speed of Innovation of Components.

Hypothesis 3b: Firms with higher external modularity of products are likely to have higher speed of innovation of components.

Hypothesis 3c: Firms with higher modularity of organizational structure are likely to have higher Speed of Innovation of components.

Hypothesis 3d: Firms with higher modularity of organizational processes are likely to have higher Speed of Innovation of components.

Hypothesis 3e: Modularity of knowledge is likely influence the Speed of Innovation of components.

Modular designs influence the innovation on the system level, i.e. the architectural innovation (Henderson and Clark, 1990; Sanchez and Mahoney, 1996). Sanchez and Mahoney (1996) propose that modular systems increase the speed of both component level and system level innovation. They argue that the decoupling of component knowledge from architectural knowledge allows the firms to pursue in a parallel way simultaneous innovation of components and architectures. For example, the theories on interfirm modular designs propose that innovation activities and learning of the multiple firms in a modular system can be achieved without problems due to the advances in IT technologies (e.g. Quinn, 2000). However, research results show that firms with high level of product modularity may have problems with architectural learning and fail to deliver architectural innovation (Chesbrough and Kusunoki, 1999).

In other approaches to flexibility as for example in improvisation, achieving flexibility typically means ability to change any element of the organization (Vera and Crossan, 2005; Moorman and Miner, 1998). In modular approaches to flexibility the architecture of the product must be relatively stable in order to ensure that components combine in a whole smoothly functioning system. Therefore, modularity may require a relatively high degree of architectural stability. Langois and Robertson (1992) suggest that modular architecture may reduce the ability to innovate on system level, because the interfaces and rules must not change to make the integration of the components possible. Firms become myopic and focus their learning effort on component innovation. Thus, modularity may lead firms to postpone architectural learning. Firms in systems of component producers may even fail at component innovation, if they do not maintain competences in a number of fields wider than those they decide to produce (Brusoni et al., 2001). Sorenson (2003) argues that when volatility of markets increases, firms must increase their vertical integration to buffer the learning activities within the firm from the market instability. Consequently modularity may decrease strategic flexibility in terms of architectural innovation. In sum, modularity of products, organizations, and knowledge may have the dysfunctional effects of slowing down architectural innovation. Therefore, I expect that each type of modularity on its own will reduce the speed of architectural innovation. In the next section I develop a hypothesis about the combined or joint effect of several types of modularity on innovation of product architectures.

> *Hypothesis 4a:* Firms with higher internal modularity of products are likely to have lower Speed of Innovation of links between components.
>
> *Hypothesis 4b*: Firms with higher external modularity of products are likely to have lower Speed of Innovation of links between components.
>
> *Hypothesis 4c:* Firms with higher modularity of organizational structure are likely to have lower Speed of Innovation of links between components.
>
> *Hypothesis 4d:* Firms with higher modularity of organizational processes are likely to have lower Speed of Innovation of links between components.
>
> *Hypothesis 4e:* Firms with higher modularity of knowledge are likely to have lower Speed of Innovation of links between components.

Strategic intent as a mediating variable

While some firms adopt modular strategies in their quest for competitive advantage, others may adopt different strategic approaches to increase their flexibility (Sanchez and Mahoney, 1996; Schilling, 2000). The strategic intent of the firm mediates the relationship between market dynamics and modularity and between market dynamics and strategic flexibility, because the overall strategic logic of the firms changes in response to the market context and influences in turn the adoption of modular strategies and the strategic flexibility of the firm. The strategic intent may influence flexibility both directly and indirectly through the adoption of modular strategies (Worren et al., 2002). In response to market dynamics firms decide how to achieve flexibility. They can adopt modular strategies in order to increase their flexibility or they can adopt alternative innovation strategies like technology integration (Iansiti, 1998) or matrix organization and cross-functional teams (Kahn, 1996, Swink et al., 1996). In addition firms can decide to use both modularity strategies and other innovation strategies like for example improvisation (Moorman and Miner, 1998) or higher investment in R&D projects (Ernst, 2005). Therefore, I expect that strategic intent mediates the relationship between market dynamics and modularity and the relationship between market dynamics and strategic flexibility.

Hypothesis 5a: Firms in more dynamic markets are more likely to adopt an entrepreneurial strategic intent.

Hypothesis 5b-g: Firms with entrepreneurial strategic intent are more likely to use internal modularity of products (5b), external modularity of products (5c), modularity of organizational structures (5e), modularity of organizational processes (5f) and modularity of knowledge structures (5g).

Hypothesis 5h: Firms with entrepreneurial strategic intent are likely to have higher Variety

Hypothesis 5i: Firms with entrepreneurial strategic intent are likely to have higher speed of innovation of components.

Hypothesis 5j: Firms with entrepreneurial strategic intent are likely to have higher speed of innovation of links between components.

RESEARCH METHOD

Sample

The unit of analysis of our study is the firm. I used as a sampling frame the population of companies in Italy, which consists of both business units of MNCs and Italian companies. I conducted a cross-sectional survey to increase the external validity of the findings. While prior research has focused on specific industries (e.g. Langlois and Robertson, 2003; Worren et al., 2002), I decided to test the theoretical model on modularity management and strategic flexibility in a wide array of industries. The final version of the questionnaire was administered to the CEOs of 1000 companies in Italy, which were randomly selected from a database of the Eurostat. There were 257 responses to the mailing, a total response rate of 25,7%. During the data cleaning procedures I removed 25 responses because of missing data. I compared the data points with the other to make sure the data was missing at random. Demographic information, such as industry and firm size, is provided in the Appendix A. To test for response bias early and late respondents were compared on the basis of industry type and firm size. No statistically significant differences were found at $p<.05$.

Data Characteristics

In order to ensure that the data meets the assumed distribution of the ML Estimation approach, I checked for multivariate normal distribution using AMOS. Non-normal data may lead to inflated goodness of fit indexes and underestimated standard errors (MacCallum, Roznowski, and Necowitz, 1992).The data are strongly nonnormally distributed. The univariate skewness values range from 0.20 to -1,69, with a mean of univariate skewness -0,59; univariate kurtosis values range from 0,27 to -10,52, with a mean of univariate kurtosis -3,56. Mardia's normalized estimate of multivariate kurtosis, which allows to test the multivariate normality, was found to be100,476. Since the value exceeds considerably the critical range of 18,669, I concluded that the the data are multivariate nonnormal. One approach to handling data, that fails to meet the assumption of multivariate normalit is to use the "bootstrap procedure" (West et al., 1995; Zhu, 1997). Bootstrapping allows the researcher to create multiple subsamples from the original database through random drawing with replacement. Then, one can examine the parameter distributions relative to each of these spawned samples. The bootstrapping sampling distribution is rendered free of from the restrictions of assumptions of normality, it is concrete and allows for comparison of parameter values over repeated samples. Within the specific context of SEM, the bootstrap estimates are less biased than the ML estimates for nonnormal distribution. Consequently, for the data analysis, I use the bootstrapping estimation procedures. I report both the ML estimates and the estimates, derived from the bootstrap samples.

SURVEY DEVELOPMENT, ADMINISTRATION, AND DATA ANALYSIS

Instrument Development

I developed a questionnaire using scales taken from prior studies except for the construct of knowledge modularity and external product modularity (see Worren et al., 2002; Jaworki and Kohli, 1993; Zahra and Nielsen, 2002). For some of the scales I limited the number of items in order to decrease the overall length of the questionnaire and to increase the response rate of the survey. There is no agreement in the literature so far as to the empirical counterpart of the construct of knowledge modularity (Brusoni et al., 2000; Sanchez and Mahoney, 1996). Drawing on commonly accepted definitions of organizational knowledge (Amit and Schoemaker, 1993; Grant, 1996; Teece et al., 1997), I considered the construct of internal knowledge modularity to considerably overlap with the construct of organizational process modularity, which I include in the model. To avoid contamination of relationships in the structural model based on tautology, I used a construct of knowledge modularity, which deliberately focused only on external knowledge modularity. The construct of external knowledge modularity was defined as company's use of knowledge components from multiple external sources. So far there has not been a study with a survey measure of external knowledge modularity. I measured the use of multiple external knowledge sources with the items developed by Zahra and Nielsen (2002). I discussed the content validity of the measures, especially of the measure of types of modularity, with professors and managers who have experience with modularity management. I then pilot tested the instrument using 90 respondents from executives from executive MBA courses. I then revised the measures on the basis of the pilot test.

The items were measured using seven-point Likert scales (see Appendix B). To assess the *Customer Uncertainty* in the industry I used three items which question speed of change of customer preferences and needs (Jaworksi and Kohli, 1993). *Competitive Intensity* includes two items which measure the dynamics of the competitive context (Jaworski and Kohli, 1993). *Technological Opportunities* consists of three items, which capture the speed of change of technology and the number of opportunities, which this change provides (Jaworksi and Kohli, 1993). *Internal Product Modularity* is captured by two items. The items assess the degree to which the company uses same standardized product modules so they can be easily reassembled /rearranged into different functional forms and model (Tu et al., 2004, Worren et al., 2002). *External Product Modularity* is measured by four items thata assess the degree to which the company has outsourced the production of some of the components it includes in its final product. I used for the development of the items the theoretical definitions of interfirm product modularity (Schilling, 2003; Schilling and Steensma, 1999; Snow et al., 1992) and modularity of manufacturing (Baldwin and Clark, 1997). I measured *Organizational Process Modularity* using three items which focus on codification, standartization, and reengineering of work processes (Worren et al., 2002). *Modularity of Organizational Structure* is evaluated with two items, which question the existence of small autonomous units to encourage flexibility and innovation (Worren et al., 2002). *External Knowledge Modularity* is captured by three items which assess the degree to which the firm puts together and uses different external knowledge components following the definition of Mahoney and Sanchez on modularity of knowledge and organizational learning and using the measures of external knowledge sources, proposed by Zahra and Nielsen (Mahoney and Sanchez, 2003; Zahra and Nielsen, 2002). I used three items to measure *Entrepreneurial intent* and asked the respondents whether they had strategic plans to develop new technologies, to enter new markets, or to improve their product development processes (Worren et al., 2002). *Strategic Flexibility 1* is evaluated by means of two items, which assess the first type of strategic flexibility and namely the effect of variety of models/variants offered by the firm in 2003 (Langlois and Robertson, 2003; Mahoney and Sanchez, 2003). I added an additional item to the one indicator measure proposed by Worren, Moore, and Cadona (2002) in order to be able to test the reliability of the measure and to reduce influence of the measurement error on the error in equation in the model test. I used two separate variables to evaluate the second type of Strategic Flexibility, the speed of innovation (Langlois and Robertson, 2003). *Strategic Flexibility Components* includes one indicator, which is a direct measure of the number of new products with only change in components introduced in 2003. *Strategic Flexibility Links* measures the number of enw products with changes in the links between the products introduced in 2003. Although the measures are simlar to the measures of the second order effect provided by Worren, Moore, and

Cadona (2002): number of new models and number of entirely new products, they explicitly question the innovation of components and innovation of links. The use of only one indicator to measure these two variables will not bias the estimates of the effects, because Strategic Flexibility is only a dependent variable in all regression equations. It is only likely to increase the error in equation and thus to lead to lower significance of the estimates.

Reliability and Validity

I assessed measures' reliability and validity using Confirmatory Factor Analysis as a part of the Structural Equation Modelling Analysis. In the CFA for each of the variables I examined the reflective factor loadings and their significance levels (see Table 1). Then, I examined the item reliability and the composite reliability for each latent construct in the model. The item reliability was assessed based on squared multiple correlations (Standartized Regression Weights> 0.40). The composite reliability, which draws on the standardized factor loadings and measurement error for each item was chosen instead of Chronbach Alpha (composite reliability > 0.60). I did not use Cronbach Alpha, because these reliability measures assumes equal factor loading of the items (Bollen, 1989), which contradicts the results of the CFA analysis. For two variables the composite reliability was bellow 0.60 (but higher than 0.50). Both variables were measure through two items, each of which had sufficient item reliability. Composite reliability is influenced by the number of items used for the scale. For theoretical reasons, I decided to keep the variables in the model.

Insert Table 1 around here

I assessed the convergent validity and the discriminant validity of the model (Bagozzi, 1994; Bollen, 1989; Shook et al., 2004). Each latent variable had acceptable convergent validity with variance extracted >0.50 (Shook et al., 2004). To assess the discriminant validity I conducted 'pairwise tests' of all theoretically related constructs (Bagozzi and

Phillips, 1982). For all pairs of variables the two-factor models fitted the data significantly better that the one-factor models.

Since the variables were derived from the same sources, I tested for common method bias with CFA linking all the measures to one common latent variable. The model fit was low (Chi-square = 1899,489 Degrees of freedom = 350, Probability level = ,000; CFI= 0,496). The resultant variance of the common method latent variable indicated the common variance of all items was less than 6 percent and not significant at $p < 0.10$ (0.056; $t=0.875$, $p>0.10$).

I used a second order CFA (Bagozzi, 1994) to test the hypothesis of the existence of a higher-order construct of market dynamics, which consists of three dimensions: consumer uncertainty, competitor intensity, and technological opportunities. The findings show that the model fits well: Chi-Square=21,875, DF=18; p=,238. The factor loadings on the second order factor (see table 2) are all statistically significant at p<,05 and higher than ,40. Thus, I use a higher level construct, market dynamics, as an antecedent in our model on modularity. The second-order CFA model overcomes problems of multicollinearity which occur when dependent variable is regressed directly on the first order constructs (Bagozzi, 1994).

Construct/ Indicator	Standartized Coefficient	Estimate/St. Error	Composite Reliability
Customer Uncertainty			0.79
Item 1	0.350	-b	
Item 2	0.679	5.604	
Item 3	0.833	5.875	
Competitive Intensity			0.66
Item 1	0.580	3.955	
Item 2	0.759	3.629	
Technological Opportunity			0.83
Item 1	0.557	-b	
Item 2	0.822	8.020	
Item 3	0.782	8.050	
Internal Product Modularity			
Item 1	0.609	10.666	0.56
Item 2	0.615	10.666	
External Product Modularity			
Item 1	0.611	-b	0.61
Item 2	0.500	3.583	
Item 3	0.510	3.573	
Organizational Process Modularity			0.70
Item 1	0.932	-b	
Item 2	0.937	25.677	
Item 3	0.910	23.774	
Organizational Structure Modularity			0.49
Item 1	0.486	7.451	
Item 2	0.520	7.451	
External Knowledge Modularity			0.80
Item 1	0.401	-b	
Item 2	0.940	5.194	

Item 3	0.946	5.198	
Entrepreneurial Intent			0.85
Item 1	0.906	-b	
Item 2	0.970	20.135	
Item 3	0.970	20.115	
Strategic Flexibility 1			
Item 1	0.708	11.569	0.58
Item 2	0.578	11.700	

* Statistically significant at $p<0,01$
b Factor loading is fixed to one for scaling of the latent variable.

Table 1: Results from CFA tests of construct reliability

EMPIRICAL RESULTS

Mixed Modularity: Towards a Multidimensional Construct of Modularity

I conducted a second order Confirmatory Factor Analysis to test whether a multidimensional concept of Modularity of firm exists (see hypothesis 10) (Bagozzi, 1994). Drawing on the general modularity theories of the firm, I hypothesized that the modularity of firms has five dimensions: external product modularity, internal product modularity, organizational structure modularity, organizational process modularity, and knowledge modularity (Sanchez and Mahoney, 1996; Schilling, 1996; Ulrich, 1995). However, the results of the second order Confirmatory Factor Analysis of the model suggested that the model does not fit the data well (see Figure 5). The External Product Modularity variable had a factor loading, which was not significant at $p<0,05$. Internal product modularity and organizational structure had standardized factor loading which were lower than the accepted threshold of 0,40. Therefore, I did not have evidence to conclude that modularity of firms represents a higher-level constructs consisting of five dimensions. The only two constructs, which seemed to be dimensions of the same higher-order construct, were Organizational Process modularity and Knowledge modularity. I conducted a post-hoc test to determine whether Organizational Process modularity and Knowledge modularity are dimensions of the same construct at a higher level of abstraction. That the second-order CFA model of a Modularity construct with two dimensions had a good fit (Chi-square= 8,045, DF=9, p=,531), all items had factor loadings on the first order factors, which are significant at $p<0,05$, and that the standardized factor loadings of the first order factors were significant at $p<0,05$ and higher than 0,40 (see Table 2). Thus, variance which is common to the two first order factors, and which represents a high level of abstraction is captured through the influence of a second-order factor, which I termed: Mixed Modularity. Firms possess a higher-level capability to manage mix internal and external knowledge components and manage simultaneously modularity of organizational processes and modularity of external knowledge sources. Thus, I find evidence on the existence of a second order capability to manage simultaneously two first order capabilities.

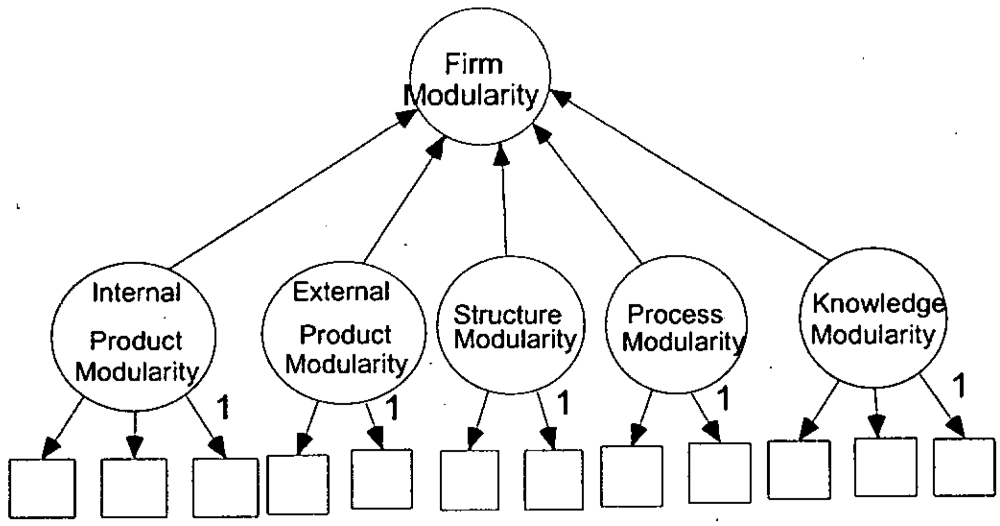

Figure 4: Mixed Modularity: A second order model of firm modularity: Hypothesis 10

Construct Level 2/ Construct Level 1	Standardized Coefficient	Estemate/St. Error	Composite Reliability
Market Dynamics			0,76
• Customer Uncertainty	0,543	3,759*	
• Competitive Intensità	0,687	2,697*	
• Tech. Opportunities	0,667	4,982*	
Mixed Modularity			0,67
• Organizational Process Modularity	0,436	13,165*	
• External Knowledge Modularity	0,917	3,069*	

* Statistically significant at p<0,01

Table 2: Results from Second order CFA on Market dynamics and the post hoc Second-Order CFA on Mixed Modularity with two first order factors

Specification of the Structural Model

Several advantages of the Structural Equation Modelling approach make it particularly effective in solving fundamental methodological problems in our field. The SEM allows the researchers to address the problems of construct validity and attenuation of correlation in strategic management research (Boyd et al., 2005). The use of latent variables in the regression equation and the Confirmatory Factor Analysis of measurement models enable to control for measurement error and to assess measure reliability and validity. SEM provides the opportunity to test for complex theoretical relationships in order to disentangle the mechanisms through which the relationships between variables occur (Bagozzi, 1994; Swedberg and Hedstrom, 1998). I used a structural equation program, AMOS, to test our model. I used Maximum Likelihood Estimation and Bootstrap Maximum Likelihood estimation to get the best possible fit between the covariance structure of the observed data and the covariance structure of the conceptual model. After the important first step of analysis of the latent variable measurement models, I tested the hypothesized structural model (Byrne, 2001). Firstly, I assessed the overall fit of the model (Joreskog et al., 1999). Then, I assessed the individual parameter estimates for the paths in the model and their statistical significance. Finally I conducted post hoc analysis on alternative models to avoid confirmation bias and consider alternative explanations of the data (MacCallum and Austin, 2000). To avoid capitalizing on sampling error, I did the model respecifications based on the theory and explicitly presented them as post hoc tests, which have to be validated into a new sample (Shook et al., 2004).

Results

The test of the overall fit of the model yielded a value of the likelihood ratio test statistic (Chi-square) of 473,04, with 315 degrees of freedom and a probability of less than 0.0001 ($p<.0001$). Because of the well-known limitations of the Chi Square statistics of overall model fit, I used the alternative goodness-of-fit statistics, recommended in the literature

(Bollen, 1989; Hu and Benlter, 1999; MacCallum and Austin, 2000; Shook et al., 2004). To test the overall fit of the model, I used four goodness of fit indexes: Comperative Fit Index (CFI), Root Mean Square Error of Approximation (RMSEA) with confidence interval, Expected Cross Validation Index (ECVI), and Incremental Index of Fit (IFI, Delta 2).The values of the CFI range from zero to 1. The values are derived from comparison of the hypothesized model with the independence model and takes sample size into account. Since, the cut-off value of 0.95 has been advised (Hu and Bentler, 1999), the CFI of our model (0.95) suggests that I have a well-fitting model. The RMSEA index has the advantage to be sensitive to model misspecifications and to have a confidence interval available (MacCallum and Autin, 2000). Value of RMSEA bellow 0.50 indicate a great fit. Our finding of RMSEA (0.047) suggests that the model fits well the data. The narrow confidence interval (0.038 to 0.55) suggests that the RMSEA index has a good precision in reflecting the model fit (Maccallum et al., 1996). The ECVI index assesses the generalizability of the model in terms of the likelihood of the model cross validation across similar –sized samples from the same population. To apply the ECVI I have to compare the ECVI value of the hypothesized model (2,836) with the ECVI of the independence model (15,198) and the ECVI of the saturated model (3,515). Given the lower value of the ECVI index in comparison both to the independence model and the saturated model, I conclude that our model fits best the data. The incremental fit index, IFI, compared the hypothesized model to a baseline model and takes into account the parsimony and the sample size of the model (Hu and Bentler, 1999). The value of the IFI close to 0,95 indicate superior fit. The IFI value of our model (0,95) indicates once again an adequate overall fit of the model to the data. Thus, I can conclude that the overall fit of the conceptual model was very good (Chi-square CFI=0.95; RMSEA=0.047; IFI=0.95; lowest ECVI).

Table 3 summarizes the relationships tested in the model. For the sake of completeness I present the p-values both of the ML Estimation results and Bootstrap ML Estimation results. However, I focus on the Bootstrap ML tests of significance, because of the problems with underestimation of standard errors by ML estimation in samples with multivariate nonnormal distribution like our. I show the significant paths in figure 5. In Hypotheses 1a, 1b, 1c, 1 d and 1 e, I predicted that market dynamics will have a positive impact on types of modularity. The parameter estimates for all the hypothesized paths, except for organizational structure modularity, were positive and statistically significant at $p<0.10$. The path between technological opportunities and modular organizational structure was added in a post hoc analysis because of the high modification indices. This path had a positive and statistically significant coefficient. In hypothesis 5a, I expected that market dynamics will be positively associated with entrepreneurial strategic intent. The coefficient of the path between market dynamics and intent was positive and statistically significant at $p<0.10$. Thus, I found support for hypothesis 2.

In Hypotehses 2a, 3a, and 4a, I suggested that there is a positive impact of internal product modularity on strategic flexibility through variants, strategic flexibility through innovation of components, and a negative impact of internal product modularity on strategic flexibility through architectural innovation of links. I did not have sufficient statistical evidence to reject the null hypotheses that there are no relationships between the variables in these hypotheses. Although the coefficient of the path between internal product modularity and strategic flexibility through variants was positive and statistically significant if estimated by ML estimation, it had a p-value higher than 0.10 in the bootstrap ML estimation (Hypothesis 2a). It seems that the effect of internal product modularity on strategic flexibility was too low in our sample of multiple industries. In the sample from the home appliance industry, Worren et al. (2002) find a significant positive effect of product modularity on strategic flexibility through product variants. However, they do not discuss the assumption of multivariate normality in their data. Consistent with our findings on Hypothesis 3a and 4a, the findings of Worren, Moore, and Cadona (2002) do not provide evidence in favour of the expected relationship between internal product modularity and strategic flexibility through component and link innovation. Thus, internal product modularity ceteris paribus does not stimulate faster learning about components or links. The finding that internal product modularity has not affect the flexibility of firms may be explained by the potential existence of a contingency. Modularity of the products without modularity of organizational structure, organizational processes, or knowledge modularity may have no impact on strategic flexibility. In the second order CFA test, I found out that in our sample firms do not manage a multidimensional modularity. Firms with internal product modularity did not build simultaneously modularity of processes, structures, and knowledge.

In Hypotheses 2b, 3b, and 4b, I predicted that external product modularity has a positive association with strategic flexibility through variants and component innovation and negative association with strategic flexibility through architectural innovation. I did not have sufficient statistical evidence to reject the null hypotheses that there were no relationships between external product modularity and flexibility in terms of number of product variants (Hypothesis 2b). I found support for the hypotheses 4b, in which I proposed a negative relationship between external product modularity and strategic flexibility of architectural innovation. Surprisingly, I found that there is a significant negative relationship between external product modularity and flexibility through innovation of components. Both path coefficients were negative and statistically significant at $p<0.10$. The negative relationship between outsourcing of product components and learning about links provides evidence which supports the ideas on the negative effects of external modularity on architectural learning (Brusoni et al., 2001; Langlois and Robertson, 1992). The findings question the arguments on the benefits of outsourcing of innovation and on the increase of pace of learning through inter-firm modularity (Baldwin and Clark, 1997; Sanchez and Mahoney, 1996). Surprisingly, outsourcing of the production of components can endanger also the learning on component level. This finding runs counter to the propositions on the component level benefits of external product modularity through parallel experimentation (Baldwin and Clark, 2000; Robertson and Langlois, 1992). However, it supports the ideas that externalization of production of product components ceteris paribus, that is without an appropriate management of the knowledge boundaries, can endanger component innovation (Brusoni et al., 2001). I did not find evidence that firms undertake simultaneous external product modularity and management of the knowledge boundaries (see hypothesis 10). This approach to management of external relationships makes their component innovation efforts vulnerable to the problems of different rates of change in different technological sectors underlying the components and the resulting imbalances in component innovation (Brusoni et al., 2001). Even in the presence of stable (physical) interfaces and a fixed product architecture, imbalances of innovation speed may emerge on the technology level, that is on the knowledge level, which require conscious coordination of knowledge management and product component management.

In hypotheses 2c, 3c, and 4c, I suggested that there is a positive relation between organizational structure modularity and strategic flexibility in terms of number of product variants and component innovation and a negative relationship between organizational structure modularity and innovation of links in product architectures. I did not have good evidence to conclude that these relationships hold for a population of multiple industries, which includes industries in which modularity has not been investigated so far. The path coefficient between organizational structure modularity and strategic flexibility through variants was positive and statistically significant at $p<0.05$ in the results of the ML Estimation. However, the standard errors were underestimated and when this problem was corrected in the the Boostrap ML estimation, the coefficient lost its significance. Therefore, I can conclude that the organizational structure modularity, operationalized as design and manufacturing of components in autonomous units, does not increase strategic flexibility holding everything else constant. This finding supports the findings on problems of architectural innovation in organizations (Henderson and Clark, 1990), but seems to run counter to the theorizing on faster component learning through modular organizational design (Baldwin and Clark, 2000; Sanchez and Mahoney, 1996). An explanation for the problems of firms to increase their rates of component learning through parallel experiments can be found in the failure of firms to address different types of modular architectures simultaneously. In particular, organizational structures with modular design must be coordinated with modular process design and knowledge design, which ensure coordination of the constant parallel experimentation. A priori definition of the process and knowledge architecture is essential in enabling the successful experimentation on the component level in the separate organizational units (Baldwin, 2001; Baldwin and Clark, 2000).

In hypotheses 2d, 3d, and 4d, I suggested that organizational process modularity will be positively associated with strategic flexibility both in terms of product variants and component innovation and negatively associated with strategic flexibility in terms of link innovation. In hypotheses 2e, 3e, and 4e, I proposed that external knowledge modularity will be positively associated with strategic flexibility in terms of variants and component innovation and negatively associated with architectural innovation. I tested the effect of Mixed Modularity, the second order factor which represents the joint effect of managing simultaneously organizational process modularity and external knowledge modularity, on the three types of strategic flexibility. The relationships between mixed modularity and strategic flexibility of product variants was positive and marginally significant at $p<0,15$. The coefficients associated with the relationship between mixed modularity and strategic flexibility of components and strategic flexibility of links were both positive and statistically significant at $p<0,10$. Thus, I have good evidence to conclude that there are positive effects of the simultaneous management of external knowledge modularity and organizational process modularity on flexibility through innovation. Since organizational processes are a key part of the organizational knowledge (Amit and Shoemaker, 1993; Argote and Darr, 2000; Zander and Kogut, 1992), I can argue that the simultaneous management of modular architectures of internal knowledge and external knowledge predict the successful learning on the component and the linkage level. This finding contributes to a better understanding of the relationships between modularizing the various architectures in organizations and innovation advantages (Baldwin and Clark, 2000; Sanchez and Mahoney, 1996; Schilling, 2000). Obviously, learning and innovation does not happen automatically with the definition of a product architecture as some theories on modularity predict, but requires the higher order capabilities in management of knowledge components, both external and internal.

In addition, I found out that external knowledge modularity on its own has negative impact on strategic flexibility of variants and strategic flexibility of component learning. Thus, firms who fail to develop the higher-order capability (Collis, 1994) to manage simultaneously external and internal knowledge components are likely to fail in learning from external sources. Organizational process modularity had nonsignificant effect on strategic flexibility everything held constant. Mixed modularity, the capability to manage the jointly the recombination of external and internal knowledge resources, acts as a mediating variable between market dynamics and strategic flexibility through innovation. It allows firms to cope with changing markets. Therefore, I consider it a dynamic capability of the firm (Teece et al., 1997; Eisenhardt and Martin, 2000).

In Hypotheses 5b, 5c, 5d, 5e, 5f, and 5g I suggested that entrepreneurial strategic intent will be positively associated with internal product modularity, external product modularity, organizational structure modularity, organizational process modularity, and knowledge modularity. I found support only for Hypotheses 5c and 5f (the effects of intent on external product modularity and organizational process modularity). The relationship between intent and external product modularity was significant but had a negative sign. The results imply that firms that develop strong innovation initiatives prefer to guard themselves against the dangers of modularity through internalization of the production of key components of their products (Chesborough and Kusunoki, 2001; Flemming and Sorenson, 2001). However, the relationship between knowledge modularity and intent was not significant at $p<0.10$ (Hypothesis 5g). Firms with high learning intent prefer to develop knowledge platforms, which are broader than their product platform, to decrease the use of external knowledge on components, and to emphasize the use of internal knowledge components (Brusoni et al., 2001).

In Hypotheses 5h, 5i, and 5j, I proposed that entrepreneurial intent will have a positive association with strategic flexibility. The coefficients of the direct relationship between intent and the three types of strategic flexibility were non significant. However, intent influenced strategic flexibility through two indirect paths. Firstly, the impact of intent on the strategic flexibility of innovation was mediated through external product modularity. Both the coefficient of the relationship between intent and external product modularity and between external product modularity and strategic flexibility were significant and negative. Thus, the indirect effect of intent on strategic flexibility is positive. A firm with more entrepreneurial intent chooses a lower level of external modularity of products and thus increases the rate of learning about components and links. Secondly, intent impacts strategic flexibility of innovation through its effect on mixed modularity. Consequently, entrepreneurial intent increases the efforts in managing organizational knowledge and thus increases the learning rate of the firm. The finding renders support to the theorizing on the importance of management of knowledge as a key resource of the firm (Grant, 1996; Spender and Grant, 1996; McEvily and Chakravarthy, 2002).

Analysis of Post Hoc Models

I tested a model in which I did not include the second order factor of Mixed Modularity. The model had a worse overall fit indexes, with CFI decreasing from 0,95 to 0,92, RMSEA increasing from 0.47 to 0,55. AIC value of the model without a second order factor (718,22) was higher than the AIC value of the model with the second order factor (655), which suggests that the model with a second order factor has a better fit with the data. Moreover, the coefficients of the first order factors, knowledge modularity and organizational process modularity, were non significant. This was the effect of the high correlation between the two factors and the multicollinearity problem, which the use of a second order factor solves.

In addition I tested a model with a control for size of the firms, measured in terms of number of employees. I expected that the size of the firm will influence positively the number of variants a firm produces (strategic flexibility 1) and on the internal product modularity (Worren et al., 2002). The overall model fit was worse with CFI value of 0,93 and RMSEA value of 0,50. The AIC index (=712) was higher than the AIC index of the model without the control (=655), which suggests that the model with the control variable has a worse fit with the data.. The coefficient of the relationship between size and strategic flexibility was not significant at $p<0,10$. The coefficient between size and internal product modularity was however significant at $p<0.10$ and positive.

Unstandardized Regression Weights:

Following construct		Leading construct	Estimate	ML S.E.	ML P	Bootstrap ML P
Internal Product Modularity	<---	Market Dynamics	,417	,178	,019	,014
External Product Modularity	<---	Market Dynamics	,199	,089	,026	,033
Mix Modularity	<--	Market Dynamics	,273	,093	,003	,007
Intent	<---	Market Dynamics	,491	,187	,009	,063
Orga Structure Modularity	<---	Technology	,620	,200	,002	,099

Following construct		Leading construct	Estimate	ML S.E.	ML P	Bootstrap ML P
Knowledge Modularity	<---	Technology	,259	,118	,028	,049
Internal Product Modularity	<---	Technology	-,005	,149	,972	,711
External Product Modularity	<---	Intent	-,075	,039	,052	,017
Orga Structure Modularity	< ---	Intent	,260	,090	,004	,079
Process Modularity	<---	Intent	,875	,063	***	,013
Knowledge Modularity	<---	Intent	-,186	,094	,049	,274
Str. Flexibility 1	<---	Intent	-,273	,091	,003	,155
Str. Flexibility 2 Component	<---	Intent	-,005	,105	,964	,980
Str. Flexibility 2 Links	<---	Intent	,011	,099	,908	,805
Orga Structure Modularity	<-->	External Product Modularity	,635	,366	,083	,187
Str. Flexibility 1	<---	Internal Product Modularity	,313	,157	,046	,172
Str. Flexibility 2 Component	<---	Internal Product Modularity	,024	,152	,872	,809
Str. Flexibility 2 Links	<---	Internal Product Modularity	-,059	,140	,673	,832
Str. Flexibility 1	<---	External Product Modularity	-,543	,316	,086	,203
Str. Flexbility 2 Component	<---	External Product Modularity	-,739	,353	,036	,065
Str. Flexibility 2 Links	<---	External Product Modularity	-,768	,353	,030	,041
Str. Flexibility 1	<---	Mixed Modularity	,898	,172	***	,135
Str. Flexibility 2 Components	<---	Mixed Modularity	2,730	,318	***	,067
Str. Flexibility 2 Links	<---	Mixed Modularity	1,636	,241	***	,085
Str. Flexibility 1	<---	Knowledge Modularity	-,392	,125	,002	,091
Str. Flexibility 2 Component	<---	Knowledge Modularity	-,510	,149	***	,079
Str. Flexibility 2 Links	<---	Knowledge Modularity	-,226	,125	,070	,268

Following construct		Leading construct	Estimate	ML S.E.	ML P	Bootstrap ML P
Str. Flexibility 2 Components	<---	Orga Process Modularity	-1,046	,240	***	,145
Str. Flexibility 2 Link	<---	Orga Process Modularity	-,710	,179	***	,142
Str. Flexibility 1	<---	Orga Structure Modularity	,330	,152	,030	,244

Table 3: Magnitude and significance of the hypothesized structural relationships (ML Estimation and Bootstrap ML Estimation)

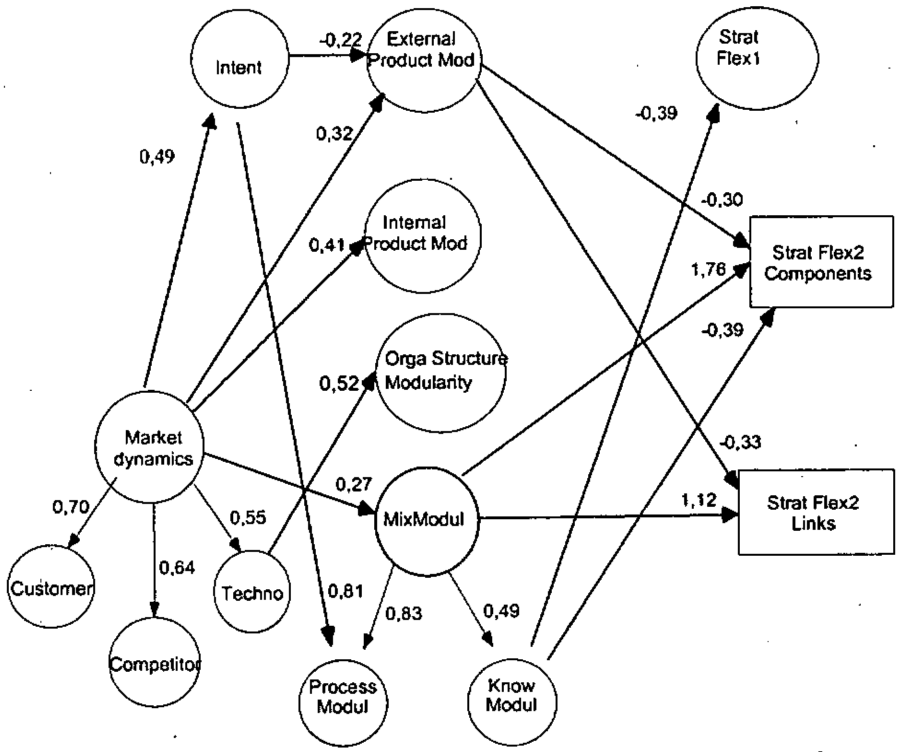

Figure 5: Structural model with obtained unstandardized coefficients: Paths, which are statistically significant at p<0,10 (Bootstrap ML)

Analysis of Post Hoc Models

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CONCLUSIONS

In this study I investigate how different types of modularity architectures influence the flexibility of the firm to match the market dynamics. I tested propositions on modular strategies in the setting of a cross-sectional sample of industries. The hypothesis on the existence of a modularity capability to manage simultaneously multiple modular dimensions was tested and refined. To refine the research project of Worren and his colleagues (Worren et al., 2002), I refined the measures of market context, and tested the structural model with latent variables to avoid systematic bias of coefficients due to measurement error.

Theories on modular design argue that modular design "enhances a company's ability to integrate market-differentiating features in products and that (it) supports rapid innovation, stringent cost controls, and the acceleration of supply timelines" (Sanchez, 2004). I find that firms do address the challenges of dynamic markets with modular strategies at product, organizational, and knowledge level. However, internal product modularity and organizational structure modularity do not increase the strategic flexibility of the firm, everything else held constant. Moreover, external product modularity and external knowledge modularity can have negative effects on strategic flexibility. Only the firms in our study that did manage organizational process modularity and external knowledge modularity simultaneously were able to achieve higher strategic flexibility. Furthermore, the strategic intent to reduce external product modularity and to develop mixed modularity capability increases the flexibility of firms.

Theorists on modularity propose that the a priori specification of product architecture allows automatically all types of modularity to function in accord and stimulates decoupled learning both about components and about architectures (Baldwin and Clark, 2000; Sanchez and Mahoney, 2003). I had limited empirical evidence on the power of product design to coordinate knowledge and organizations so far (Brusoni and Prencipe, 2000). The results of our study imply that internal product modularity may have no impact on other kinds of modularity and no impact on strategic flexibility. The negative impact of external product modularity on strategic flexibility suggests that when decoupled from knowledge modularity and organizational modularity product modularity can fail to generate learning advantages. I provide evidence that architectural and component learning can be harmed by organizational process modularity and knowledge modularity, if they are not managed together by a higher order capability.

Going back to the definitional features of modular architectures (Baldwin and Clark, 2000), I conclude that the third feature of modular architectures, namely effective functioning as an integrated whole, may be present or absent depending on the way managers approach modularity. Modules may be distinct parts of a larger system, modules may be independent of one another, but still modules can fail to function as an integrated, seamless whole. A system of modularity may partially function as an integrated whole with regard to the first order effects of efficiency and cost saving, but it may fail to foster learning and innovation. The counterintuitive negative signs of the impact of separate types of modularity on flexibility can be explained by the failure of decomposed systems to function as an integrated whole in terms of learning and innovation (Fleming and Sorenson, 2001; Brusoni and Prencipe, 2001). The failure of internal product modularity and organizational structure modularity to influence learning suggests that isolated management of single modular architectures can hinder the strategic flexibility effects of modular designs.

The construct of mixed modularity, a higher-order modularity capability, can help us come closer to an understanding of the management of a learning modular architecture. It shifts the focus from managing the design of the output, the product, to managing the combination of input, the knowledge resources. Consistent with the knowledge-based view of the firm, I provide empirical evidence that the capability to manage simultaneously internal knowledge components and external knowledge components matters for flexibility through product innovation. On the basis of the evidence, I argue that integration of product, process, and knowledge or resource modularity does not occur automatically as a result of the use of internal product modularity designs as Sanchez and Mahoney (1996) predict, but requires specific capabilities and management. Knowledge and organizational coordination cannot be achieved relying on the automatic mechanisms of a specified architectural product structure. Brusoni and Prencipe (2001) suggest that companies with specific capabilities shall play these coordination functions. I add the importance of the coordination capabilities of each firm in a modular system.

The potential for innovation comes from managing the recombinations of knowledge structure (Galunic and Rodan, 1998). The mixed modularity capability is a mediating variable of the effect of dynamic market on dynamic firm behaviour. Thus, it is one specific mechanism through which firms become dynamic in dynamic markets (Eisenhardt and Martin, 2000; Teece et al., 1997).

An interesting extension of the study would be to include performance as an outcome variable in the model. I did not include performance because of the problems with specification of the time lag between innovation and its influence on performance in a cross sectional study (e.g. Worren et al., 2002). Longitudinal studies can provide insights on the processes through which modular architectures influence performance.

Further research projects can test the model in larger samples, which will make possible to detect effects with smaller size. Although I followed the rules for determining the adequate sample size to guarantee sufficient power of the tests (Shook et al., 2004), it is possible that internal product modularity for example has a small effect on strategic flexibility which requires a larger sample size to be detected. In addition, our sampling frame was limited to companies with operations in Italy. There could be some potential differences in the local culture or institutions (Peng, 2000), which influence our findings.

While this research provides interesting insights on the higher-order modularity management capability, further work is needed to replicate the test in another sample. Another opportunity will be the incorporation in the model of other constructs like synergistic specificity (Shilling, 2000). The construct of synergistic specificity represents the need for modular product architecture from the perspective of the consumer and adds a further factor to the antecedents of product modularity. The study of the effects of this construct may help disentangle the contexts in which product modularity leads to strategic flexibility of variants or innovation from the contexts in which product modularity has no impact on strategic flexibility of variants or innovation.

Constraining explanations of firm's flexibility in dynamic markets only to the use of product modularity allows just a glimpse on a part of the picture and can mislead managers and researchers in their conclusions. In this study, I provided initial insights on mechanisms with multiple dimensions through which firms respond to dynamic markets and I encourage further multi-method studies in this direction.

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Appendix A: **Demographic Data of Repondent Firms**

Industry type

	Frequency	Percent
Electronics	95	37,0
Automotive or parts	23	8,9
Software	16	6,2
Furniture and fixtures	17	6,6
Fabricated Metal Products	11	4,3
Transportation equipment	20	7,8
Appliances	3	,8
Textiles	7	2,7
Industrial machinery and equipment	55	21,4
Hardware	10	3,9
Total	257	100,0

Sales

	Frequency	Percent
Less than 1 million	20	7,8
1 to 10 million	65	25,3
10 to 50 million	67	26,1
50 to 100 million	29	11,3
100 million and above	76	29,6
Total	257	100,0

Employees

	Frequency	Percent
Less than 50	79	30,7
50 to 200	68	26,5
200 to 500	43	16,7

500 to 1000	12	4,7
1000 and above	55	21,4
Total	257	100,0

Appendix B: **Measurement**

Variable	Questionnaire Items
Internal Product Modularity	1. Our products have been decomposed into separate components and each component performs a specific function. 2. For our products we can make changes in key components without redesigning others.
External Product Modularity	6. The part of the final product which composes of components produced by our company is: 40. We have outsourced the production of a part of the components of the final product. 44. Our company has contracted out a major part of its manufacturing/production activities.
Organizational Structure Modularity	32. We try to develop small autonomous units to encourage innovation and flexibility. 34. Each of the components of the product is designed in separate high-autonomous units of the organization.
Organizational Process Modularity	36. We have documented the steps involved in key business processes. 37. We have defined business processes that cut across functional boundaries. 38. We have standardized business processes across departments and organizational units.
Knowledge Modularity (external)	39. We have procedures and systems for transferring knowledge across projects and organizations. 42. Our company uses joint ventures or alliances to acquire innovative manufacturing technologies. 43. Our company uses joint ventures or alliances to gain knowledge about new manufacturing systems and methods.
Strategic Flexibility 1	7. We offer a high variety of products, constructed of different components. 8. We have in comparison with our leading competitors a small number of variants within our main product family. (reversed)
Strategic Flexibility 2 Components	12. We introduced the following number of products with changes only in components. (transformed into categorical variable)
Strategic Flexibility 2 Links	13. We introduced the following number of product with changes in the links between the components. (transformed into categorical variable)
Intent	16. We have a business plan to develop new technologies for new markets. 17. We have a business plan to use existing technologies to enter new markets. 18. We have an overall business plan to redesign our product development process.

Technological Opportunities	72. Technological developments in our industry are rather minor. (reversed) 78. A large number of new product ideas have been made possible through technological breakthroughs in our industry. 77. Technological changes provide big opportunities in our industry.
Competitive Intensity	69. Competition in our industry is cutthroat. 70. There are many promotion wars in our industry.
Customer Uncertainty	66. We are witnessing demand for our products and services from customers who never bought them before. 67. New customers tend to have product-related needs that are different from those of our existing customers. 64. In our kind of business, customers' product preferences change quite a bit over time.