MIXING AND MATCHING MODULARITY: A STUDY OF STRATEGIC FLEXIBILITY

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Abstract

Modularity makes complexity manageable. Proponents of modularity argue that modular architectures lead to higher strategic flexibility both through mass customisation and through innovation. Furthermore, they propose that a modular product design in the firm influences directly and automatically the organizational knowledge and structure creating modular organizational and knowledge architectures. There is little direct evidence, however, on how firms manage all different types of modular architectures to achieve the expected advantages. In this paper, we 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. Using structural equation modelling and data from 233 firms, we 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 organizational process modularity and knowledge modularity succeed to innovate faster both at components and at architectural level.

Keywords: modularity, innovation, strategic flexibility, organization design, knowledge management, dynamic capabilities
INTRODUCTION

Managing modular architectures is an area of intense interest both to scholars and practitioners (Baldwin and Clark, 2000; Ethiraj and Levinthal, 2004; Helfat and Eisenhardt, 2004; Karim, 2006; Pil and Cohen, 2006; Schilling, 2000). In increasingly dynamic markets modularity of products enables managers to exploit economies of scale and scope and to enhance product variety to meet heterogeneous customer needs (Garud and Kumaraswamy, 1995; Gaware and Cusumano, 2002; Helfat and Eisenhardt, 2004; Tu, Vonderembse, and Ragu-Nathan, 2004; Wheelwright and Clark, 1992). Moreover, students of modularity promise a faster learning at both component and architectural level through coupling of modular product designs with modular organization designs and modular knowledge structures (Baldwin and Clark, 1997; Sanchez and Mahoney, 1996; Schilling, 2000).

In this paper, we investigate whether different types of modularity affect strategic flexibility in markets with varying dynamics. We question the existence and the outcomes of the capability to manage simultaneously multiple types of modularity. Our research answers the question of 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. We create a path model of the antecedents, types, and outcomes of modular strategies of firms, which we test in a large-scale cross sectional study (see Figure 1).

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Theories on modular management of products, 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 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 stereo component and microcomputer industries, Langlois and Robertson (1992) provide evidence of the positive impact of product modularity on the rate of innovation of product components. However, they find that the innovation rate of architectural knowledge is actually slower in interorganizational systems with product modularity. Chesbrough and Kusunoki (1999) advance the investigation with evidence that product modularity also has 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 (2001) conclude that product modularity may harm component innovation if knowledge boundaries are allowed to become too narrow. In sum, the literature so far abounds with contradictory 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.

We provide initial evidence on how firms mix and match five different types of modularity. In a large-scale study of the home appliance industry, Worren, Moore, and Cardona (2002) found that internal product modularity had an impact on enhancing the number of variants of a product, but did not influence the pace of innovation. We replicate their finding in a cross-sectional sample. We found that modularity of organizational structures and processes had impact on first order strategic flexibility too. Extending the study of Worren and colleagues (2002), we provide evidence on predictors of second order strategic flexibility, i.e. innovation of components and links. We found that knowledge modularity, process modularity, and external product modularity had negative effects on innovation of components and links. Furthermore, only when firms managed simultaneously modularity of knowledge and modularity of processes did they achieve higher second order strategic flexibility in terms of innovation of components and links. We termed the capability to manage simultaneously modularity of knowledge and processes integrated modularity. We argue that the capability to mix and match knowledge and process modularity represents a new type of dynamic capability.

We contribute to theory and research on modularity, innovation, and learning in three ways. First, while researchers so far have investigated the types of modular architectures separately, we attempt to contribute to a better understanding of the interdependencies between the types of modular architectures. We test for the expected existence of a multidimensional construct of overall firm modularity and introduce the term ‘integrated modularity’. Building on the general theories on modularity proposed by Schilling (2000) and Sanchez and Mahoney (1996) as well as on current empirical research, we advance the investigation of Worren and his colleagues (2002) with the missing external product modularity (Langlois and Robertson, 1992; Schilling, 2000) and knowledge modularity (Sanchez and Mahoney, 1996). Second, we distinguish between two types of second order strategic flexibility: innovation of components and innovation of links. Thus, we are able to demonstrate that different types of innovation require different modular designs. Third, research efforts so far have been constrained to a few industries, e.g. computer, automotive, and home appliance, which seem to be favourable setting for modular strategies. We address this gap in the research stream on modularity with a study using a cross-sectional sample of industries.
In the next section, we discuss extant theories on modular designs, innovation, and knowledge structures of the firm. We provide definitions of the constructs and build the research hypotheses. Then, we discuss the method, the context of the study, and the instrument development. By means of a second order Confirmatory Factor Analysis, we test the validity of a model of overall multidimensional modular capability, an integrated mix of multiple modular architectures. Using a Structural Equation Modelling, we assess the model of modular architectures and their antecedents and outcomes (see Figure 1). Finally, we discuss the findings and avenues for future research.

DEFINITIONS, CONCEPTS, AND HYPOTHESES

We develop a holistic model, which captures the antecedents, components, and strategic outcomes of modularity. The theoretical model is depicted in figure 1. In the next subsections we first define the central concepts of types of modularity. Then, drawing on theorizing and research on modularity, learning, and innovation, we build the research hypotheses.

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 we 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, we 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), we distinguish between internal and external product modularity. The concept of interfirm modularity (Baldwin and Clark, 2000; Langlois and Robertson, 1992; Schilling, 2000; Staudenmayer, Tripsas, and Tucci, 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. We 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.** Modularity scholars argue that modularization of products requires and enables new kinds of organizational structures and processes (Baldwin and Clark, 2000; Helfat and Eisenhardt, 2004; Karim, 2006; 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 or business 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). We 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). We 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 (Amit and Shoemaker, 1993; Dietrix and Cool, 1989; Kogut and Zander, 1992; Winter, 2003). To avoid tautology and contamination, we 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).

The impact of market dynamism on modularity management

We 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 Staudemayer and colleagues (2005) emphasize the competitive dynamics, Tu and colleagues (2004) focus exclusively on customer uncertainty. In their study of modularity in the home appliance industry, Worren and colleagues (2001) define market dynamics as the speed of change of both customer preferences and competitors’ products. We 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 we build on prior research and study simultaneously all three antecedents of modularity: customer uncertainty, competitive intensity, and technological opportunity.

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, we 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. We 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, we expect that market dynamics motivates firms to adopt internal product modularity, external product modularity, organizational process modularity, organizational structure modularity, and knowledge modularity. Therefore, we 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**

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, 1997, 2000; Worren et al., 2001). Strategic flexibility means the ability to do new things quickly (Shilling 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, we incorporate all three types of strategic flexibility in our model.

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 customization 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) explored the mechanisms through which modular product architectures increased product variety and innovation. He concluded that modular products, which were supported by modular process architectures achieved higher dynamic efficiency. This strategic approach reduced further the complexity of the managerial task and gage the organization a greater flexibility to undertake a larger number or a greater variety of new product development projects. We 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, 2002). 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 Nielsen, 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, we expect that knowledge modularity will influence the innovation of components, but we cannot predict the direction of the effect of knowledge modularity on speed of innovation of components based on the conflicting evidence in prior research. We 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. We 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 interfirrm 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, we expect that each type of modularity on its own will reduce the speed of architectural innovation. In the next section we 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

Drawing on prior research on modularity, we 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. We 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, we wanted to embed in our research a replication of the study of Worren et al. (2002) and to investigate how companies choose modularity initiatives in planning their strategies (Sanchez and Heene, 1996).

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, Sandvig, and Mabert, 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, we expect that strategic intent mediate 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.

The construct of integrated modularity

Scholars theorize on the impacts of modular architectures of products on the rest of the systems in an organization (Baldwin and Clark, 1997; Schilling, 2000). Schilling (2000) discusses the advantages of external product modularity within a system of loosely coupled organizations. According to Kusiak (2002), product modularity has a strong relationship with process modularity and resource modularity. To denote valuable simultaneous use of product, process, and resource modularity, he introduces the concept of integrated modularity. Furthermore, Sanchez (2000) argues that the use of modular product and process architectures influences organizational knowledge and learning in creating modular knowledge structures and new forms of organizational learning. “Thus, using technological knowledge to create modularity in product design becomes an important strategy for achieving modularity in organization designs” (Sanchez and Mahoney, 2003: pp. 362).

Firms with modular product architectures are likely to have modular architectures of processes, knowledge structures, and organizational structure. Consequently, we developed a hypothetical measurement model of multidimensional modularity of firms. We proposed that a the five types of modularity, internal product modularity, external product modularity, organizational process modularity, organizational structure modularity, and knowledge modularity, represent dimensions of a multidimensional construct of modularity with a higher level of abstraction. In order to test
empirically for the validity of the higher order construct of overall modularity, we propose to test the validity of a second order factorial structure. We develop the following hypothesis:

\textit{Hypothesis 10: The use of the five types of modularity is likely to be interdependent and can be explained by a higher order multidimensional construct of overall modularity.}

After we test hypothesis 10, we incorporate the concept of integrated modularity in our model for both theoretical and methodological reasons. On the theoretical level, we want to investigate the effects of market dynamics on the simultaneous implementation of several modularity types as a higher order capability as well as the impact of a simultaneous implementation of several modularity types as a higher order capability on strategic flexibility. From methodological point of view, we solve statistical problems of multicollinearity through the use of a higher order factor (see Bagozzi, 1994).

\section*{METHODS}

\textbf{Sample}

The unit of analysis of our study is the firm. We used as a sampling frame the population of companies in Italy, which consists of both business units of MNCs and Italian companies. We 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, 1992; Worren et al., 2002), we 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 we removed 25 responses because of missing data. We 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 \( p < .05 \).

\textbf{Instrument Development}

We built a questionnaire using scales developed and validated in prior research. Only for the construct of knowledge modularity and external product modularity we had to develop new scales.
We used theory and interviews with experts to develop the two new scales. 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, Pisano, and Shuen, 1997), we considered the construct of internal knowledge modularity to considerably overlap with the construct of organizational process modularity, which we include in the model. To avoid contamination of relationships in the structural model based on tautology, we 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. We measured the use of multiple external knowledge sources with the items developed by Zahra and Nielsen (2002). We 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. We then pilot tested the instrument using 90 respondents from executives from executive MBA courses. We 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 we used three items which question speed of change of customer preferences and needs (Jaworski 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 (Jaworski 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 that assess the degree to which the company has outsourced the production of some of the components it includes in its final product. We used for the development of the items the theoretical definitions of interfirm product modularity (Schilling, 2000; Schilling and Steensma, 1999) and modularity of manufacturing (Baldwin and Clark, 1997). We measured Organizational Process Modularity using three items which focus on codification, standardization, 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). Knowledge Modularity is captured by three items which assess the degree to which the firm puts together and
uses different external knowledge components. We used the measure based on the definition of Mahoney and Sanchez (2004) and on the empirical research of Zahra and Nielsen (2002) about the use of different external knowledge components.

We 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, 2004; Sanchez and Mahoney, 1996). We 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. We 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 new products with changes in the links between the products introduced in 2003. Although the measures are similar 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**

We 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 we examined the reflective factor loadings and their significance levels (see Table 1). Then, we 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 (Standardized Regression Weights > 0.40). The composite reliability, which draws on the standardized factor loadings and measurement error for each item, was estimated. It was above the accepted cut-off for all constructs (composite reliability > 0.60). We did not use Cronbach Alpha, because this reliability measure assumes equal factor loading of the items (Bollen, 1989), which contradicts the results of the CFA analysis.
We assessed the convergent validity and the discriminant validity of the model (Bagozzi, 1994; Bollen, 1989; Shook, Ketchen, Hult, and Kacmar, 2004). Each latent variable had acceptable convergent validity with variance extracted >0.50 (Shook et al., 2004). To assess the discriminant validity we 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 than the one-factor models.

Since the information on variables was provided by the same respondent, we conducted Harman’s one-factor test for common method bias. When we estimated 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< .10 (var=0.056; t=0.875, p>0.10). The results showed that a single common method factor did not account for a large portion of the covariance in the measures.

We 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, we 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).

**FINDINGS**

**Towards a Multidimensional Construct of Modularity**

We 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, we 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 2). The External Product Modularity variable had a factor loading, which was not significant at p<.05. Internal product modularity and organizational structure had standardized factor loading which were lower than the accepted threshold of .40. Therefore, we 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.

We 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<.05, and that the standardized factor loadings of the first order factors were significant at p<.05 and higher than .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 we termed: Integrated 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, we find evidence on the existence of a second order capability to manage simultaneously two first order capabilities.

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Insert Figure 2 around here
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**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, Gove, and Hitt, 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). We used a structural
equation program, AMOS, to test our model. We used 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, we tested the hypothesized structural model (Byrne, 2001). Firstly, we assessed the overall fit of the model (Joreskog, Soerbom, and du Toit, 1999). Then, we assessed the individual parameter estimates for the paths in the model and their statistical significance. Finally we 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, we did the model re-specifications 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, we used the alternative goodness-of-fit statistics, recommended in the literature (Bollen, 1989; Hu and Bentler, 1999; MacCallum and Austin, 2000; Shook et al., 2004). To test the overall fit of the model, we used four goodness-of-fit indices: Comparative 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). CFI (0.95) and RMSEA (0.047) suggest that the model fits well the data. The narrow confidence interval for RMSEA (0.038 to 0.55) suggests that the RMSEA index has a good precision in reflecting the model fit (MacCallum, Browne, and Sugawara, 1996). Given the lower value of the ECVI index in comparison both to the independence model and the saturated model, we 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 IFI value of our model (.95) indicates once again an adequate overall fit of the model to the data. Thus, we can conclude that the overall fit of the conceptual model was very good (CFI=0.95; RMSEA=0.047; IFI=0.95; lowest ECVI).

Table 3 summarizes the coefficients and the p-values of the relationships tested in the model. We show the significant paths in figure 3. In Hypotheses 1a, 1b, 1c, 1d and 1e, we predicted that market dynamics will have a positive impact on internal product modularity (hypothesis 1a), external product modularity (hypothesis 1b), structure modularity (hypothesis 1c), process modularity (hypothesis 1d) and knowledge modularity (hypothesis 1e). The parameter estimates for two of the hypothesized paths, internal product modularity and external product
modularity, were positive and statistically significant at p<.05 (b=.41; p=.02 and b=.20; p=.03). Thus, hypotheses 1a and 1b were supported. Moreover, the path between market dynamics and the new construct of integrated modularity, a combination of process modularity and knowledge modularity) was positive and statistically significant (b=.27; p=.003). Thus, hypotheses 1d and 1e were supported too. Market dynamics influences positively knowledge modularity when it is integrated with process modularity. The path between technological opportunities and modular organizational structure and between technology opportunities and knowledge modularity were added in a post hoc analysis because of the high modification indices. These paths had positive and statistically significant coefficient. Thus, we have evidence that only one dimension of market dynamics, namely technological opportunities, influenced the choice of structure and knowledge modularity.

In hypothesis 5a, we 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 (b=.49; p=.01). Thus, we found support for hypothesis 5a.

Hypotheses 2a, 3a, and 4a predicted that there will be 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. We found support only for Hypothesis 2a. The coefficient of the path between internal product modularity and strategic flexibility through variants was positive and statistically significant supporting Hypothesis 2a (b=.31; p=.046). This finding replicates the results of Worren and colleagues (2002). We did not find evidence in favour of the expected relationship between internal product modularity and second order strategic flexibility (Hypothesis 3a and 4a).

In Hypotheses 2b, 3b, and 4b, we 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. We found that there is a negative and marginally significant relationship between external product modularity and flexibility of product variants (Hypothesis 2b) (b=-.54; p=.09). Surprisingly, we found that there is a significant negative relationship between external product modularity and flexibility through innovation of components (b=-.74; p=.04). External product modularity influences strategic flexibility of components as we expected but the impact is negative. We found support for the
hypotheses 4b, in which we proposed a negative relationship between external product modularity and strategic flexibility of architectural innovation (b=-.77; p=.03).

In hypotheses 2c, 3c, and 4c, we suggested that there is a positive relationship between organizational structure modularity and strategic flexibility in terms of number of product variants and flexibility of components and a negative relationship between organizational structure modularity and flexibility of links in product architectures. We found support only for Hypothesis 2c (b=.33; p=.03). Only the path coefficient between organizational structure modularity and strategic flexibility through variants was positive and statistically significant at p<0.05.

In hypotheses 2d, 3d, and 4d, we suggested that organizational process modularity will be positively associated with strategic flexibility in terms of product variants and component innovation (hypotheses 2d and 3d) and negatively associated with strategic flexibility in terms of link innovation (hypothesis 4d). We found support only for hypothesis 4d (b=-.71; p=.001). Hypothesis 3d was partially supported because we found a significant relationship between process modularity and strategic flexibility of components but the sign was negative (b=-1.05; p=.001).

In hypotheses 2e, 3e, and 4e, we proposed that external knowledge modularity will be positively associated with strategic flexibility in terms of variants and component innovation and negatively associated with strategic flexibility in terms of architectural innovation. We found that knowledge modularity has a significant impact on all three types of strategic flexibility but the impact is always negative (Hypothesis 2e: b=-.39; p=.002; Hypothesis 3e: b=-.51; p=.001; Hypothesis 4e: b=-.23; p=.07). We explain the opposite signs of the findings with the existence of the integrated modularity construct, which captures the positive effects of knowledge modularity and organizational process modularity on strategic flexibility.

We tested the effect of integrated modularity, the factor which represents the joint effect of organizational process modularity and external knowledge modularity, on the three types of strategic flexibility. The relationship between integrated modularity and strategic flexibility of product variants was positive and significant (b=.90; p=.001). The coefficients associated with the relationship between integrated modularity and strategic flexibility of components and strategic flexibility of links were both positive and statistically significant at p<.01 (b=2.73; p=.001 and b=1.64; p=.001). Thus, we have good evidence to conclude that there are positive effects of the simultaneous management of external knowledge modularity and organizational process modularity on all types of strategic flexibility flexibility. This finding supports and extends the understanding of the positive effects of knowledge modularity and process modularity.

In Hypotheses 5b, 5c, 5d, 5e, 5f, and 5g we 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. We found support only for Hypotheses 5e and 5f ($b=.26; p=.01$ and $b=.87; p=.001$). Thus, there was a positive effect of intent on structure modularity and process modularity. The relationship between intent and external product modularity was marginally significant and had a negative sign. The relationship between knowledge modularity and intent was negative and significant at $p<0.05$ (Hypothesis 5g). Firms with high learning intent prefer to decrease knowledge modularity.

In Hypotheses 5h, 5i, and 5j, we proposed that entrepreneurial intent will have a positive association with strategic flexibility. Only the coefficient of the direct relationship between intent and strategic flexibility through variants was significant and negative ($b=-.27; p=.01$). However, intent influenced positively strategic flexibility of variants and the two other types of strategic flexibility through indirect paths. For example, the impact of intent on the strategic flexibility of innovation of links 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 of links were significant and negative. Thus, the sign of 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 links. Consequently, entrepreneurial intent increases the efforts in managing modular organizational structure and thus increases the learning rate and flexibility of the firm.

**Analysis of Post Hoc Models**

We tested a model in which we did not include the second order factor of integrated 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 we tested a model with a control for size of the firms, measured in terms of number of employees. We 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.

**DISCUSSION**

In this study we investigate how different types of modular architectures influence the capability of the firm to match the market dynamics. We test a system of hypotheses on modular strategies in the setting of a cross-sectional sample of industries. The hypothesis on the existence of a capability to manage simultaneously multiple modular dimensions was tested for the first time and was refined. To further extend theories on modularity, we added new types of modularity and flexibility to the model of Worren and his colleagues (2002), improved the measures of market context, and tested the structural model with latent variables to avoid systematic bias of coefficients due to measurement error.

Students of 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). First, we find that firms do address the challenges of dynamic markets with modular strategies at product, organizational, and knowledge levels. However, we find that not all types of modular design are beneficial for all types of strategic flexibility. Internal product modularity and organizational structure modularity increase only one type of strategic flexibility of the firm, number of product variants. Moreover, external product modularity, organizational process modularity, and external knowledge modularity can have negative effects on innovation of components and links, i.e. on second order strategic flexibility. Third, only the firms that did manage organizational process modularity and external knowledge modularity simultaneously and thus possess the integrated modularity capability were able to achieve higher innovation. Finally, the strategic intent increased flexibility through its impact on modular design. The intent to learn leads to reduction of external product modularity and to development of integrated modularity capability thus increasing the innovation in firms.

Scholars of modularity propose that the a priori specification of product architecture allows automatically all types of modularity to function in accord and stimulates decoupled learning about both components and architectures (Baldwin and Clark, 2000; Sanchez and Mahoney, 1996). We 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 the speed of innovation. An explanation for the problems of firms to increase their rates of innovation through
product modularity can be found in the failure of firms to address different types of modular architectures simultaneously. In particular, modular design must integrate modular process design and knowledge design, which will in turn ensure coordination of the constant parallel experimentation. A priori definition of both modular process and knowledge architectures is essential in enabling the successful experimentation on the component level in the separate organizational units (Baldwin, 2001; Baldwin and Clark, 2000).

The negative impact of external product modularity on strategic flexibility suggests that when decoupled from knowledge modularity and organizational modularity, external product modularity is likely to fail to generate learning advantages. 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). We did not find evidence that firms undertake simultaneous external product modularity and external knowledge modularity. This approach of product-focused management of external relationships makes component innovation efforts vulnerable to the problems of different rates of change in different technological sectors and the resulting imbalances in component innovation (Brusoni et al., 2001). Even in the presence of stable (physical) interfaces and fixed product architecture, imbalances of innovation speed may emerge on the technology level, i.e. on the knowledge level. Therefore, firms cannot benefit from external product modularity without an active integration of knowledge management and product component management.

With regard to the definitional features of modular architectures (Baldwin and Clark, 2000), we 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 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 (Fleming and Sorenson, 2001; Brusoni and Prencipe, 2001). The failure of internal product modularity and organizational structure modularity to influence learning rate suggests that isolated management of single modular architectures can hinder the second order strategic flexibility effects of modular designs.

On the basis of the evidence, we 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. Knowledge and organizational coordination cannot be achieved relying on the automatic mechanisms of a specified product structure. Since organizational processes are a key type of the organizational knowledge (Amit and Shoemaker, 1993; Argote and Darr, 2000; Zander and Kogut, 1992), we 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). Brusoni and Prencipe (2001) suggest that companies with specific capabilities shall play the coordination and integration functions for products with modular design. We add evidence on the importance of the coordination capabilities such as integrated modularity in each firm participating in a modular system.

The construct of integrated modularity, a higher-order modularity capability, can help us come closer to understanding the management of a learning modular architecture. We provide evidence that architectural and component learning can be harmed by both organizational process modularity and knowledge modularity, if the two types of modularity are not managed simultaneously by the higher order capability of integrated modularity. The construct of integrated modularity shifts the focus from managing the design of the output, the product, to managing the design of the input, the knowledge and process resources. Consistent with the knowledge-based view of the firm (Grant, 1996), we provide empirical evidence that the capability to manage simultaneously internal knowledge components and external knowledge components matters for achieving flexibility through product innovation. The potential for innovation comes from managing the recombination of knowledge structures (Galunic and Rodan, 1998). The integrated modularity capability, a capability to manage simultaneously internal and external knowledge modularity, is the mediating variable of the effect of a dynamic market on the dynamics of a firm’s behaviour in terms of innovation. Therefore, we argue that integrated modularity is one specific
dynamic capability, a 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. We 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., Worrren 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 it possible to detect effects with smaller size. 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 (Zucker, 1977), which influence our findings.

Another opportunity will be to incorporate into the model other constructs related to modularity 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.

Explanations of firm’s flexibility in dynamic markets based solely on the use of product modularity allow us to see only a piece of the whole picture. The overemphasis on the relatively simple product modularity and the neglect of the complexities of managing organizational and knowledge modularity can mislead both managers and researchers. In this study, we provided insights about management of modular designs, a concrete capability through which firms respond to dynamic markets. We encourage further multi-method studies in this direction.
Theoretical Model:

Figure 1: Theoretical model
<table>
<thead>
<tr>
<th>Construct/Indicator</th>
<th>Standartized Coefficient</th>
<th>Estimate/St. Error</th>
<th>Composite Reliability</th>
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<td>0.940</td>
<td>5.194</td>
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</tr>
<tr>
<td>Item 3</td>
<td>0.946</td>
<td>5.198</td>
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<tr>
<td>Entrepreneurial Intent</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Item 1</td>
<td>0.906</td>
<td>-b</td>
<td>0.85</td>
</tr>
<tr>
<td>Item 2</td>
<td>0.970</td>
<td>20.135</td>
<td></td>
</tr>
<tr>
<td>Item 3</td>
<td>0.970</td>
<td>20.115</td>
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<tr>
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<td>-------</td>
<td>--------</td>
<td></td>
</tr>
<tr>
<td><strong>Strategic Flexibility 1</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Item 1</td>
<td>0.54</td>
<td>6.092</td>
<td>0.83</td>
</tr>
<tr>
<td>Item 2</td>
<td>0.74</td>
<td>-b</td>
<td></td>
</tr>
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Note: b Factor loading is fixed to one for scaling of the latent variable.

**Table 1: Results from CFA tests of construct reliability**
Figure 2: Second -order CFA model of firm modularity: hypothesis 10

<table>
<thead>
<tr>
<th>Construct Level 2/ Construct Level 1</th>
<th>Standardized Coefficient</th>
<th>Estimate/St. Error</th>
<th>Composite Reliability</th>
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</thead>
<tbody>
<tr>
<td><strong>Market Dynamics</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Customer Uncertainty</td>
<td>0.543</td>
<td>3.759*</td>
<td>0.76</td>
</tr>
<tr>
<td>• Competitive Intensity</td>
<td>0.687</td>
<td>2.697*</td>
<td></td>
</tr>
<tr>
<td>• Tech. Opportunities</td>
<td>0.667</td>
<td>4.982*</td>
<td></td>
</tr>
<tr>
<td><strong>Integrated modularity</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Organizational Process Modularity</td>
<td>0.436</td>
<td>13.165*</td>
<td>0.67</td>
</tr>
<tr>
<td>• External Knowledge Modularity</td>
<td>0.917</td>
<td>3.069*</td>
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</table>

* Statistically significant at p<0.01

Table 2: Results from Second order CFA on Market dynamics and the post hoc Second-Order CFA on Integrated modularity with two first order factors
<table>
<thead>
<tr>
<th>Following construct</th>
<th>Leading construct</th>
<th>Estimate</th>
<th>ML S.E.</th>
<th>ML P</th>
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<tbody>
<tr>
<td>Internal Product Modularity</td>
<td>Market Dynamics</td>
<td>.417</td>
<td>.178</td>
<td>.019</td>
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<tr>
<td>External Product Modularity</td>
<td>Market Dynamics</td>
<td>.199</td>
<td>.089</td>
<td>.026</td>
</tr>
<tr>
<td>Integrated modularity</td>
<td>Market Dynamics</td>
<td>.273</td>
<td>.093</td>
<td>.003</td>
</tr>
<tr>
<td>Intent</td>
<td>Market Dynamics</td>
<td>.491</td>
<td>.187</td>
<td>.009</td>
</tr>
<tr>
<td>Structure Modularity</td>
<td>Technology</td>
<td>.620</td>
<td>.200</td>
<td>.002</td>
</tr>
<tr>
<td>Knowledge Modularity</td>
<td>Technology</td>
<td>.259</td>
<td>.118</td>
<td>.028</td>
</tr>
<tr>
<td>Internal Product Modularity</td>
<td>Technology</td>
<td>-.005</td>
<td>.149</td>
<td>.972</td>
</tr>
<tr>
<td>External Product Modularity</td>
<td>Intent</td>
<td>-.075</td>
<td>.039</td>
<td>.052</td>
</tr>
<tr>
<td>Structure Modularity</td>
<td>Intent</td>
<td>.260</td>
<td>.090</td>
<td>.004</td>
</tr>
<tr>
<td>Process Modularity</td>
<td>Intent</td>
<td>.875</td>
<td>.063</td>
<td>.000</td>
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<tr>
<td>Knowledge Modularity</td>
<td>Intent</td>
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<td>.094</td>
<td>.049</td>
</tr>
<tr>
<td>Str. Flexibility 1</td>
<td>Intent</td>
<td>-.273</td>
<td>.091</td>
<td>.003</td>
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<tr>
<td>Structure Modularity</td>
<td>External Product Modularity</td>
<td>.635</td>
<td>.366</td>
<td>.083</td>
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<td>Str. Flexibility 1</td>
<td>Internal Product Modularity</td>
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<td>.157</td>
<td>.046</td>
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<td>External Product Modularity</td>
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<td>.086</td>
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<td>External Product Modularity</td>
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<td>Str. Flexibility 1</td>
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<td>.000</td>
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<td>Str. Flexibility 2</td>
<td>Integrated modularity</td>
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<td>Str. Flexibility 2 Links</td>
<td>Integrated modularity</td>
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<td>.000</td>
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<tr>
<td>Str. Flexibility 1</td>
<td>Knowledge Modularity</td>
<td>-.392</td>
<td>.125</td>
<td>.002</td>
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<tr>
<td>Str. Flexibility 2</td>
<td>Knowledge Modularity</td>
<td>-.510</td>
<td>.149</td>
<td>.000</td>
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<tr>
<td>Str. Flexibility 2 Links</td>
<td>Knowledge Modularity</td>
<td>-.226</td>
<td>.125</td>
<td>.070</td>
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<td>Str. Flexibility 2</td>
<td>Orga Process Modularity</td>
<td>-1.046</td>
<td>.240</td>
<td>.000</td>
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<tr>
<td>Str. Flexibility 2 Link</td>
<td>Orga Process Modularity</td>
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<td>.179</td>
<td>.000</td>
</tr>
<tr>
<td>Str. Flexibility 1</td>
<td>Orga Structure Modularity</td>
<td>.330</td>
<td>.152</td>
<td>.030</td>
</tr>
</tbody>
</table>

Table 3: Magnitude and significance of the hypothesized structural relationships (ML Estimation and Bootstrap ML Estimation): unstandardized path coefficients
Figure 3: Structural model with obtained unstandardized coefficients: Paths with full lines are statistically significant at p<.05. Paths with punctuated lines are statistically significant at p<.10.
**Appendix A: Demographic Data of Respondent Firms**

### Industry type

<table>
<thead>
<tr>
<th>Industry type</th>
<th>Frequency</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electronics</td>
<td>95</td>
<td>37.0</td>
</tr>
<tr>
<td>Automotive or parts</td>
<td>23</td>
<td>8.9</td>
</tr>
<tr>
<td>Software</td>
<td>16</td>
<td>6.2</td>
</tr>
<tr>
<td>Furniture and fixtures</td>
<td>17</td>
<td>6.6</td>
</tr>
<tr>
<td>Fabricated Metal Products</td>
<td>11</td>
<td>4.3</td>
</tr>
<tr>
<td>Transportation equipment</td>
<td>20</td>
<td>7.8</td>
</tr>
<tr>
<td>Appliances</td>
<td>3</td>
<td>1.1</td>
</tr>
<tr>
<td>Textiles</td>
<td>7</td>
<td>2.7</td>
</tr>
<tr>
<td>Industrial machinery and equipment</td>
<td>55</td>
<td>21.4</td>
</tr>
<tr>
<td>Hardware</td>
<td>10</td>
<td>3.9</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>257</strong></td>
<td><strong>100.0</strong></td>
</tr>
</tbody>
</table>

### Sales

<table>
<thead>
<tr>
<th>Sales</th>
<th>Frequency</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 1 million</td>
<td>20</td>
<td>7.8</td>
</tr>
<tr>
<td>1 to 10 million</td>
<td>65</td>
<td>25.3</td>
</tr>
<tr>
<td>10 to 50 million</td>
<td>67</td>
<td>26.1</td>
</tr>
<tr>
<td>50 to 100 million</td>
<td>29</td>
<td>11.3</td>
</tr>
<tr>
<td>100 million and above</td>
<td>76</td>
<td>29.6</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>257</strong></td>
<td><strong>100.0</strong></td>
</tr>
</tbody>
</table>

### Employees

<table>
<thead>
<tr>
<th>Employees</th>
<th>Frequency</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 50</td>
<td>79</td>
<td>30.7</td>
</tr>
<tr>
<td>50 to 200</td>
<td>68</td>
<td>26.5</td>
</tr>
<tr>
<td>200 to 500</td>
<td>43</td>
<td>16.7</td>
</tr>
<tr>
<td>500 to 1000</td>
<td>12</td>
<td>4.7</td>
</tr>
<tr>
<td>1000 and above</td>
<td>55</td>
<td>21.4</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>257</strong></td>
<td><strong>100.0</strong></td>
</tr>
</tbody>
</table>
### Appendix B: Measurement

<table>
<thead>
<tr>
<th>Variable</th>
<th>Questionnaire Items</th>
</tr>
</thead>
</table>
| **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** | 1. The part of the final product which composes of components produced by our company is: (Reversed)  
2. We have outsourced the production of a part of the components of the final product.  
3. Our company has contracted out a major part of its manufacturing/production activities. |
| **Organizational Structure Modularity** | 1. We try to develop small autonomous units to encourage innovation and flexibility.  
2. Each of the components of the product is designed in separate high-autonomous unit of the organization. |
| **Organizational Process Modularity** | 1. We have documented the steps involved in key business processes.  
2. We have defined business processes that cut across functional boundaries.  
3. We have standardized business processes across departments and organizational units. |
| **Knowledge Modularity (external)** | 1. We have procedures and systems for transferring knowledge across projects and organizations.  
2. Our company uses joint ventures or alliances to acquire innovative manufacturing technologies.  
3. Our company uses joint ventures or alliances to gain knowledge about new manufacturing systems and methods. |
| **Strategic Flexibility 1** | 1. We offer a high variety of products constructed of different components.  
2. We have in comparison with our leading competitors a small number of variants within our main product family. (reversed) |
| **Strategic Flexibility 2 Components** | 1. We introduced the following number of products with changes only in components. |
| **Strategic Flexibility 2 Links** | 1. We introduced the following number of product with changes in the links between the components. |
| **Intent** | 1. We have a business plan to develop new technologies for new markets.  
2. We have a business plan to use existing technologies to enter new markets.  
3. We have an overall business plan to redesign our product development process.  
1. Technological developments in our industry are rather minor. (reversed)  
2. A large number of new product ideas have been made possible through technological breakthroughs in our industry.  
3. Technological changes provide big opportunities in our industry. |
| **Technological Opportunities** | 1. Competition in our industry is cutthroat.  
2. There are many promotion wars in our industry. |
| **Competitive Intensity** | 1. We are witnessing demand for our products and services from customers who never bought them before.  
2. New customers tend to have product-related needs that are different from those of our existing customers.  
3. In our kind of business customers’ product preferences change quite a bit over time. |
| **Customer Uncertainty** | 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. |

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REFERENCES


Hu, L., and Bentler, P.M. 1999. Cut-off criteria for fit indexes in covariance structure analysis:


