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MODULARITY, STRATEGIC FLEXIBILITY, AND FIRM PERFORMANCE: A STUDY OF THE HOME APPLIANCE INDUSTRY

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Recent theorizing has proposed that modular product and process architectures are key enablers of strategic flexibility. We formulated an integrative conceptual model encompassing antecedents, contributing factors, and outcomes of modularity. We then tested this model on data from managers in U.S. and U.K. home appliance companies using structural equations modeling. The results indicate a positive relationship between modular product architectures and performance, with product model variety as a mediating variable. The results also highlight linkages between perceptions of market context and the use of modular products architectures, and between complementary organizational capabilities and firm performance. Copyright © 2002 John Wiley & Sons, Ltd.

INTRODUCTION

Modular product and process architectures are considered prerequisites for efficient mass customization and cycle time reduction, and thus potential sources of increased strategic flexibility for firms facing dynamic market environments (Sanchez, 1995; Pine, 1993; Meyer and Lehnerd, 1997). *Modular product architectures (or platforms)* are created by decomposing a product design into relatively independent components and by specifying standard interfaces that define the inputs and outputs that flow between interacting components (Sanchez, 1998; Shirley, 1992; Suh, 1996). Similarly, *modular process architectures* are decompositions of the company's key activities into specific routines and interfaces that allow frequent reconfiguration of processes, in the same way as for modular components in physical products (Sanchez and Mahoney, 1996).

Sanchez (1995, 1998) predicted three 'first-order' effects of modular product designs. Through new combinations of standard modules, modularity should enable a high number of product variations (or 'product options'). At the same time, the reuse of standard modules should reduce the time of switching between options (compared to integrated designs), as well as the cost of switching. Home appliance companies create different models of vacuum cleaners, washing machines, freezers, and refrigerators by mixing and matching key components in different combinations. For example, General Electric leverages several models of dishwashers by installing different doors and controls on common assemblies of enclosures, motors, and wiring harnesses (Sanchez, 1998). Electrolux recently tested a concept of mass customizing refrigerators by letting consumers chose between 15,000 combinations of colors and materials, such as between stainless steel or wooden shelves. This concept also offers customers the ability to upgrade parts of their refrigerators (such as the color of the body or the handles) to fit the new style of kitchens that are renovated or refurbished (Rayner, 1999).

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Sanchez (1995, 1998) and Garud and Kumaraswamy (1995) have also described some important 'second-order' effects. Modularity should allow parallel and distributed business processes, increase incremental innovation by separating component-level and architectural learning processes, and enable interactive and real-time market research based on analyzing customer perceptions to new product variations. Because the strategic use of modularity is still a recent phenomenon in home appliances, these second-order effects are perhaps less evident. However, some of the global home appliance firms have made local development centers responsible for specific modules (for a vacuum cleaner, these modules may be the motor, the electronic circuit board, or the accessories). Because task interdependencies have been reduced by establishing standard interfaces, these centers are allowed to carry out their development efforts in a relatively autonomous fashion. Incremental innovation is fostered because home appliance companies have identified modules that undergo frequent technological change (e.g., filters in vacuum cleaners) and often outsource the development of these to suppliers with distinctive capabilities. In the future, some appliance firms are also likely to imitate the strategies of electronics firms such as Sony that carry out real-time market research on small lots of trial models leveraged from modular architectures. For example, Electrolux recently established an 'excitement center' in Paris to test customer reactions to experimental concepts for future home appliances.

A number of case studies have described the use of modular systems in industries such as software (Cusumano, 1991; Post, 1997; Meyer and Seliger, 1998), computers (Baldwin and Clark, 1997), consumer electronics (Sanderson and Uzumeri, 1997), and car manufacturing (Cusumano and Nobeoka, 1997). However, whereas these cases represent 'best practice' of applying modular platforms, the key proposition is that *all* companies would benefit from implementing modular systems if they face dynamic market conditions (Sanchez, 1995). Although it is clear that some firms have derived benefits from introducing modular systems, we know little about the effects for populations of firms within industries. Some authors have argued that establishing modular systems incurs significant coordination costs and point to case studies of failed attempts at introducing global platforms in the car industry (Tagliabue, 1996; Fisher, Jain, and MacDuffie, 1995). Successfully introducing modular systems does require fundamental technological and organizational reorientation and it is little surprise to find that many traditional manufacturing firms struggle to implement these principles (Marsh, 1997).

In this research, we sought to contribute to the extant literature in the following ways. We were interested in looking systematically at a sample of 'average' firms, with varying degrees of modularity in their products and processes.[1] Nobeoka and Cusumano (1997) previously conducted a study of modular platforms in the car industry, and Meyer and Roberts (1986) in small technology-based firms. This study adds to the existing knowledge base by focusing on the home appliances industry, which so far has received little attention.[2] This industry is also relevant to study because there might be more variance between firms with regard to product architectures than in more high-technology (or network based) industries, where industry-wide standards often dictate product architectures. In home appliances, product platforms are usually proprietary to every firm and there have so far been few incentives for creating industry-wide standards.

In addition to technology management theories, our research was also informed by organizational and strategic management theories that address the role of *complementary resources*. The role of complementary resources can be viewed from two perspectives. The first concerns the *process* of adopting new product creation frameworks. This process is often initiated when managers perceive the competitive environment to be changing more rapidly than before and then develop an explicit commitment to increasing flexibility by renewing their firms' products and processes. Implementing new principles for product design and development may in turn lead to (or depend on) changes in culture or work patterns. In other words, it seems reasonable to assume that the causal links between product modularity and strategic flexibility are *mediated* by other factors, such as managerial perceptions of the market context, the firm's strategic intent, and organizational climate and structure. We thus follow the recommendations of Sanchez

[1] Modularity is not a dichotomous variable (Ulrich and Eppinger, 1995) in that most systems can be classified along a continuum from highly modular to highly integrated.

[2] Recent exceptions are John and Harrison (1999), Sobrero (1995), and Sobrero and Roberts (1999).

and Heene (1996) in explicitly incorporating cognitive elements in a systems view of how managers respond to dynamic environments.

Secondly, resource-based theory (Teece, 1978; Barney, 1991) suggests that it is important to consider complex sets of organizational resources in understanding how strategic flexibility may result in *competitive advantage*. For example, the strategic value of product modularity may be linked to the presence of other organizational resources such as flexible structures, processes, or culture. It has already been demonstrated that investments in technological resources such as information technology require the existence of complementary resources to confer competitive advantage (Powell and Dent-Micallef, 1997). Again, we assumed that a holistic model would be necessary to capture the antecedents, contributing factors, and strategic outcomes of modularity. Our propositions and research questions link the different dimensions of our conceptual model that appears in Figure 1. The particular methodology we apply is structural equations modeling, which allows us to consider simultaneously the relationships between single variables (as in correlational techniques) as well as the fit of a more complex overall model with reinforcing and counteracting causal links.

PROPOSITIONS AND RESEARCH QUESTIONS

The traditional paradigm for product competition and manufacturing relied on *minimizing variety and change* to achieve economies of scale, low cost, and quality. This paradigm grew in response to the need for techniques for managing firms in product markets with mostly stable technologies and market preferences. More variety (or more frequent model changes) was associated with higher unit costs (due to a correspondingly lower volume for each item in a product line) and to higher complexity of the manufacturing operations (leading to higher requirements for coordination and control of inventory, scheduling, defects, etc.). The

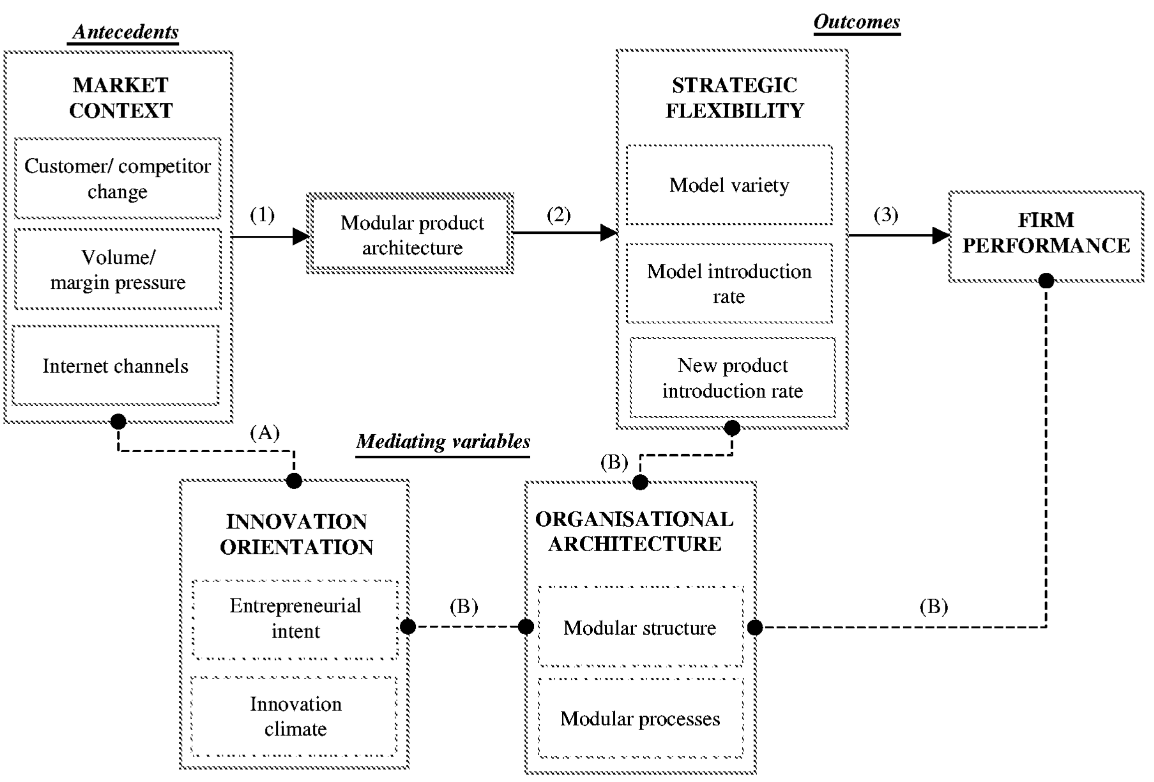

Figure 1. The hypothesized conceptual model of the relationship between market context, innovation orientation, organizational architecture, modularity, strategic flexibility, and performance. The numbers refer to the propositions and the letters to the research questions

low rate of change meant that conventional principles for product design defined product architectures as the *output* of the development process. These *integrated* designs contained many interrelated components that made the overall design time-consuming and costly to change, since change in one component required compensating changes in other components (Sanchez, 1995).

New strategic principles have emerged for managing firms in product markets characterized by changing technologies, by customer preferences that are shifting, uncertain, or heterogeneous, and by the threat of being outmaneuvered during frequent competitive interactions with competitors. In dynamic product markets, there are no specific tangible resources that can provide 'sustainable competitive advantage.' However, a superior ability to leverage existing competencies to take advantage of emerging customer needs may lead to *temporary* advantage. The concept of strategic flexibility broadly denotes such firm abilities to respond to rapidly changing markets (Sanchez, 1995).[3] In the context of product competition it can be operationalized as *the number of product variations* offered, *the frequency of new model introductions*, as well as *the number of entirely new products* introduced. It has been suggested for some time that manipulating product variety and change are vital aspects of competitive strategy (Hofer and Schendel, 1978; Lancaster, 1990; Kekre and Srinivasan, 1990). The contribution of the strategic flexibility approach is to highlight the enabling role of *modular product architectures.* This approach highlights how strategic flexibility can be increased through the recombination of modules, while costs and complexity are contained by reusing the same, standard modules across models (component sharing) or model generations (component carry-over). For example, after acquiring Philips' home appliance business in 1991, Whirlpool modularized the products to ensure that many models could be built on the same basic platforms (Maruca, 1994). Whereas competitors typically had one motor for each vacuum cleaner model or product family, Whirlpool introduced one standard motor for all models.

Formally speaking, a modular architecture is one that minimizes interdependencies between modules performing different functions.[4] This principle is applicable to any complex system, including work processes, organizational structures, or knowledge systems, which can be decomposed into relatively autonomous entities that are coordinated by means of standard interfaces (Sanchez and Mahoney, 1996). For example, Zenger and Hesterly (1997) note that self-managing teams are increasingly replacing hierarchy and considered separate 'economic units' that are configured to product and exchange definable outputs, be measured as separate units, and rewarded directly for their performance. Jarvenpaa and Ives (1994) describe the 'dynamic network organization' as one where modular units are mixed and matched according to unique customer needs.

One should note that the modular approach represents a departure from conventional ways of viewing organizational flexibility. For example, in previous studies of decision making, flexibility has sometimes been operationalized as recursiveness—the tendency to revisit or change earlier decisions (e.g., Sharfman and Dean, 1987). In contrast, the notion of architecture implies that certain higher-level elements (e.g., interface specifications) need to be 'frozen' for a predetermined period of time to allow modular development processes at the component level. In both classic organization theory (e.g., Morgan, 1986) as well as in more recent theorizing on organizational improvisation (e.g., Moorman and Miner, 1998; Barrett, 1998), flexibility is typically equated with informal and ad hoc systems. However, it is impossible to decompose a system that does not have an explicit structure. Modularization of business processes thus requires a relatively high degree of *formalization and codification.* As with earlier approaches to process innovation such as Total

[3] The concept of strategic flexibility (Sanchez, 1995) primarily addresses the technological and product design dimensions of an organization's flexibility in competing in product markets. It is similar but not identical to the following concepts, most of which also include other dimensions such as culture and structure: transformative capability (Garud and Nayyar, 1994), dynamic capabilities (Teece, Pisano, and Shuen, 1997), adaptive capacity (Astley and Brahm, 1989), strategic response capability (Bettis and Hitt, 1995), organizational flexibility (Volberda, 1996), self-designing organizations (Hedberg, Nystrom, and Starbuck, 1977), sustained innovation (Dougherty and Hardy, 1996), and enacting organizations (Daft and Weick, 1984).

[4] Complex systems may allow many different decompositions, only some of which provide the desired flexibility in a given market context. Decisions about how to define and select modules are based on the particular *functional requirements* for the product or process as well as considerations of the costs and benefits of alternative ways of modularization (see Erixon, 1996; Robertson and Ulrich, 1998; Thomke and Reinertsen, 1998).

Quality Management and reengineering, modularization begins with an analysis and documentation of existing processes in order to identify and define the units that are to be the reconfigurable building blocks. Codification and partitioning of knowledge and processes then allow the leveraging of resources across organizational boundaries (Zander and Kogut, 1995; Szulanski, 1993). This is analogous to leveraging modular product designs except that the resources that are transferred are process specifications and best practices as opposed to physical components. For example, one home appliance company we studied standardized its product development processes across different product divisions producing stoves, dishwashers, and refrigerators. This standardization defined common approaches, stages, and criteria (e.g., for product concept development and screening). By having all the involved teams and departments follow the same basic process architecture, the company achieved more rapid knowledge transfer and rotation of personnel across organizational boundaries.[5] By decoupling resources (in this case, knowledge and human capital), flexibility is increased because the resources can be applied to a range of alternative work processes instead of being limited to a specific department or division.

In sum, modularity has been proposed as a key principle for firms adapting to dynamic markets. We thus expected that firms in which managers perceive the environment to be more dynamic will be characterized by higher degrees of product modularity; that product modularity will be positively related to strategic flexibility, which in turn should positively influence firm performance. Our arguments can be summarized in the following propositions:

Proposition 1: Firms facing a more dynamic market context are more likely to employ modular product architectures.

Proposition 2: Modular product architectures are associated with higher strategic flexibility (model variety and model and product introduction rate).

Proposition 3: Strategic flexibility (product variety and model and product introduction rate) is associated with higher firm performance.

As noted above, we adopted a holistic model to capture some of the intermediate variables that may moderate the relationships between modularity and firm performance (see Figure 1). However, these linkages are complex and extant theory did not provide a clear rationale for specifying the direct or indirect links that may exist. Consequently, we framed this part of our investigation as two research questions related to factors that influence the process of adopting modular principles and factors that influence the strategic value of modularity.

The strategic flexibility approach prescribes that firms facing increased dynamism first change their overall strategic logic governing product creation and marketing, and then introduce modularity as a means to achieve higher strategic flexibility. However, our initial fieldwork had suggested that the principles governing product architectures were partly disassociated from strategic planning in some firms, and that some manufacturing managers viewed modularity more as a means for reducing cost rather than as a means for increasing strategic flexibility. For researchers it is important to remember that the level of modularity in any given firm may reflect both intended strategic adaptation as well as the heritage of existing, integrated systems, as the process of modularization may take several years in a large firm. Some firms may also adopt modular principles for product design without revising their fundamental strategic logic.[6] Such firms may make incremental adjustments to their product structures (for example, standardize certain components across product lines or product generations) as an isolated effort to reduce cost rather than as a strategically motivated attempt at introducing new product development processes. In our model we therefore included a construct—entrepreneurial strategic intent—to examine whether there is a linkage between product modularity and the firms' articulated strategic intent for developing new products or entering new markets with existing products.

[5] Werr, Stjernberg, and Docherty (1996) made the interesting point that standard methodologies provide 'cognitive interfaces' that improve coordination across organizational boundaries.

[6] See Sanchez and Heene (1996) for an insightful discussion of the consequences of driving adaptive change from the 'bottom up' vs. 'top down' through fundamental reorientation of strategic logic.

Another important mediating variable is organizational climate, which is defined as the perceptions organization members share of fundamental elements of their organization (West *et al.*, 1998). Organizational climate has been considered a centrally important factor in determining organizational effectiveness (Denison, 1990; Ghoshal and Bartlett, 1994). Although organizational climate is a multidimensional construct encompassing elements such as trust, support, shared values, and vision, in the present context we were particularly interested in the effect of one element, the firm's orientation toward innovation, which we label innovation climate. It is now well documented that a firm's organizational climate may either facilitate or impede individual creativity and innovation; it is also possible that the organizational climate influences the strategic logic adopted and followed by decision-makers (cf. Sanchez and Heene, 1996; Daft and Weick, 1984). A positive innovation climate exists where the development of new ideas is encouraged and rewarded (Amabile *et al.*, 1996) and where there is a strongly shared mission among employees (West, 1992). We included this variable to investigate whether the firms' innovation climate influences the degree of modularity, and also to examine the links between market context, innovation climate, and entrepreneurial intent. In other words, we explored the following research question:

Research question A: What is the relationship between market context, entrepreneurial intent, organizational climate and product modularity?

Although the modularity concept originated in technology management, many authors emphasize that firms need complementary organizational resources and capabilities to exploit the 'economics of substitution' afforded by modular product structures (e.g., Cusumano and Nobeoka, 1998; Garud and Kumaraswamy, 1995). These capabilities include a system for continuous improvement of work processes through codification and standardization; appropriate organizational structures (e.g., platform teams or centers); and an infrastructure to facilitate knowledge sharing and reuse such as electronic networks and databases. Thus it is not enough to merely redefine product architectures in order to increase flexibility: firms also need to simultaneously realign organizational structures and processes. The nature of the process of alignment is typically complex, tacit, and firm-specific, and it may result in a unique configuration of organizational capabilities that provide significant impediments to competitive imitation. At the same time, research indicates that such alignment is difficult to achieve, and our fieldwork had also suggested a relatively low level of alignment in the typical home appliance company. For this reason we were interested in exploring how the organizational variables in our model (Figure 1) relate to each other and how they influence strategic flexibility and firm performance. Apart from innovation climate and entrepreneurial intent (described above) we defined two other complementary resources: modular organizational structures, and modular work processes. Hence this reasoning led us to formulate our second research question:

Research question B: How do complementary organizational resources influence the relationship between product modularity, strategic flexibility, and firm performance?

RESEARCH METHODOLOGY

Instrument

We developed Likert-type measurement scales for the variables described above related to market context, organizational resources, modularity, and firm performance. Wherever possible, we reused items or the general question format from existing scales. However, we were unable to use existing scales in their entirety. A key priority was to keep the total questionnaire relatively short in order to increase response rate (cf. Dillman, 1978). This concern precluded the incorporation of existing scales measuring constructs such as innovation climate (e.g., Amabile *et al.*, 1996) or environmental uncertainty (e.g., Miles and Snow, 1978; Milliken, 1990), which would have doubled the length of the total questionnaire.

We developed new items tapping the dimensions of modularity related to product architecture and process and structure as we were unaware of any previous attempts to measure these constructs. The development of these items was informed by our field studies, which included semi-structured interviews with around 20 managers and executives in three leading home appliance companies.

These interviews helped us refine the definition of key variables and identify the appropriate wording in this particular industry. Two leading experts on modular systems (one academic and one consultant) then provided feedback on a pilot version of the questionnaire.[7]

Our fieldwork had indicated that there were some specific events that led companies to reexamine their product design philosophies and consider increased modularization. These included falling margins or sales volume; the appearance of new competitors with products utilizing new technologies; and the emergence of new Internet-based supplier and distribution channels.[8] Consequently, we wrote seven items to assess market context. For each item the respondents were asked to indicate the future probability of the event mentioned. In contrast to scales that tap global attributes of the environment we thus followed the approach used by Milliken (1990), who focused on perceptions and interpretations of specific changes in the industry environment.

To capture the firms' entrepreneurial intent, we included three items that asked respondents to indicate whether they had formulated plans to improve their product development processes, to use existing or new technology to develop new products, or to enter new markets with existing products. Although some authors have conceptualized entrepreneurship in broad terms such as 'the process of pursuing opportunities,' we took the narrower approach suggested by Lumpkin and Dess (1996), who defined entrepreneurship as new entry, which can be accomplished by entering new or established markets with new or existing goods or services. As a contrast we also included one item that asked respondents to rate their firm's commitment to cost reduction.

Modularity in processes and structure were measured by nine and three items, respectively. We developed items based on the recent theorizing reviewed above (in particular, Sanchez and Mahoney, 1996). In capturing modular structure we included items about the existence of small, autonomous units and rotation of personnel between different product areas. As indicators of modular process we used several items focusing on codification, standardization and reengineering of work processes, as well as items asking about knowledge management systems and knowledge transfer. Innovation climate was assessed by items adopted from Amabile *et al.* (1996) and Powell and Dent-Micallef (1997), asking respondents to assess the degree of shared vision and the encouragement of creativity in their firms.

In line with the conceptual frameworks proposed by Sanchez (1995), Sanderson and Uzumeri (1997), and Nayyar and Bantel (1994), we operationalized strategic flexibility as: (1) the total number of models/variants offered by the firm;[9] (2) the total number of new models/variants introduced during 1998; and (3) the number of entirely new products introduced during 1998.[10] Our interviews had indicated that manufacturing and marketing managers easily could identify such figures for their company or division.

Perceived performance was measured using three items developed by Powell and Dent-Mitcallef (1997). Subjective measures of performance have been widely used and most studies find high convergent validity with objective measures such as publicly available accounting data (e.g., Powell and Dent-Micallef, 1997; Hart and Banbury, 1994; Dess and Robinson, 1984; Venkatraman and Ramanujam, 1987).

We included some questions that collected background information and two control variables: firm size and age. Respondents were asked to indicate

[7] A group of managers attending an executive course also provided feedback on a slightly modified version of the questionnaire which was intended for another industry.

[8] There are different and partly conflicting conceptions of environmental dynamism and uncertainty in the literature (e.g., Miles and Snow, 1978; Dess and Beard, 1984; Milliken, 1987, Slater and Narver, 1994; Jaworski and Kohli, 1993). Sutcliffe and Zaheer (1998) defined three different categories of environmental uncertainty, but also noted that they may be parts of a continuum. These categories were: *primary uncertainty* (arising from exogenous sources such as changing customer preferences and new technologies), *competitive uncertainty* (arising from the actions of potential or actual competitors), and *supplier uncertainty* (caused by opportunism by upstream or downstream exchange partners). Conceptually, our scales relate mainly to the first two categories, although the last subscale on Internet-based supplier and distribution channels overlap with the construct of supplier uncertainty.

[9] As a control we also asked respondents to indicate the number of variants within their main product family, but because this variable correlated strongly with the total number of variants, we used the latter in our analyses because it had fewer missing cases.

[10] The authors cited all emphasize the dual objectives of variety and speed. However, as in the conceptual model proposed by Sanderson and Uzumeri (1997) our measures focus on the product level only. Thus benefits of modular architectures relating to processes (such as decreased throughput time and speed to market) were not directly assessed in this study.

the number of employees in their division, and the date the company and their division were established. As with the other constructs these were measured using Likert scales. To reduce autocorrelation effects, questions pertaining to key constructs were placed in separate sections of the questionnaires.

Sample

As described above, we focused on firms in the home appliance industry to test our model. Administration of the survey followed guidelines prescribed in Dillman (1978). We identified home appliance firms through lists provided by a U.K. industry association (Association of Manufacturers of Domestic and Electrical Appliances—AMDEA) and a U.S. industry magazine (*Appliance*). We called up every firm on the lists to verify names and to confirm that it was a manufacturer of branded consumer appliances. After excluding firms that did not satisfy this criterion, we sent out questionnaires to manufacturing and marketing managers in the remaining 500 firms (50 in United Kingdom and 450 in the United States). Follow-up letters and faxes were sent to managers who did not respond to the initial mailing. In the larger, multidivisional firms we sent the questionnaire to managers at the divisional level, and they were asked to respond based on the products and characteristics of their division. We chose this approach as our fieldwork had indicated that the divisions for the global firms were largely independent business entities with responsibility for separate product lines (washing machines, vacuum cleaners, stoves, etc.).

Of the 500 questionnaires mailed, 103 were returned for a response rate of 20 percent. Although we sent questionnaires to multiple respondents within each firm or division, we only received multiple responses from seven firms. As a control, respondents were asked to indicate the category of products they manufactured, and one firm was excluded because it was not in our target group as defined above. Firms differing in size, age, and geographical scope were represented in the sample. In terms of size, mean employees[11] was 1050, while the median was 750 and the standard deviation 580. The majority of the companies (62%) indicated that they manufactured for global markets, while 32 percent served local and 5 percent regional markets. Most of the companies in the study were fairly old: 70 percent of the mother companies were incorporated more than 30 years ago and only 15 percent were incorporated during the last 20 years. However, some of the divisions or business units of these managers were more recent, with 30 percent having been established after 1980. To control for nonresponse bias we compared early with late respondents (Armstrong and Overton, 1977). The first 75 percent of the returned questionnaires were defined as early responses and the remaining 25 percent as late responses and thus deemed representative of firms that ultimately did not respond to the survey. First we compared the means of four background variables (geographical scope, firm size, firm age, division age), and no significant differences were found. We then compared the means of 13 explanatory variables; 12 of these were nonsignificant, with one variable showing a significant difference. Nevertheless, we attributed this finding to chance because of the lack of significant differences among the other 16 variables that were compared.

Construct validation and scale purification

We followed the usual steps in exploratory factor analysis to validate the constructs and create indices summarizing the items. In general, the factor analysis confirmed the structure of the constructs as defined above. For the seven environment items the analysis suggested a three-factor solution. This result is consistent with other studies that have found that environmental uncertainty and dynamism are multidimensional constructs (e.g., Milliken, 1990; Sutcliffe and Zaheer, 1998). It was relatively easy to interpret the pattern suggested by the factor loadings. We consequently created three variables, labeled ‘customer/competitor changes,’ ‘margin/volume pressure,’ and ‘Internet channels’, respectively. The subsequent analysis confirmed that these three dimensions of the environment had distinct effects on other key variables. For the product modularity items, the factor analysis produced a two-factor solution. Four ‘core’ items were combined into the main variable for modularity; in addition, two items were combined to form an ‘advanced modularity’ variable. Only the analysis for the core items is reported in the remainder of this paper.

[11] Respondents indicated the size of their division or business unit on a Likert scale.

Two items correlated poorly with either variable and were subsequently dropped. For the modular process construct, seven items loaded on the same factor. These were combined to form an index whereas two items that had poor item-to-factor correlations were dropped from the scale.

The reliability (Cronbach alpha) of all variables is reported in Table 1. Alphas ranged from 0.56 for modular structure to 0.84 for firm performance. Although some of the alphas are under 0.70, customarily used as a cut-off point, we are of the opinion that the inclusion of these variables is

Table 1. Factor analysis outcome for key variables[a]

Variable name and items[b]	Factor loading
Customer/competitor change ($\alpha = 0.58$)	
Competitors will introduce products with superior performance compared to ours	0.70
Customer preferences for product functions and features will change significantly	0.79
Competitors will increase their product variety	0.76
Margin/volume pressure ($\alpha = 0.62$)	
Margins on our key products will fall by more than 10%	0.82
Sales volume for our key products will fall by more than 5%	0.85
Internet channels ($\alpha = 0.74$)	
New entrants in our industry will use the Internet as their main channel to customers and suppliers	0.91
Customers will use the Internet to configure products themselves rather than choosing from standard assortments	0.85
Entrepreneurial intent ($\alpha = 0.70$)	
We have a business plan to use existing technology to enter new market segments	0.82
We have a business plan to develop new technologies for new kinds of products	0.77
We have an overall business plan to redesign our product development process	0.70
Innovation climate ($\alpha = 0.80$)	
People here are encouraged to solve problems creatively	0.76
In general, our people accept change readily	0.88
People here share a view of where the company should be in the future	0.84
Modular structure ($\alpha = 0.56$)	
We try to create small, autonomous units to encourage innovation and flexibility	0.65
We frequently rotate people between different product areas	0.82
Modular processes ($\alpha = 0.80$)	
Improving work processes has become a key part of our business plan	0.55
We have documented the steps involved in our key work processes	0.69
We have defined business processes that cut across functional boundaries	0.66
We have standardized work processes across departments and business units	0.62
In the concept development stage, we use a formal procedure to analyze customer needs and define product specifications (e.g., Quality Function Deployment)	0.74
Our product development engineers have electronic databases listing standard components and their interface specifications	0.65
We have procedures and systems for transferring knowledge across projects and business units	0.70
Modular products ($\alpha = 0.64$)	
Our products have been decomposed into separate modules	0.51
For our main product(s), we can make changes in key components without redesigning others	0.39
The extent of reuse of components (Likert scale from 0–20% to 80–100%)	0.82
The degree of component carry-over (Likert scale from 0–20% to 80–100%)	0.74
Performance ($\alpha = 0.84$)	
Over the past 3 years, our financial performance has been outstanding	0.88
Over the past 3 years, our financial performance has exceeded our competitors'	0.90
Over the past 3 years, our sales growth has exceeded our competitors'	0.82

[a] The strategic flexibility indicators (model variety, model introductions, new products) were not included in the factor analysis but used directly after a log transformation as explained in the text.
[b] Some of the items have been slightly abbreviated.

warranted. Methodologists have demonstrated that the routine use of a 0.70 cut-off is inappropriate unless other types of information are taken into account (Schmitt, 1996; Cortina, 1993). Classic test theory essentially holds that reliability places a bound on the upper limit on validity (the relationship between a predictor and a criterion variable). The upper bound of validity is the square root of the reliability of the criterion or outcome variable. This means that relatively large differences in alpha have relatively small effects on validity: with an alpha of 0.70 the upper limit is 0.84, whereas with an alpha of 0.49 the upper limit is still as high as 0.70. Schmitt (1996) argues that even relatively low (e.g., 0.50) alphas are acceptable if the measures have other desirable characteristics, such as meaningful content coverage and reasonable unidimensionality. We ascertained that the measures have satisfactory unidimensionality by first performing factor analysis, which showed that items belonging to each variable load on the same factor (items with poor loadings were abandoned). Note also that lower than ideal reliabilities actually mean that we provide conservative tests of the hypothesis (i.e., that the true correlations between variables are underestimated).

We investigated the distributional properties of the data using residual scatterplots and normal probability plots. We found clear departures from the assumption of equal variance for the three strategic flexibility indicators. Consequently we used a log transformation to correct these indicators. We also examined outliers and influential observations using indicators such as Cook's distance (Norusis, 1990). We corrected the data for one influential outlier that strongly affected the parameter estimates.[12]

Following the recommendations of Kendall (1975: 25) indices were constructed by applying the weights for each item obtained by principal components analysis then summing the weighted items.[13] These indices were used in the subsequent analyses.

[12] We called up the respondent submitting these data, who said that he had misunderstood some of the questions in that he had considered e.g., component sharing *between* product lines rather than *within* product lines when filling out the questionnaire. Based on our telephone interview we subsequently corrected this company's score on one variable (product modularity).

[13] This approach is similar to using factor scores in regression analyses except that it allowed us to eliminate items with reliability alphas or low item-factor loadings or high cross-factor loadings (we used 0.4 as a cut-off point).

Analysis

The model presented in Figure 1 was tested with structural equations analysis using the software package EQS Version 5 (Bentler and Wu, 1995). EQS is similar to the more frequently used LISREL (Jöreskog and Sörbom, 1993). There were missing data on one variable (strategic flexibility) for 14 firms. Given the difficulty of using pair-wise deletion with covariance matrices, we chose to delete missing cases from the analysis, which was carried out with the remaining 73 firms. Although this sample size is small, it is above the minimum sample size required for estimation of covariance matrices (Jöreskog and Sörbom, 1993: 26).[14] On the other hand, the sample size restricted the number of variables that we could examine simultaneously as the required sample size depends on the number of variables included in the model being tested.[15]

Statistical packages provide different indices of fit to determine whether the overall model fits the data well. During the analysis we assessed the goodness of fit using the comparative fit index (CFI), an index that reflects fit relatively well at all sample sizes. Values of CFI range from zero to 1.00. A value of CFI greater than 0.90 has been proposed as an acceptable fit to the data, indicating that 90 percent of the covariation in the data can be reproduced by the model (Bentler, 1990). As alternatives we also provide chi-square and values of the root mean squared error of approximation (RMSEA), a recently developed index. Chi-square should *not* be significant if there is good fit. We included the chi-square value because it is a common test statistic, but one should note that many authors believe chi-square to be misleading in some circumstances, such as when ideal sample size and distributional requirements are violated. Values of RMSEA range from 1.00 to 0.00,

[14] As a control we also ran regression analyses of pairs of variables in the structural model (e.g., modular products and model variety, controlling for firm size). Taken together the regressions produced the same general pattern of relationships as in the structural model. There was one exception, however: in the regression analysis, modular products correlated with new product introduction rate, when corrected for firm size ($R = 0.22$; F prob. = 0.6).

[15] The questionnaire included three control variables: firm size, firm age and division age. Because of the restriction on the number of variables we included only firm size as a moderator (with paths to model variety and modular products in Figure 2) because firm age and division age were uncorrelated with these variables. Firm age and division age were also uncorrelated with firm performance.

with values closer to zero indicating better fit. By convention, there is an adequate fit if RMSEA is less than or equal to 0.08 and there is good fit if RMSEA is less than or equal to 0.05. However, cut-off points are arbitrary and it has been pointed out that what is deemed acceptable depends on the level of fit achieved by prior models of the same phenomenon (Kline, 1998).

As is common in structural equations modeling, our analysis was both confirmatory and exploratory. We started with a model representing several possible cross-paths between the variables, and then used the Lagrange multiplier and Wald tests to assess which ones should be omitted from or added to the theoretical model. The main post hoc improvements that we made to the model were the interrelationships between the variables measuring innovation orientation and organizational architecture, which we had left unspecified in the hypothesized model presented in Figure 1. We also added a path (a correlation) from performance to strategic intent. This correlation indicates that the causal direction may be in any direction. In Figure 2 the correlation is represented by a two-way arrow whereas the regression coefficients are represented by one-way arrows. As is customary, the standardized path coefficients (effect sizes) are displayed above their respective arrows.

RESULTS

Descriptive statistics are provided in Table 2. The results from the structural equations modeling are presented in Figure 2. The results generally support the proposed relationships, with some exceptions. Compared to our conceptual model in Figure 1 the structural model suggests a more fine-grained picture of the interrelationships between the variables in our model.

Proposition 1 stated that firms operating in a more dynamic market context should employ higher degrees of product modularity. This proposition was only partially supported. Recall that the operationalization of the market context variable

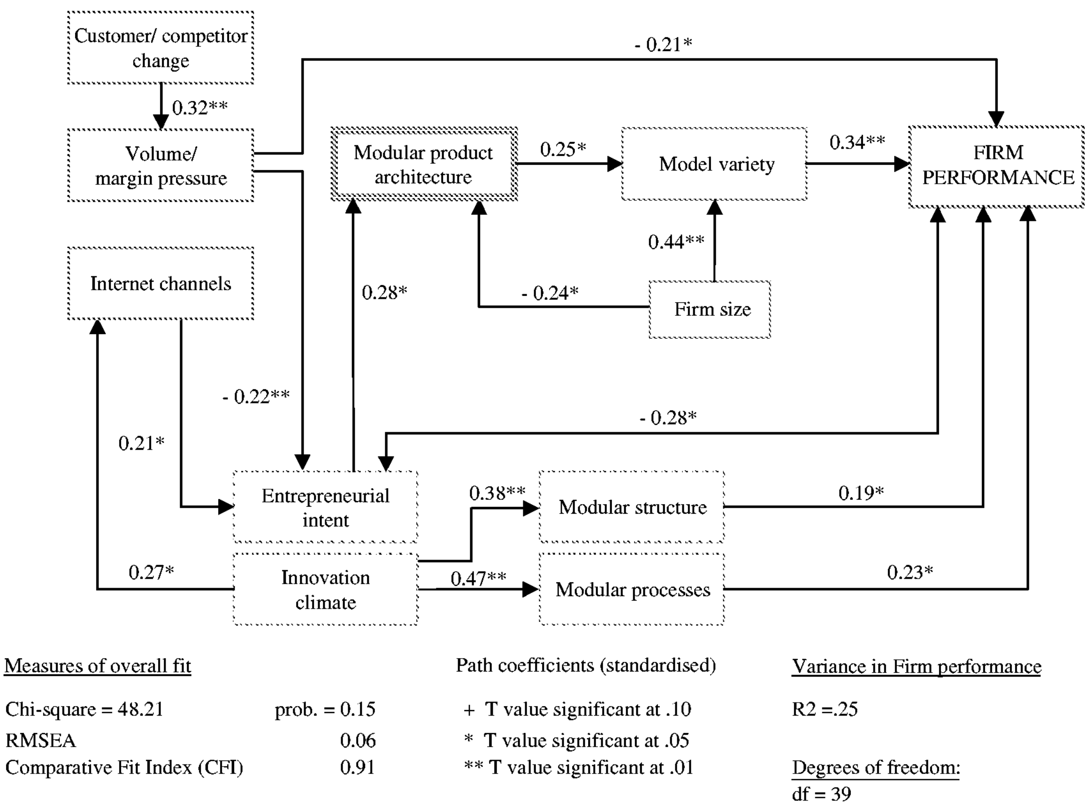

Figure 2. Structural equations model of the relationship between market context, organizational variables, modularity, model variety, and performance

Table 2. Descriptive statistics and intercorrelations

Variables	N	Items	Means[a]	S. D.	1	2	3	4	5	6	7	8	9	10	11	12
1. Customer/competitor changes	87	3	3.24	0.73												
2. Margin/volume pressure	87	2	2.43	0.80	0.131											
3. Internet channels	87	2	2.30	0.96	0.254*	0.034										
4. Entrepreneurial intent	87	3	3.53	0.87	−0.058	−0.303**	0.241*									
5. Cost reduction	87	1	4.31	0.80	0.071	0.319**	−0.132	−0.005								
6. Innovation climate	87	3	3.55	0.78	−0.045	−0.264*	0.196	0.373**	−0.122							
7. Modular structure	87	2	2.81	0.91	0.032	−0.094	0.233*	0.251*	−0.125	0.303**						
8. Modular processes	87	7	3.45	0.71	0.002	0.015	0.308**	0.336**	0.152	0.433**	0.352**					
9. Modular products	87	4	3.20	0.75	−0.136	−0.060	−0.004	0.231*	−0.083	0.069	0.152	−0.170				
10. No. of models/ variants	73	1	988	2327.2	0.062	−0.184	0.163	0.231*	−0.064	0.155	0.041	−0.054	0.156			
11. New model/variant introduction	73	1	130	405.4	0.089	−0.106	0.107	0.245*	0.063	0.134	−0.094	−0.028	0.099	0.802**		
12. New product introductions	73	1	7	13.8	0.233*	0.210	0.262*	0.183	0.009	0.212	0.075	0.035	0.215	0.346**	0.306**	
13. Performance	87	3	3.38	1.11	0.089	−0.299**	0.237*	0.115	−0.152	0.342**	0.307**	0.260*	−0.004	0.340**	0.115	0.112

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).
[a] In order to facilitate comparison, the means and standard deviations are pre-transformation. The correlations are for the transformed variables.

led to the construction of three subscales measuring the perceived market environments. As can be seen in Figure 2, these subscales have distinct effects on the other variables. Customer/competitor change has a fairly strong positive influence on Internet channels ($\beta = 0.32$, $p \leq 0.01$). Firms experiencing more uncertainty with regard to customer preferences and competitors' actions perceive that the Internet will be a significant force in the industry. Internet channels in turn has a positive impact on entrepreneurial intent ($\beta = 0.21$, $p \leq 0.05$). However, the third market context subscale, volume/margin pressure, *negatively* influences entrepreneurial strategic intent ($\beta = -0.22$, $p \leq 0.01$). In other words, we do not find that increased uncertainty and pressure in the environment spur companies to make plans for improving the product development process or enter existing or related markets with existing or new products. The analysis also reveals some other linkages of interest. As would be expected, volume/margin pressure negatively impacts firm performance ($\beta = -0.21$, $p \leq 0.05$); i.e., firms that fear declining margins and sales have already experienced poor performance. We also note the positive influence of innovation climate on Internet channels ($\beta = 0.27$, $p \leq 0.05$). This linkage suggests that organizational climate has an effect on managers' interpretations of external events such as the emergence of Internet-based distribution channels.

Our second proposition stated that modular product architectures should have a positive impact on strategic flexibility. This proposition was also partially supported. We operationalized strategic flexibility as: (1) model variety; (2) number of model introductions during 1998; and (3) number of entirely new products introduced during 1998. Modular product architectures showed a positive influence on model variety ($\beta = 0.25$, $p \leq 0.05$), using firm size as a control variable. However, modular product architectures did not have a significant impact on model introductions or new products.

Our third proposition stated that strategic flexibility impacts firm performance. There is a significant relationship for model variety ($\beta = 0.34$, $p \leq 0.05$), but again, there were no significant effects for model introductions or new product introductions. Consequently, we dropped these variables from the model. Although the latter finding is somewhat counterintuitive, Nobeoka and Cusumano (1997) also found that companies that frequently introduced new products did not do very well in the marketplace (unless the products reused existing platform designs).

We had also formulated two exploratory research questions related to the mediating variables. The first research question concerned the relationship between innovation climate and entrepreneurial intent and modular architectures. As described above, we found that entrepreneurial intent mediates the effect of market context on modular products. Secondly, note the strong links between innovation climate and modular process ($\beta = 0.47$, $p \leq 0.01$) and modular structure ($\beta = 0.38$, $p \leq 0.01$). This finding suggests that firms with organizational climates conducive to innovation are more likely to implement programs to improve the flexibility of structures and work processes. The second research question concerned the relationship between complementary, organizational capabilities and product modularity, strategic flexibility and firm performance. The most notable aspect of this part of the analysis is that we found significantly positive *direct* linkages between modular structure and process and firm performance ($\beta = 0.23$, $p \leq 0.05$ and $\beta = 0.19$, $p \leq 0.05$, respectively). In other words, although these results indicate a positive contribution of modular organization on performance, they suggest that this effect is independent from the effects on performance of product modularity through model variety. Finally, note the negative correlation between firm performance and entrepreneurial intent ($\beta = -0.28$, $p \leq 0.05$). This correlation indicates that poor firm performance may motivate managers to formulate an entrepreneurial intent; at the same time, it indicates that committing resources to product development may hurt firm performance, at least in the short term.

Limitations

This study is subject to the usual limitations inherent in cross-sectional research designs employing single respondents and subjective measures. Although both type 1 and type 2 errors are possible, the risk of type 2 error (failure to detect a true population relationship) is probably greatest given the sample size,[16] research

[16] However, one should recall that two of the measures used to assess overall fit of the model take into account sample size (RMSEA and CFI).

design, and scale reliabilities. Particular care should be exercised when interpreting the causal relationship between modularity and performance. The appropriate way of viewing the study is as a comparison between firms varying in degrees of modularity, conceptualized as relatively stable organizational and product-related characteristics. This is not an unrealistic assumption, given that it takes several years to change product and process architectures. However, the cross-sectional nature of the study precludes us from detecting 'lag effects.' For example, whereas we failed to find a link between model introduction rate and performance, Nobeoka and Cusumano (1997), who looked at a 3-year period, did find a positive relationship between model introduction rate (labeled product introduction rate in their paper) and sales growth. Similarly, in considering the relationship between modularity and strategic flexibility, a cross-sectional study like ours may fail to detect effects for firms that recently introduced modular architectures as it takes time both to implement modular systems and to learn how to manage them effectively. This research thus represents a description of *actual* antecedents, contributing variables, and outcomes of modularity among home appliance firms at the time of the study, as opposed to a test of the *potential*, future benefits that firms may gain from introducing modular architectures.

The resulting model contains many variables and interrelationships and one may thus question the theoretical parsimony of the model. However, we were faced with a trade-off between focus and inclusiveness. One of goals at the outset of this research was to heed the calls for more active use of systems models that consider interactions between the firm's technological resources, organizational behavior, and competitive context (e.g., Barney and Zajac, 1994). This is also important because the modularity literature itself makes many predictions that go across levels that traditionally have been studied in isolation, such as product structure and organizational structure. On the other hand, what it means in practice is that more variables need to be included in the model.

There are also limitations related to the measures that were used. Because we formulated an integrated model with a large set of variables, we were limited in the number of items we could use to assess each variable due to restrictions on the length of the questionnaire. This aspect probably reduced construct validity somewhat compared to more complete scales. The dearth of existing measures also meant that we had to develop new items tapping the modularity construct. The factor analysis indicated satisfactory internal consistency, but the scale obviously needs modification and refinement in future research. The strategic flexibility construct was operationalized simply as the number of model variants. A more sophisticated approach would take into account on which dimensions these models vary, for example, whether the models represent different peripheral options (e.g., colors) or more fundamental recombinations of key components (cf. Fisher *et al.*, 1995).

DISCUSSION

The main contribution of this study is the development of an integrative model and specification of links between perceived market context, modular architectures, strategic flexibility, and firm performance. In the following we highlight the key findings from the structural equations analysis.

Our results lend support to some of the hypothesized causal links in the strategic flexibility approach (Sanchez, 1995). First, we find that model variety (i.e., the number of product models offered by the firm) is positively related to firm performance. This finding is consistent with a study using a much larger sample drawn from the PIMS database, which showed that firms offering broader product lines have significantly higher market shares and profitability (Kekre and Srinivasan, 1990). Secondly, we find that product modularity is positively related to model variety. Our study thus contributes to extant research by emphasizing *product architecture* as a key lever in attaining high levels of product variety. Product variety allows the firm to cater to diverse or unpredictable customer needs, while modular architectures ensure a low incremental cost of producing new variations. In their study Kekre and Srinivasan (1990) noted the absence of any negative effects of product variety on manufacturing costs. Compared to producing a corresponding number of models based on integrated or unique designs, modular architectures reduce design and development cost by allowing the reuse of existing components, and reduce manufacturing costs by lowering variety of parts moving through the assembly line and by increasing volume for common parts (Fisher *et al.*, 1995).

However, we did not find a significant relationship between product modularity and the two other indicators of strategic flexibility: new model introductions and new product introductions.[17] This finding can be interpreted in several ways. The organizational capabilities necessary for creating frequent model and product introductions might differ from those that are required to produce high variety. Normally, it is assumed that modularity should enable increased variety and change *simultaneously*, but there are also authors (e.g., Sanderson and Uzumeri, 1997: 31–41) who argue that there is a trade-off between model variety and rate of change, and that firms need to choose between allocating resources to maintaining variety vs. directing resources to reinventing a smaller number of models on a more frequent basis. In home appliances, the relative stability of the core technologies may make variety more important than frequent product introductions. However, our analysis cannot conclusively support or reject this explanation.

Our model offers some insight into the role of complementary, organizational capabilities. Our operationalization of the modular process construct meant that we focused on codification and standardization of work processes as key indicators of modularity. Some scholars have treated codification and standardization as equivalent to routinization and process stability, and as antithetical to flexibility and innovation. However, we relied on the alternative view that codification and standardization in fact are necessary prerequisites for achieving high levels of process flexibility (Adler and Borys, 1996; MacDuffie, 1997). It is therefore interesting to note that our model shows innovation climate to be *positively* correlated with modular processes. This finding is consistent with the study conducted by Damanpour (1991), who found a positive correlation between formalization and innovation in manufacturing firms and for both product and process innovations. However, whereas the strategic flexibility approach emphasizes how product architectures shape process architectures (Sanchez and Mahoney, 1996), we find that modular structures and processes have direct effects on performance, independently of product modularity. For this sample, the effects of product and process modularity are additive rather than interactive. This finding may indicate that these firms have failed to closely align product architectures and process architectures in the way prescribed by the theory.

Finally, our model suggests a complex relationship between managerial cognition, market context, and the use of modular architectures. A key mediating variable is entrepreneurial intent, defined as the existence of plans for redesigning product development processes and for entering new or existing markets with new or existing technologies. We find a positive link between entrepreneurial intent and the use of modular product architectures. This suggests, as prescribed by the strategic flexibility approach (Sanchez, 1995), that modular product architectures are employed in a strategic manner to improve product creation processes.

Scholars studying cognition in organizations have demonstrated that the relations between an organization and its environment are socially constructed or enacted (Daft and Weick, 1984). Research on managerial decision making has also indicated that managers process issues differently depending on whether the issues are categorized as threats vs. opportunities (Fredrickson, 1985). This may explain the discrepancies between the effects of different market context variables. We found that managers in firms with innovation-oriented climates are more likely to rate the Internet as a future channel to customers and suppliers. This finding indicates that managers' perceptions are extensions of their firm's corporate organizational culture and climate. Moreover, we found that high pressures on margins and sales volumes make firms *less* likely to formulate an entrepreneurial intent, whereas perceptions of new Internet channels make firms *more* likely to formulate an entrepreneurial intent. In other words, some home appliance firms may have more market-oriented or proactive cultures that lead managers to interpret external events—in this case, the emergence of new Internet-based channels—as implying new opportunities. In contrast, the negative linkage between volume/margin pressure and entrepreneurial intent may indicate, as predicted by

[17] In fact, these indicators of strategic flexibility are not well explained by any of the variables in the model presented in Figure 1. Additional regression analyses indicated that entrepreneurial intent predicted new model introductions ($R = 0.36$, $p \leq 0.05$), but not new product introductions (controlling for firm size).

the threat-rigidity hypothesis (Staw, Sandelands, and Dutton, 1981), that declining firms fail to fundamentally change their strategies, even when external threats (i.e., probable decline in margins or sales) are cognitively recognized. These firms may focus on cost reduction efforts as opposed to new product creation systems.[18] Also note the negative correlation between firm performance and entrepreneurial intent. Poor firm performance may motivate firms to formulate an entrepreneurial intent. At the same time, formulating an entrepreneurial intent—which implies committing significant resources to renewing product creation processes—may also hurt firm performance in the short term.

Our study contributes to the growing interest in achieving strategic flexibility through leveraging architectural knowledge, which, according to some authors, represents a new mode of competing that may supplant previous craft and mass production paradigms (Victor and Boynton, 1998; Cusumano, 1992). Future research, using enhanced methodologies, may replicate and extend these results in several ways. Research designs that control for lag effects (e.g., longitudinal) may be preferred to test the hypothesized linkages between modular systems and firm performance. Beyond the issues studied here, there are many other issues that remain to be addressed. One critical process is the definition of product architectures and platforms. Particularly where there are few industry-wide standards, product structures allow different decompositions, and companies may make different choices with regard to how they define key modules (e.g., Ulrich and Pearson, 1998). Another critical process is planning of future platforms. As pointed out by Meyer, Tertzakian, and Utterback (1997), it is often difficult to reconcile the desire to leverage current platform investments with the risk of becoming obsolete if the platform is not continuously renewed. Companies continuously need to balance leveraging current resources with building future capabilities. Important insights may thus be gained by studying how different companies define their product architectures and how managers integrate market and technological knowledge to make decision about future architectures.

[18] This interpretation is supported by the positive correlation (see Table 1) between margin/volume pressure and an item tapping commitment to cost reduction. This item was not included in the structural model due to the limitation on variables caused by the low sample size.

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