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Reconsidering Novel Technology Introduction Strategies: Impacts of Technology, Design, and Market Attributes on 118 Japanese Product Development Projects

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Abstract: This study reconsiders product development strategies for the introduction of advanced technologies into new products. The exploitation and exploration of novel technologies in product development are critical issues for manufacturing firms. Yet, thus far, the concept and determinants of novel technology introduction strategies have often been blurred. Drawing on 118 successful Japanese assembly product development projects, this study attempts to elaborate the concept of novel technology introduction strategies and explores the effects of other determinants on the strategies. The study finds two alternative novel technology introduction strategies: technology integration and separated technology development. The results demonstrate that successful projects exploit either of these strategies according to knowledge regarding product designs and/or customer/market needs as well as technological uncertainty. The findings of this study should help firms contrive to develop novel technology introduction strategies at the project level, as well as multiproject strategies at the business level.

Keywords: technology integration, separated technology development, product attributes

Introduction

Cross-functional integration and associated collaborative practices across different development stages (e.g., overlapping, preliminary information exchange, and so on) are critical factors for project success (Brown & Eisenhardt, 1995; Clark & Fujimoto, 1991). Furthermore, researchers have found cross-functional integration and related practices to be vehicles of exploratory knowledge creation (Benner & Tushman, 2003; Iansiti & Clark, 1994; Kusunoki, Nonaka, & Nagata, 1998).

The interest in technological changes and related industrial dynamism highlights the role of cross-functional integration for novel technology introduction (e.g., Chesbrough & Kusunoki, 2001; Eisenhardt & Tabrizi, 1995; Henderson & Clark, 1990; Iansiti, 1997; Tatikonda & Rosenthal, 2000). Rapid technological changes have dramatically shortened product life cycles in hi-tech industries. Industrial volatility urges firms to employ novel technologies faster than ever. Reflecting the industrial volatility, cross-functional integration and associated practices for novel technology introduction are regarded as key factors for project success in high-tech industries.

Levels of product development performances, such as productivity, development speed, and product quality, depend on how firms choose and refine novel technologies so that the technologies work well together in new products. Cross-functional integration teams for novel technology introduction are reported to contribute to the performance of product development based on novel technologies (e.g., Eisenhardt & Tabrizi, 1995; Gobeli & Foster, 1985; Gomory, 1989; Iansiti, 1997; Song & Xie, 2000; Tatikonda & Rosenthal, 2000).

Yet, the industrial volatility resulting from interfirm modularity and related open interfirm networks also draws our attention to another novel technology introduction strategy (e.g., Chesbrough, 2003; Christensen, Verlinden, & Westerman, 2002). This strategy exploits basic product design rules and standardized element technologies that are prepared by developers who are not involved with specific product development projects. A typical case is the product development based on product modularity, which is found particularly in digital product segments such as software, personal computers, network systems, and so on (e.g., Baldwin & Clark, 1999; Cusumano & Yoffie, 1998; MacCormack & Verganti, 2003; MacCormack, Verganti, & Iansiti, 2001). In relation to the design concept of “product architecture,” these studies suggest that firms may refurbish a portion of a product system by adopting element technologies from outside the product development group, thereby fostering novel technology introduction in volatile industries.

At the same time, the surge of globalization encourages firms to prepare technologies apart from product development in order to quickly release a variety of products at a low cost (Tatikonada & Stock, 2003). For instance, wireless handset manufacturers in China make use of the interfirm modularity of “modular production networks” (Sturgeon, 2002) in which specialized suppliers provide element technologies (i.e., wireless cores/platforms, components, handset designs, software, etc.) to help handset manufacturers release a new model every 2-3 months. In the mean time, major global wireless handset manufacturers attempt to adapt to the diversity of the global market by separating their proprietary core technology development (i.e., handset platform development) from specific handset model development projects (Funk, 2002).

The above situation reveals two issues pertaining to novel technology introduction strategies at the project level. First, whether the concept of novel technology introduction strategies is explicit is still open to doubt. The concept seems rather vague as it includes several interrelated product development strategies. Second, we may ask what the determinants of each novel technology introduction strategy are. When novel technologies are introduced, other factors like design and market attributes may influence the choice of the apt novel technology introduction strategies.

These issues confuse the relevance between the determinants of novel technology introduction strategies and the technology introduction strategies themselves. The choice of novel technology introduction strategies is one of the most critical issues for manufacturing firms (Iansiti, McFarlan, & Westerman, 2003). At the project level, firms in turbulent environments need to make proper use of novel technology introduction strategies, which are closely interrelated to platform/multiproject strategies (e.g., Krishnan & Gupta, 2001; Robertson & Ulrich, 1998; Tatikonda, 1999; Ulrich & Ellison, 1999) and related outsourcing strategies (e.g., Chesbrough, 2003) at the business level. Yet, the lack of knowledge about the determinants of novel technology introduction strategies would hamper firms from the effective exploitation and exploration of technologies.

Drawing on the data from successful product development projects of Japanese firms, the aim of this study is to explore how firms utilize novel technology introduction strategies. Based on a contingency perspective, the article posits that product development strategies for novel technology introduction may differ according to product and market attributes as well as technological change/novelty.

While focusing on project level strategies for novel technology introduction, the attempt of this study also contributes to elucidating the impacts of critical factors of effective platform/multiproject strategies on novel technology introduction (e.g., how platform and derivative projects should each play different roles according to the factors). Since the purpose of the article rests in hypothesis generating rather than hypothesis testing, the study does not hypothesize any specific causality. All we predict is that product development strategies for novel technology integration may differ according to product attributes.

The outline of the paper is as follows. First, we review past researches to streamline the concepts of product development strategies and their determinants, on the basis of which we propose generic predictions based on a contingency perspective. Reflecting these predictions, we examine the questionnaire-based data from 118 successful Japanese assembly product development projects. Finally, from the results, we attempt to draw implications about novel technology introduction strategies.

Backgrounds

Product development strategies for novel technology introduction

Since the 1990s, researchers have suggested that effective product development strategies may differ according to product attributes and/or industrial dynamism (e.g., Eisenhardt & Tabrizi, 1995; Song & Montoya-Weiss, 2001; Song & Xie, 2000; Souder, Sherman, & Davis-Cooper, 1998; Tatikonda & Rosenthal, 2000; Yasumoto & Fujimoto, 2005a). The line of studies revealed that the mode of novel technology introduction is contingent upon product characteristics and/or industrial dynamism. Therefore, our next step is to examine how firms employ product development strategies in relation to novel technology introduction.

First, let us review how researchers have characterized effective product development strategies for novel technology introduction. From the mid-1980s, drawing on the successful cases of technology-based product development projects, researchers have attempted to explore effective product development strategies for introducing novel technologies into new products (e.g., Gobeli & Foster, 1985; Gomory, 1989).

In the 1990s, researchers collected the product/industry-specific data of successful projects and explored effective product development strategies for introducing novel technologies. Drawing on the data of about 30 super computer or workstation development projects of US and Japanese firms, Iansiti (1997) examined product development projects that were accompanied by core technology development.

The study suggested that the “system-focused” approach fosters “technology integration” among related functional groups; this is characterized by overlapping and the associated intensive communication between element technology development and product/process engineering groups. Compared to the “element-focused” approach, the system-focused approach results in the development of more radical technologies in a shorter development lead time. The study demonstrated that the technological uncertainty in advanced core technology development enhances the integration for novel technology introduction.

Also, several generic studies drawing on large sample data from various industries suggested that cross-functional integration is critical for developing new products with novel technologies (e.g., Song & Montoya-Weiss, 2001; Song & Xie, 2000; Tatikonda & Rosenthal, 2000). The line of studies suggested that communication and overlapping between advanced technology development and product/process engineering groups are critical for the successful commercialization of novel technologies.

These studies stressed the role of cross-functional integration for novel technology development and introduction. However, the concept of cross-functional integration often involves confusing technology integration with cross-functional integration at the product/process engineering stages (e.g., Eisenhardt & Tabrizi, 1995; Olson, Walker, & Ruekert, 1995; Song & Montoya-Weiss, 2001; Song & Xie, 2000; Takeishi, 2002; Tatikonda & Rosenthal, 2000).

Eisenhardt and Tabrizi (1995) examined 72 development projects involving computer products, such as personal computers, supercomputers, workstations, and peripheral products, and concluded that under volatile environments, cross-functional integration contributes to rapid product development. Yet, the distinction between technology integration and cross-functional integration at the product/process engineering stages still remains blurred in the study. This problem obscures the required range of coordination in novel technology introduction.

On the other hand, when examining knowledge partitioning in automobile development projects, Takeishi (2002) found that when an automobile project includes the development of components based on new technologies, the fluidity of the boundaries of knowledge calls for overlapping problem-solving processes even across firm boundaries (e.g., design-in activities). The exchange/sharing of specific knowledge in the process involves close manufacturer-supplier collaborations as well as cross-functional integration within manufacturers. In the analysis, novel technology introduction strategies are, at large, identified with cross-functional integration within and across firms.

Product development capabilities that yield complex/novel, and thus, inimitable products are regarded as sources of competitiveness (Anderson, 1999; Pil & Cohen, 2006). Cross-functional integration is highlighted because of its contribution to developing these complex/novel products. The interdependency between product elements enhances the problem-solving by means of overlapping between stages, design-test-build cycle iterations, and the related tight coordination between engineers (Adler, 1995; Clark & Fujimoto, 1991; Iansiti, 1997; Terwiesch & Meyer, 2002; Thomke, 1997). Thus, tight cross-functional integration and associated practices are effective for the product complexity of automobiles (Clark & Fujimoto, 1991).

Yet, the accumulation of industry/product specific studies shows that novel technology integration is distinguished from cross-functional integration at the product/process engineering stages. For instance, Iansiti and Clark (1994) asserted that technology integration, which deals with high technological uncertainty (e.g., super computers), is an effective product development strategy for technology-based complex products. In contrast, automobile development calls for “internal integration”—cross-functional integration at the product/process engineering stages—to deal with the product complexity, and "external integration" to deal with the uncertain customer/market needs.

Both the cross-functional integrations are vehicles to enhance the coordination between elements. Nevertheless, it should be noted that technological uncertainty stemming from drastic technological change is the factor that demands technology integration. This factor requires us to distinguish novel technology introduction strategies from cross-functional integration, which aims at improving and/or reusing current technologies, at the product/process engineering stages.

Making proper use of product development capabilities

On the contrary, since the 1990s, product modularity and related open intefirm networks seem to have been increasingly eroding the importance of cross-functional integration and associated practices, which were once regarded as one of the most critical factors of effective product development (Chesbrough, 2003; Christensen, Verlinden, & Westerman, 2002; Gawer & Cusumano, 2002; Sturgeon, 2002). Studies have suggested that modular product designs enable manufacturers to break down complex problem-solving into a set of localized problem-solving steps (Baldwin & Clark, 1999). Modularity permits the rapid introduction of novel elements/technologies into products at a relatively low cost.

This advantage enables the drastic improvement of product performance, without tight organizational coordination (Garud & Kamaraswamy, 1995; Langlois & Robertson, 1992). Thus, relatively successful developers of a more modular product do not call on cross-functional integration at the product/process engineering stages; rather, they form a federation of many small module-specific teams that are relatively independent of each other (Cusumano & Yoffie, 1998; MacCormack & Verganti, 2003; MacCormack, Verganti, & Iansiti, 2001).

These contrasting novel technology introduction strategies indicate that technology introduction strategies can be divided into two types, "technology integration" and "separated technology development," on the basis of the level of product design stability. The difference in novel technology introduction strategies can be partly attributed to the design attributes of the concerned product. Product complexity, which arises from the insufficiency of architectural knowledge of the relationships between product elements, has impacts on product development projects. The patterns of product innovations reflect the architectural stability of the product design (Chesbrough & Kusunoki, 2001; Henderson & Clark, 1990).

Novel technology introductions and related product design changes lead to technology integration due to the insufficiency of both component and system knowledge (Iansiti, 1997). Takeishi (2002) further elucidated the integration for novel technology introductions within and between firms, examining the manufacturer-supplier relationships in the automobile industry. When novel technologies have impacts on the architectural knowledge of product design, firms are liable to coordinate between elements even across firms to compensate for the insufficiency of architectural knowledge related to the product system and its components.

Generic studies based on large sample data from various industries have also demonstrated the impacts of the architectural stability of product designs. When the concerned products are complex, technological uncertainty is likely to enhance the need for cross-functional integration (Tatikonda & Rosenthal, 2000). Compared to the case of incremental model change projects, projects for novel products, which include design changes, urge firms to adopt the cross-functional integration and related overlap between element technology development and product/process engineering (Olson, Walker, & Ruekert, 1995; Song & Montoya-Weiss, 2001; Song & Xie, 2000).

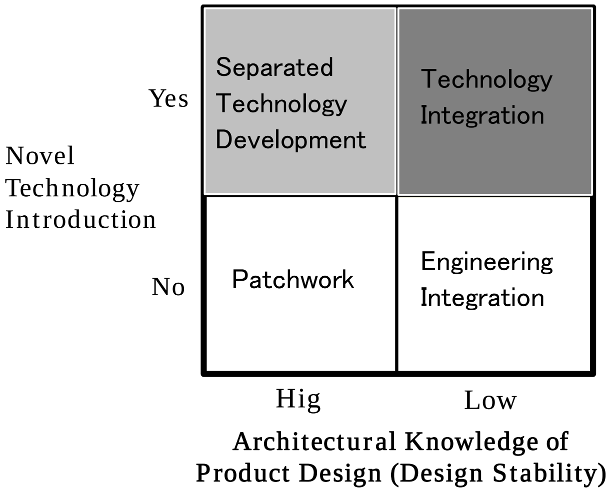
Nevertheless, element technologies can be developed so that they are separated from product/process engineering and are introduced into products when the architectural attributes of the product designs are provided or relatively stable. Firms need to design their products aligned with novel technology development, unless sufficient architectural knowledge is provided by stable designs (e.g., Baldwin & Clark, 1999). Without the stability of product designs, firms cannot separate advanced component/element technology development from specific product development projects due to the insufficient knowledge of the interrelationships between components.

Even the decomposability of products into relatively independent components, such as modules, is not secured until sufficient architectural knowledge is provided (Baldwin & Clark, 1999; Ulrich, 1995). Facing the interdependencies between components, firms cannot divide product development tasks into distinctive subtasks (von Hippel, 1990). Thus, firms cannot introduce novel technologies without technology integration when decomposability is not secured due to the lack of stable product designs.

On the other hand, the separation of technology development from the product/process engineering stages alleviates heavy task loads in the development of complex products. Stable designs, such as platforms, provide the architectural knowledge between product elements, and thus, save the cost and time involved in the integration of these elements (Baldwin & Clark, 1999; Cusumano & Nobeoka, 1997; Funk, 2002; Tatikonda, 1999). This efficiency increases the organizational flexibility of product development in response to environmental variety and/or volatility (Krishnan & Gupta, 2001; Sanchez & Mahoney, 1996).

Following the perspectives in terms of novel technology introduction and product designs, we can streamline product development strategies (Figure 1).

Figure 1.



Product attributes and technological change/novelty and complexity provide the minimum conditions to adopt either of the novel technology introduction strategies. Yet, ultimately, the adoption of the strategies would depend upon market factors.

Eisenhardt and Tabrizi (1995) elucidated that in the field of rapidly evolving products, the cross-functional integration relevant to the "experiential approach" contributes to shortening the development of lead time to a greater extent than in the "compression approach" based on planning and overlapping in relatively stable environments. Yet, firms could augment the organizational flexibility to the level of environmental volatility. Firms may also introduce advanced element technologies into products through modularized technology development, independent of product development (e.g., Chesbrough, 2003; Cusumano & Yoffie, 1998; Funk, 2002; MacCormack & Verganti, 2003; MacCormack, Verganti, & Iansiti, 2001; Ulrich & Ellison, 1999). In volatile environments, novel technology development is separated even from the product development for existing businesses/markets (Iansiti, McFarlan, & Westerman, 2003).

Organizational flexibility to market variety and/or volatility would depend upon the architectural attributes of the product designs. Yet, these conflicting suggestions about industrial volatility may result from the insufficient attention to the effects of market attributes. The effects of market uncertainty under the concept of industrial volatility are often entangled with the effects of technological change/novelty. Many of the studies conducted seem to regard industrial volatility simply as technological change/novelty and focus on the dynamism of the technologies (e.g., Chesbrough & Kusunoki, 2001; Christensen, 1997).

With regard to product development management, Eisenhardt and Tabrizi (1995) examined the impacts of model change cycles as the variable of industrial volatility, particularly highlighting the relationship of the cycles with technological change/novelty. Nevertheless, at the same time, the line of studies also stressed that market variability calls for product development capabilities based on cross-functional integration (Eisenhardt & Martin, 2000). As such, model change cycles may reflect both technological change/novelty and market variability, resulting in the impacts of market factors on the choice of novel technology introduction strategy remaining blurred.

Technological change/novelty enhances technology integration in coping with technological uncertainty only when architectural knowledge is also simultaneously insufficient. In contrast, firms may exploit various technologies developed elsewhere so long as the concerned product designs are stable. This study sheds light on the impacts of market and product attributes, presuming that successful projects make proper use of novel technology introduction strategies according to product and market attributes.

Research direction and data collection

Basic direction

Let us describe the direction of our analysis. First, the study attempts to classify novel technology introduction strategies by sorting them on the basis of cross-functional integration during product/process engineering. Second, the study examines how successful projects adopt novel technology introduction strategies according to product and market attributes.

Because of the variety of products, modern manufacturing firms are required to employ novel technology introduction strategies with regard to product characteristics and/or for industrial dynamism. Examining the contingent application of the strategies would help us understand how firms can successfully introduce novel technologies into the concerned products.

Although the basic logic of the present contingency analysis is relatively simple, actual data collection and empirical analysis is not easy, partly because of some difficulties in measuring product characteristics, development strategies, and performances across various industries. After trying various methods, we decided to use subjective measures as the main yardsticks, and considered that each of the respondents would have a broad perspective in evaluating product development strategies.

In this study, we measured the “perceived” characteristics of the product in question and the product development practices. Levels of product development performance were also measured in terms of respondents’ perceptions. This method may have some potential problems with regard to measurement and validity. There is a fundamental trade-off here between accuracy and comparability of data.[1]

After considering the trade-off, we presumed that objective environments, novel technology introduction strategies, and aspects of performance would be aligned in projects that project leaders themselves regarded as successful. Therefore, focusing on projects deemed as successful, we also examined the relationship between product characteristics and estimated the success levels of product development strategies.

Data Collection

We combined clinical field studies and statistical data collection. First, from 1995 to 1997, we visited 32 development projects involving products from various industries, such as the apparel, automobile, construction equipment, chemical textile and resin, consumer electronics, communication devices, electronic components, food/beverage, pharmaceuticals, industrial chemical, industrial machinery, mechanical parts, medical equipment, office equipment, precision mechanics, software, and toiletry industry, covering virtually all the product/industrial categories we intended to study in our questionnaire survey. Combining our knowledge from both the literature survey and field research, we selected the variables and designed the questionnaire. We then proceeded to the questionnaire survey.

We collected data in July 1997, through a questionnaire survey mailed to 700 business units and research laboratories of Japanese public firms. The survey inquired about product development projects of commercialized mass-production products.

The unit of analysis was an individual project of product development. Some of the surveys were sent to different business units or institutes within the same multidivisional company. We asked the potential respondents to select a relatively successful project that they had direct experience with in recent years, and to consistently answer the questions about this particular project.[2]

We received 203 completed surveys (response rate: 29%) from 145 firms by the end of October 1997. We checked the nonresponse bias with regard to firm size (sales).[3] No significant difference in firm size between the respondent firms and other potential respondent firms was found (t = 1.34, p = 0.18). The product development of the 203 respondent firms was spread across a variety of products/industries: textile and apparel, food/beverage, chemical, pharmaceutical and rubber, consumer chemical and toiletry, metal, electronics,

[1] A popular method for understanding effective or adaptive strategies is the pair approach. This approach involves asking the respondent firms to name a pair of projects, a successful and an unsuccessful one from their point of view, and to evaluate the level of adoption or effectiveness of each routine. If the level is significantly different between the pairs for a given routine, we can say that it is an effective or adaptive routine. In reality, however, it is rather difficult to get responses about failed projects from firms.

[2] Core project members had, on an average, worked at the respondent firms for 14.21 years. Projects for novel product categories accounted for 23.98% of the samples. The mean period after the first model of the product genre was released was 10.13 years, and the mean generation period of the product in the product line was 3.14 years.

[3] The mean of the sales of the potential respondent firms was 6.84 billion yen.

systems and software, precision mechanics, and transportation machines. The diffusion of respondents by industry was not significantly different from that of potential respondent firms.

Focusing on assembly product development projects

In our analysis, we chose assembly product development project cases in order to examine our predictions using more controlled data settings. We attempted to divide the samples into two groups: "assembly product" and "process product" groups.[4] Innovation management studies have suggested that product development capabilities are different between assembly products and process products (e.g., Kusunoki, Nonaka, &, Nagata 1998; Utterback, 1994). Kusunoki et al. asserted that effective product development capabilities are significantly different between these groups according to the difference in assembly/system and process/material development project groups.

However, the distinction between assembly and process products is not as clear as is usually expected. For instance, products with a small amount of components/ingredients are not always process products and visa versa. We asked the respondents to provide the ratio of engineering hours to the total product engineering hours for product and component design in the product/process engineering stages.

We presumed that the ratio of engineering hours to the total product engineering hours for the product/component design would reflect the fundamental product complexity of the product in question. The fundamental complexity would define the knowledge level with regard to the product structure. Firms of assembly products at least possess the knowledge that an assembly product is designed as a set of distinctive components. Accordingly, assembly product development projects are expected to allocate many of the resources to product/component design and related prototyping and testing.

On the contrary, in many cases, firms of process products scarcely have sufficient knowledge to articulate the structure of a process product into a set of physical designs. Thus, process product development projects use most of the resources for process design and related prototyping/testing. The difference in knowledge level with regard to the fundamental product complexity could bring about the critical differences between the assembly and process product groups with regard to the product development strategies they use.

Reflecting this difference, we tentatively divided the samples on the basis of the ratio of 36% since the mean of the ratios was 35.13%.[5] The mean engineering hours ratio of the assembly product

[4] See Yasumoto and Fujimoto (2005b) for details of the entire analysis including the process product development group and other product development strategies and factors.

[5] The ratio of engineering hours for product/component design to total engineering hours had a significant positive correlation with the amount of product elements/design drawings ($r = .30$, $p < 0.01$).

group was 43.06% while that of the process product group was 23.26%. The ratio of the assembly product group seemed to be relatively low. The reason for this is that many of the resources were allocated to prototyping and testing even in assembly product development projects.

In order to confirm the differences in statistical structure between these groups, we applied Brown-Forsythe's *F*-test to the ratio of engineering hours for product/component design. The standard deviations of the assembly and process product groups were 1.98 and 2.59, respectively. The result evidenced the significant difference in the variance between the assembly and process product groups ($F = 12.96$, $p < 0.0001$). The distinction between the assembly and process product groups could also have significant implications in terms of statistical structure.

After the elimination of the samples that included defect values, we focused on the 118 assembly product group samples for our analysis. The assembly product group included the following industries/products: computer systems/software (n = 12), consumer electronics (n = 23), electronic parts (n = 21), industrial machinery (n = 24), mechanical parts (n = 7), precision mechanics (n = 24), and transportation machines (n = 7).

Product development performance

Much of the literature on product development management has considered project performance in order to identify the effective attributes of product development projects (e.g., Clark & Fujimoto, 1991; Iansiti, 1997). Since the unit of analysis in our study was a single product development project, we collected the data of six performance variables of the product in question: customer satisfaction/total quality, engineering hours, development lead time, specific functional performance, sales/market share, and profit.[6]

Considering the problem of comparability of performance between industries, we asked respondents to check each of the performance levels on a 5-point Likert scale (1 = "not successful at all" to 5 = "highly successful"). Objective performance measures are not deemed appropriate for interindustrial studies. Even though we could successfully collect objective performance data, the comparison of data across various industries would be almost impossible.

On an average, across all the product types, the performance scores of the sample projects appeared rather high. With regard to all the measures, every respondent estimated the selected project as more or less successful. Mean scores of customer satisfaction and functional performance and sales/market share were particularly high in the assembly product group: 4.41, 4.37, and 4.22, respectively (4.46, 4.40, and 4.24 across all the industries). This might indicate that in all the industries, customer satisfaction/total quality, functional performance, and sales/market share are particularly critical

[6] All the performance variables significantly contributed to sales and profits ($p < 0.01$).

performance measures for successful projects.

In order to verify that the respondents applied similar success criteria, we collected data on success criteria by asking respondents to choose the latter from five alternatives (multiple-choice format). The success criteria that the respondents chose were "compared with those of the products of rivalry firms" (*n* = 148, 37.19%), "past products" (*n* = 109, 27.39 %), "past products of the concerned firm" (*n* = 67, 16.83 %), "success criteria within the concerned firm" (*n* = 71, 17.84 %), and "others" (*n* = 3, .75 %). The ratios with regard to the success criteria were not significantly different between the assembly and process product groups, [7] implying that the respondents adopted similar success criteria even across multiple industries.

We also examined the differences in the mean scores and the variance of each performance measure between the assembly and process product groups (Appendix 1). In spite of the difference between the groups, we could not identify any significant differences. This result seemed to suggest that despite the variety of industries, the subjective project performance estimation, which indicates how project managers prioritize performance variables, of the project managers, was similar across the sample projects. Thus, it could be concluded that across all the industries, respondents would provide data in terms of similar performance criteria.

Product development strategies

We questioned the respondents about 19 variables of product development strategies, and conducted a factor analysis. The respondents of the questionnaire were asked if each of the descriptions (mentioned later) fitted a characteristic of the product development project in question; they were asked to respond by comparing the concerned product to other products in general. Responses were made using a 5-point Likert-scale (1 = "not successful at all" to 5 = "quite successful").

After eliminating 15 cases with defect values, we applied factor analysis (principal components analysis) to 188 samples, selected the factors with an eigenvalue greater than one (1.00), and following past studies, named the selected factors "types of development strategies" (Appendix 2). The measures loaded mostly on separate factors, and all the factor loadings were above 0.40, which is a common threshold for acceptance. The factor analysis model fitted the data reasonably well (χ square = 888.495, $df = 210$, $p < 0.001$).

From the original factor analysis, we chose the results of 11 variables concerning element technology development, function design, product design, prototyping and testing, and manufacturing process design.[8] We identified three factors related to novel technology introduction and

[7] The results were as follows: "compared with products of rivalry firms" (χ square = 0.01, p = 0.98), "compared with past products" (χ square = 0.01, p = 0.92), "compared with past products of the concerned firm" (χ square = 0.02, p = 0.89), and "compared with success criteria within the concerned firm" (χ square = 0.61, p = 0.44).

[8] We eliminated three factors and variables related to concept integration, front-loading, and leadership, from the original result of the factor analysis on 19 variables.

product/process engineering, and used the cases of the assembly product group for our analysis.[9]

We found that Factor 1 (eigenvalue = 3.96, contribution ratio = 0.21, α = 0.82) consisted of variables such as communication at the product/process engineering stages and overlapping between the product and process engineering stages. Therefore, Factor 1 was named “engineering integration.” The factor included cross-functional integration across engineering sections and overlapping between product engineering stages and premanufacturing stages.

Effective overlapping contributes to shortening lead time, thereby increasing the accuracy of the simulation (Clark & Fujimoto, 1991). While overlapping between related stages is not necessarily accompanied by communication between the stages, information exchange is critical for effective problem-solving in overlapping (Adler, 1995; Clark & Fujimoto, 1991; Terwiesch & Meyer, 2002). This is nothing more than cross-functional integration at the product/process engineering stages.

Factor 2, the first factor of a novel technology introduction strategy, was named “technology integration” (eigenvalue = 1.41, contribution ratio = 0.07, α = 0.71) as it was heavily loaded with five variables related to the search and simulation of element technologies in the early stages.

Project members need to collaborate among technology and product/process development groups to effectively integrate novel technologies into products (Iansiti, 1997; Tatikonda & Rosenthal, 2000). This is nothing more than “technology integration” (Iansiti, 1997). For instance, in super computer product development, from the early stages, product development projects conduct intensive searches and simulations of materials, components, and product designs.

Factor 3, the second factor of novel technology introduction into products, was heavily loaded with the variables of separation of element technology development from product/process engineering. Therefore, we called this factor “separated technology development” (eigenvalue = 1.18, contribution ratio = 0.06, α = 0.60). Studies reported that the separation of novel technology development from current product development enables firms to respond to drastic technological changes while pursuing effective product development based on current technologies (Iansiti, McFarlan, & Westerman, 2003). Firms may reduce technological uncertainty in product development by the separation of element technology development. Separating problem-solving with regard to element technology development from product/process engineering diminishes the search and simulation for technology integration undertaken to accelerate product engineering *per se* in each project (Cusumano & Nobeoka, 1998; Cusumano & Yoffie, 1998; Funk,

[9] All the strategies are significantly correlated with the collaboration with suppliers (r = 0.24, p < .0.01; r = 0.3, p < 0.01; r = 0.21, p < 0.05). The collaboration with suppliers could work with any of the strategies. These results partly explicate why novel technology introduction strategies were not distinguished from cross-functional integration—in terms of supplier involvement—at the engineering stages (e.g., Takeishi, 2002).

2002; MacCormack, Verganti, & Iansiti, 2001).

The relationships of these strategies with aspects of product development performance further revealed the necessity of these distinctions. Therefore, we examined the correlations between aspects of product development performance and strategies (Appendix 3). The analysis demonstrated that engineering integration was significantly correlated with all the performance measures, with the exception of customer satisfaction/total quality ($p < 0.01$ or $p < 0.05$). At least for the sample Japanese product development projects, most of the aspects of product development performance could be attributed to engineering integration.

Technology integration was significantly related to several specific aspects of performance such as customer satisfaction/total quality and specific functional performance. Yet, separated technology development did not show a significant correlation with any of the performance measures. These differences supported the fact that these product development strategies are mutually distinguishable also in terms of the aspects of performance.

Analysis

Does market differences matter?

We may presume that the predictability of product development strategies depends upon the distinction between consumer and industrial products.[10] The characteristics of target markets would depend upon the target customers of the product in question. In the development projects for many consumer goods such as automobiles, consumer electronic appliances, and so on, customer needs are uncertain and/or equivocal. For example, while exterior styling, color, aesthetic design, and feelings are critical factors in automobile development, these ergonomic features can hardly be defined in an articulate manner; moreover, changes in tastes are also difficult to predict (Clark & Fujimoto, 1991; Iansiti & Clark, 1994).

On the contrary, the goal specifications of business/industrial products (e.g., products for businessmen, professionals, SOHO, hospitals) can be derived from specific functional criteria such as processing speed, capacity size, and so on (e.g., Christensen, 1997; Iansiti, 1997). For example, Iansiti described the advancement in a single technological function—processing capacity—as the major goal of super computer development. Thus, in contrast to the cases of consumer product development projects, developing industrial products are focused on relatively instrumental and specified features that are sometimes directly provided by the customers (von Hippel, 1994).

However, this simple categorization of the target market—whether consumer or industrial—has the risk of obscuring more specific market characteristics,[11] which might be perceived by

[10] We asked the respondents to choose the most approximate product category—in terms of the target market—from two categories: consumer products (= 1) or industrial products (= 0). The number of consumer assembly products was 35 (29.66%), while that of industrial assembly products was 83 (70.34%).

[11] The mean number of competing products—10.18—in the consumer product group was significantly larger

project members as having direct impacts on product development strategies. Product development strategies are not adopted according to the dichotomy of markets, which could be fluid according to the attributes of target customers. Even consumer/industrial products (e.g., copiers, personal computers, software, wireless phones, etc.) are often tailored to industrial/consumer customers.

The fluid boundary between consumer and industrial products made us infer that perceived market uncertainty rather than market dichotomy has more direct impacts on product development strategies. The dichotomous characterization of the target markets would blur the factors that have direct impacts on product development strategies. Thus, we contrived several perceived measures to explicate product development strategies.

Independent variables

We employed three measures of product characteristics. With regard to technological uncertainty, we measured "necessity of element technology development" with a 5-point Likert scale (1 = "not necessary at all" to 5 = "extremely necessary"). Past studies have mainly focused on the impacts of technological change/novelty. Yet, these factors are rarely examined separately from customer/market volatility (e.g., Christensen, 1997; Cusumano & Yoffie, 1998; Dater, 1997; Eisenhardt & Tabrizi, 1995; MacCormack, Verganti, & Iansiti, 2001).

Further, the intensity of technology development was measured by the quantity of preceding patents related to the product (e.g., Tatikonda & Rosenthal, 2000). However, the quantity of patents could be largely related to the complexity of the concerned products;[12] this means that in general, products with more distinctive elements could yield more patents. It should also be noted that as demonstrated in pharmaceutical industries, patents do not necessarily account for firms' capabilities (Henderson & Cockburn, 1994). Thus, following Song and Montoya-Weiss (2001), we attempted to measure perceived technological uncertainty.

On the other hand, we measured the level of product complexity by using two measures. First, we attempted to measure the "quantity of evaluated product functions," which was checked in the test process of the concerned projects. We asked the respondents to check the approximate number on a

than that in the industrial product group—6.12 ($F = 6.46$, $p < 0.01$). Also, the mean period—21.57 months—of the standard model change cycle of the consumer product group was significantly shorter than that of the industrial product group—36.3 months ($F = 6.82$, $p < .0.01$). These differences indicate that competition is, in general, more intensified in consumer product markets than in industrial ones due to the fundamental unpredictability of customer/market needs. In practice, the consumer product group was significantly correlated with the elusiveness of customer/market needs ($r = 0.29$, $p < 0.01$).

[12] The quantity of patents were significantly related to both the necessity of element technology development ($r = 0.19$, $p < 0.05$) and technology integration ($r = 0.2$, $p < 0.05$). Yet, the quantity of patents was also significantly correlated with the quantity of evaluated product functions ($r = 0.27$, $p < 0.01$), the quantity of product elements/design drawings ($r = 0.22$, $p < 0.01$), and the number of project members ($r = 0.25$, $p < 0.01$). These results showed that the quantity of patents is related to quantitative product complexity rather than technological uncertainty.

5-point logarithm scale (1 = "1," 2 = "10," 3 = "100," 4 = "1,000," 5 = "10,000").[13] Product complexity could be captured in terms of the amount of product elements (Anderson, 1999). An automobile has product complexity largely because an automobile consists of 20,000 to 30,000 parts.

Other things being equal, a larger amount of evaluated product functions will be related to several interdependent elements and are attained as the results of the synthesis of the interdependent elements. In effect, Kusunoki (1999) considered product complexity in terms of the amount of evaluated product functions, thereby explicating the cross-functional integration and related routines in Japanese semiconductor firms.

Nevertheless, we predicted a fundamental difficulty in measuring product complexity with the quantity of product elements. The amount of product elements may be independent of the level of interdependencies. Product complexity has been conceptualized in terms of the level of interdependencies between product elements, which define the required knowledge, cost, and time for realizing a new product (e.g., Baldwin & Clark, 1999; Garud & Kamaraswamy, 1995; Langlois & Robertson, 1992).

Thus, we also measured the architectural attributes of product complexity with the level of "decomposability of the concerned products into independent components," using a 5-point Likert scale (1 = "extremely low" to 5 = "extremely high"). Product design complexity, which could, for instance, be characterized by the concept of product architecture, determines the mode of organizational coordination (Sanchez & Mahoney, 1996; Ulrich, 1995).

Finally, we measured the "elusiveness of customer/market needs" as the variable of market uncertainty, using a 5-point Likert scale (1 = "not necessary at all" to 5 = "extremely necessary").[14] The impacts of market volatility are often considered in terms of the model change cycle (e.g., Eisenhardt & Tabrizi, 1995; MacCormack, Verganti, & Iansiti, 2001). When the model change cycle is short, firms can hardly have sufficient knowledge of the requirements of customers/markets. Yet, such industrial volatility does not necessarily cause market uncertainty.

In volatile markets, faster product releases can help firms obtain a competitive advantage against competitors (Dater, 1997). Volatile markets in terms of the model change cycle encourage firms to adopt cross-functional routines to develop products faster than competitors (e.g., Eisenhardt & Martin, 2000;

[13] The quantity of evaluated product functions had positive correlations with the quantity of product functions required by customers ($r = 0.26$, $p < 0.01$) and the amount of product elements ($r = .49$, $p < 0.01$).

[14] Model change cycles had a slight negative correlation with the elusiveness of customer/market needs ($r = –0.15$, $p < 0.10$). The mean of the supplier involvement of the consumer product group—3.98—was significantly larger than that of the industrial product group, 3.50 ($F = 3.19$, $p < 0.01$). On the contrary, the mean of the customer involvement of the consumer product group—3.17—was slightly smaller than that of the industrial product group, 3.17 ($F = 3.19$, $p < 0.10$). These results indicate that facing more customer/market needs uncertainty, consumer product development projects are liable to adopt suppliers' capabilities.

Eisenhardt & Tabrizi, 1995). Nevertheless, volatile markets may also urge firms to separate element technology development from product/process engineering in order to quickly adopt novel element technologies for products (e.g., Chesbrough, 2003; Cusumano & Yoffie, 1998; MacCormack and Verganti, 2003; MacCormack, Verganti, & Iansiti, 2001). These conflicting findings may arise because model change cycle as a variable of industrial dynamism could reflect both market and technological volatilities.

A shorter model change cycle may not be an appropriate variable of market uncertainty since the model change cycle often reflects the velocity of technological change rather than market uncertainty (Yasumoto & Fujimoto, 2005a). The customer/market needs of personal computers are not necessarily more uncertain than those of automobiles, even though the former's model change cycle is much shorter than that of the latter. Automobile firms may face more ambiguous customer/market needs even when the model change cycle is long (i.e., several years) (Clark & Fujimoto, 1991). Thus, we decided to adopt a more direct measure of market uncertainty.

Contexts

In order to examine the contextual differences between product types, we measured several context variables related to the concerned products. These context variables were expected to provide the fundamental conditions of the product development projects. After the examination of the correlations between independent and context variables, we decided to use three context variables—model change cycle, industrial difference, and product novelty—for our analysis. Project size,[15] which we measured with the number of core project members, was substituted by the product complexity variable: the quantity of evaluated product functions.

First, with reference to the past studies reviewed in the previous section, we measured the real duration of the standard "model change cycle" (months) within the market of the concerned product. Second, we divided the samples into two industry categories (1 = "electronic" or 0 = "mechanical") according to the industrial categories of the products concerned. The difference between these two industries is important since the impacts of product design attributes are more emphasized in the case of electronic industries than in the case of mechanical ones (e.g., Baldwin & Clark, 1999).

The number of electronic products was 56 (47.46%), while that of mechanical products was 62 (52.54%). Electronic products included computer systems/software, consumer electronics, and electronic parts. Mechanical products included industrial machinery, mechanical parts, precision mechanics, and transportation machines. This variable was used as a dummy variable.

[15] Studies have suggested that the scale of an organization influences the organizational structure. See Clark and Fujimoto (1991). The number of project members was positively correlated with the quantity of evaluated product functions ($r = 0.31$, $p < 0.01$) and the amount of product elements ($r = 0.5$, $p < 0.01$). The number of project members depends on product complexity.

Third, we considered "product novelty" as another context variable. This variable was also used as a dummy variable. We asked respondents whether or not the concerned product was completely new to the preceding product genre within the respondent firm (1 = "novel" or 0 = "conventional"). The number of novel products was 27 (22.88%), while that of conventional products was 91 (77.12%). Product novelty could have significant impacts on product development strategies (Olson, Walker, & Ruekert, 1995; Song & Xie, 2000).

The question was intended to capture product novelty in terms of the distinction between conventional products following past product technologies and novel products without any preceding product technologies. If firms do not have preceding product models/lineups of the concerned product, firms can hardly reuse the knowledge, namely, the marketing, technologies, design, parts, and/or manufacturing process of the preceding products.

Results

We considered five multiregression analysis models from the product characteristics and context variables with regard to the two novel technology introduction strategies. Table 1 shows the results (see the correlation matrix between these variables in Appendix 4).

Model 1 was the baseline model that included only product characteristics as the main factors. Model 2 examined the effects of the model change cycle instead of the elusiveness of customer/market needs, which had a slight negative correlation with model change cycle ($r = -0.15$, $p < 0.10$). In model 3, two context variables were added to model 1. In model 4, the interaction terms for the three product characteristic variables were added to model 1. In model 5, the context variables were added to model 4. In the other potential models, either the R squares or F-values decreased drastically compared to in the presented models, with the exception of model 2. Thus, in order to simplify our examination, we decided to consider the four presented models 1, 3, 4, and 5.

The variation inflation factors (VIF) and condition indexes associated with each of the regression coefficients ranged from 1.03 to 1.08, and the condition indexes associated with each of the regression coefficients were below 2.56. The results suggested no serious problems with multicollinearity in any of our models.

For each of the variables, we paid attention to the significant effects that were common across the models. Yet, it is important to note that the main effects of the product characteristics remained robust in all the models, even when the interaction terms and context variables were included. These interaction terms and context variables increased the R squares slightly, while reducing the F-values; further, they rarely showed prominent effects on novel technology introduction strategies. These results suggested that each of the factors could severally explicate novel technology introduction

Table 1. Results of multiple regression analysis

Independent and Context Variables	Technology Integration					Separated Technology Development				
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 1	Model 2	Model 3	Model 4	Model 5
Necessity of Element Technology Development	**0.33	**0.32	**0.32	**0.36	**0.35	*0.18	†0.16	*0.20	*0.17	*0.19
Quantity of Evaluated Product Functions	0.00	−0.01	0.03	0.00	0.03	**0.20	*0.19	*0.18	**0.21	*0.19
Decomposability into Independent Components	**−0.28	**−0.25	**−0.28	**−0.25	**−0.25	0.10	0.12	0.10	0.10	0.10
Elusiveness of Customer/Market Needs	†−0.15		−0.14	†−0.16	−0.14	**−0.23		**−0.23	**−0.24	**−0.24
Necessity of Element Technology Development *Quantity of Evaluated Product Functions				−0.10	−0.06				0.03	0.01
Necessity of Element Technology Development *Decomposability into Independent Components				0.11	†0.15				0.05	0.03
Necessity of Element Technology Development *Elusiveness of Customer/Market Needs				0.09	0.12				0.13	0.11
Quantity of Evaluated Product Functions*Decomposability into Independent Components				0.10	0.10				−0.07	−0.05
Quantity of Evaluated Product Functions*Elusiveness of Customer/Market Needs				−0.05	−0.07				−0.05	−0.04
Decomposability into Independent Components*Elusiveness of Customer/Market Needs				0.00	−0.02				−0.13	−0.11
Model Change Cycle		0.00					0.06			
Industry Dummy (0 = mechanics, 1 = electronics)			−0.10		†−0.16			0.03		0.00
Product Novelty (dummy, 0 = conventional, 1 = novel)			0.13		†0.15			**−0.21		†−0.19
R square	0.20	0.17	0.20	0.25	0.27	0.14	0.07	0.16	0.17	0.19
F	**6.05	*5.05	**4.58	**3.0	**2.96	**5.13	*2.77	**4.74	**2.62	**2.65

notes: $n = 118$. Standardized values of dependent and independent variables were used for all the models.
† $p < .10$, * $p < .05$, ** $p < .01$

strategies.

The necessity of element technology development and technological uncertainty strongly explained both technology integration ($p < 0.01$) and separated technology development ($p < 0.05$). Yet, separated technology development was explicated by the quantity of evaluated product functions and quantitative product complexity ($p < 0.05$ or $p < 0.01$), rather than technological uncertainty.

The result evidenced that element technology development should be separated from product/process engineering, particularly when quantitative product complexity is relatively high. Accordingly, the task loads of product/process engineering are high as the projects need to cope with a variety of element technologies. Thus, the task loads for element technology development at the product/process engineering stages could be alleviated by separating element technology development from product/process engineering.

On the other hand, the decomposability of products into independent components, which would indicate product complexity in terms of architectural stability, did not show any significant effects on separated technology development, but had significant negative impacts on technology integration ($p < 0.01$). The result revealed that projects are liable to adopt technology integration when architectural knowledge, which provides the stability of product designs to secure the independency of each component, is insufficient.

These results seem to support the finding concerning product architecture such as modularity and platform management. Yet, we should note that decomposability is not necessarily bound to modularized product development based on a separated core technology/platform development. The results did not show any significant effects of decomposability on separated technology development.

These results on the decomposability of products into independent components are in accordance with those on product novelty. Product novelty, which is liable to arise with drastic design changes, had slightly significant positive effects on technology introduction ($p < 0.10$); however, it had significant negative effects on separated technology development ($p < 0.01$ or $p < 0.10$).

The elusiveness of customer/market needs had significant negative effects on both the strategies ($p < 0.01$ or $p < 0.10$). The results revealed that firms are not liable to adopt novel technologies unless customer/market needs are relatively explicit. In particular, separated technology development was elucidated by explicit customer/market needs. The strategy of separated technology development was slightly correlated with customer involvement ($r = 0.15$, $p < 0.10$), while technology integration was not. Accordingly, industrial product development projects, which entail customer involvement more than consumer development projects do ($F = 39.21$, $p < 0.001$), are more liable to adopt separated technology development as compared to consumer development projects ($F = 11.24$, $p < 0.001$). However, technology integration did not show such a difference. These results suggested that firms employ separated technology development in order to respond to each of the specific requirements directly designated by customers.

Finally, the model change cycle and industry dummy did not have any effects on either of the novel technology introduction strategies. These industrial variables *per se* did not determine the novel technology introduction strategies. Instead, more specific product attributes, namely, product complexity and market uncertainty, are the critical determinants of novel technology introduction strategies.

Discussion

The concept of cross-functional integration included a broad range of organizational routines for information exchange and collaboration between functional units. In many past studies, cross-functional integration has been generalized as the bundle of communication and collaboration for knowledge processing across functional organizational units (e.g., Brown & Eisenhardt, 1995; Clark & Fujimoto, 1991; Eisenhardt & Tabrizi, 1995; Iansiti, 1997; Iansiti & Clark, 1994; Kusunoki, Nonaka, & Nagata, 1998; Takeishi, 2002).

To further examine cross-functional integration, the analysis began with the demonstration of the fact that technology integration is distinguished from cross-functional integration at the product/process engineering stages (i.e., engineering integration).

Then, we verified that novel technology introduction strategies are divided into technology integration and separated technology. Following the distinctions between product development strategies, the study provided evidence that successful projects choose either of the novel technology introduction strategies according to product characteristics and/or contexts.

The results showed that both the strategies arise from the necessity for novel technologies. Yet, technology integration would be effective in the case where the architectural knowledge of product designs is not sufficient to secure the decomposability of the products into independent components. This novel technology introduction strategy is particularly critical in order to realize drastic technological changes, which involve architectural changes of product designs (Chesbrough & Kusunoki, 2001; Henderson & Clark, 1990; Iansiti, 1997). Technology integration is suitable for industrial volatility in the sense of drastic technological change, though seemingly contributing to respond to both market and technological volatility (Eisenhardt & Martin, 2000; Eisenhardt & Tabrizi, 1995).

Cross-functional integration for novel technology introduction enables exploratory knowledge creation for the acquisition of novel knowledge, which competitors can hardly imitate or acquire (Benner & Tushman, 2003; Iansiti & Clark, 1994; Kusunoki, Nonaka, & Nagata, 1998). Each of the element technologies, such as patented technologies and modularized components, does not necessarily contribute to fundamental product innovativeness, which results from organizational capabilities (Henderson & Cockburn, 1994). Element technologies such as standardized modules in particular, could be transferable between firms and/or imitated by other firms, so that these technologies would not necessarily secure firms' competitiveness (Anderson, 1999; Pil & Cohen, 2006).

Even if a large portion of a product comprises modularized/standardized components, a firm that has the capabilities to manage the interdependencies between the components and integrate them (Brusoni & Prencipe, 2001) would be prominent in markets. In practice, the data showed that technology integration contributes to some aspects of product development performance, particularly specific functional performance.

Nevertheless, technology integration, which encourages firms to design products aligned with novel component development, requires cost and time for each project. Firms can utilize separated technology development to reduce the task load of each development project (Cusumano & Nobeoka, 1998; Krishnan & Gupta, 2001; MacCormack & Verganti, 2003; Tatikonda, 1999). The results suggested that this strategy is particularly called upon for the development of quantitatively complex products, which accordingly include a variety of element technologies changing at uneven paces.

Past studies have also suggested that separated technology development may contribute to shortening product development lead time and would thus be flexible to industrial volatility (e.g., Cusumano & Yoffie, 1998; MacCormack, Verganti, & Iansiti, 2001; Thomke, 1997). However, rather than technological uncertainly and model change cycle, this strategy was explicated by the specificity of customer/market needs, which, above all, are directly provided by customers (von Hippel, 1994). These findings allow us to infer that separated technology development could be flexible to a variety of specific customer/market needs and technologies, rather than to industrial volatility.

The impacts of industrial volatility are often considered in terms of model change cycle (e.g., Cusumano & Yoffie, 1998; Eisenhardt & Tabrizi, 1995; MacCormack, Verganti, & Iansiti, 2001). In volatile industries, faster product releases could help firms obtain a competitive advantage against competitors (Dater, 1997). Thus, in terms of model change cycles, volatile industries encourage firms to develop products faster than competitors. Nevertheless, we did not find any significant effects of model change cycle on novel technology introduction strategies. Both the conflicting strategies, technology introduction and separated technology development, are explicated more appropriately by technological uncertainty, quantitative product complexity, product decomposability, and/or market uncertainty. The results suggest that industrial volatility *per se* is not as critical as these factors.

While adaptive to industrial volatility with radical technological changes, technology integration can hardly cope with market and technological varieties/variations. Separated technology development would complement technology integration. The attempt to utilize separated technology development, which is adopted in conventional product development projects rather than novel ones, would be indispensable for responding to the product design varieties following product designs verified in preceding projects.

Simply relying on either of the strategies would jeopardize firms' competitiveness in the age of interfirm modularity and related open interfirm networks (e.g., Chesbrough, 2003; Christensen, Verlinden, & Westerman, 2002; Gawer & Cusumano, 2002; Sturgeon, 2002). Firms need to refurbish core technologies on one hand, and employ element technologies for various customers/markets on the other. Any single novel technology introduction strategy at the project level can hardly cope with "variety" or "volatility." The role of mediating between conflicting requirements is assigned to contrived product design strategies, for instance, multiproject/platform strategies that are beyond single product development projects (e.g., Cusumano & Nobeoka, 1998; Funk, 2002; Krishnan & Gupta, 2001; Tatikonda, 1999; Ulrich & Ellison, 1999).

Conclusions

Preceding studies have particularly focused on the impacts of technological change/novelty on product development, and have emphasized cross-functional integration for novel technology introduction (e.g., Eisenhardt & Tabrizi, 1995; Iansiti, 1997; Song & Xie, 2000; Tatikonda & Rosenthal, 2000). In the line of studies, the effects of design and market attributes were often blurred and confused with those of technological change/novelty. Yet, the results here indicated that technological change/novelty, product design, and customer/market needs, each have different effects on novel technology introduction strategies.

The architectural attributes of product design could determine the range of technological innovations (Chesbrough & Kusunoki, 2001; Henderson & Clark, 1990). Novel technology introduction with drastic element technology change may erode the decomposability between product designs and elements, and would thus enhance technology integration for problem-solving (Iansiti, 1997; Takeishi, 2002). Yet, novel technology introduction does not necessarily result in technology integration (Chesbrough, 2003; Iansiti, McFarlan, & Westerman, 2003).

Firms may separate technology development from each of its specific projects and introduce new element technologies into a portion of the product systems (e.g., Chesbrough, 2003; Cusumano & Yoffie, 1998; MacCormack & Verganti, 2003). The difference between the two strategies mostly emerges from design attributes and quantitative product complexity and decomposability, which provide the conditions for novel technology introduction modes. Reflecting the difference, firms would adopt novel technology introduction strategies according to customer/market attributes.

The results revealed that both novel technology introduction strategies are adaptive to relatively explicit customer/market needs. Yet, separated technology development responds to a variety of specific requirements directly provided by customers; on the other hand, technology integration focuses on specific aspects of technological performance. Technology integration is the strategy suitable in the case of strong industrial volatility caused by drastic technological changes. In contrast, the aim of separated technology development is to respond to the varieties of specific customer/market needs and technologies rather than industrial volatility. Separated technology development is necessary when drastic technological changes through technology integration are not geared to existing customers/markets (e.g., Iansiti, MacFarlan, & Westerman, 2003).

Simply relying on technology integration is a rather risky approach, even though firms' competitive advantages rest in their capabilities to integrate various elements. Refurbishing product designs and components for each novel technology introduction would not be effective, particularly where open interfirm networks to foster product development are shaped (Chesbrough, 2003; Christensen, Verlinden, and Westerman, 2002; Sturgeon, 2002). At the business level, beyond the project level, firms need to integrate various technologies, paying sufficient attention to both uneven changes of various elements and interdependencies between components (Brusoni & Prencipe, 2001).

In order to make proper use of both novel technology introduction strategies, firms should devise coherent product development strategies, such as multiproject/platform strategies, at the business level (Cusumano & Nobeoka, 1998; Robertson & Ulrich, 1998; Tatikonda, 1999). Without product strategies to increase the flexibility at the business level, firms may face the problem of optimization within single projects, for example, over-specification and high product cost despite high project performance (Clark & Fujimoto, 1991; Cusumano & Nobeoka, 1998; Funk, 2002).

The case of Japanese mobile phone manufacturers might provide the emblematic example. While rapidly commercializing a variety of advanced technologies in the world, Japanese mobile phone handset manufacturers' performances are mostly not prominent in the world of mobile phone industries. Japanese manufacturers have commercialized novel technologies focusing on the Japanese market without sufficient consideration of product lineup strategies and platform management for the world market (Funk, 2002).

In effect, in most of the regular handset model development projects, Japanese manufacturers are liable to employ technology integration changing the handset architectural attributes, resulting in them having difficulties in responding to the variety of elusive customer/market needs in the global markets (Yasumoto & Fujimoto, 2005b). In spite of the functional novelty and product integrity, the problem of product development strategies ruins the competitiveness of Japanese firms in the world market in terms of cost, speed, and product variety. The implications from this study would spell out the nature of these problems.

In closing, this study may be regarded as an attempt to bridge the chasm between generic and industry-specific studies in the field of product development management. The present study attempted to examine past findings from industry-specific studies within a generic study context. Hereafter, drawing on the cases of specific industries, we should further excavate how the implications on novel technology introduction strategies are related to product architectures and platform/multiproject strategies. At the same time, we also need to conduct international research as the results in this study may be influenced by the attributes that are specific to Japan. While we are still taking initial steps in this research area, this line of study seems to deserve further exploration in terms of both content and methodology.

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Appendices

Appendix 1. Performance differences between assembly and process product groups

	Number of Samples	Customer Satisfaction /Total Quality	Product Development Cost	Product Development Lead time	Specific Functional Performance	Sales/Market Share	Profit
Assembly mean	118	4.41	3.75	3.81	4.37	4.22	3.91
s.d.		0.62	0.77	0.86	0.61	0.79	0.74
Process mean	70	4.53	3.80	3.84	4.47	4.18	3.92
s.d.		0.50	0.70	0.81	0.53	0.73	0.79
t		1.36	0.68	0.39	1.28	−0.98	−0.04
F		1.06	0.45	0.15	1.51	0.19	0.19
Total mean	188	4.45	3.77	3.82	4.41	4.21	3.91
s.d.		0.57	0.74	0.83	0.58	0.76	0.76

Note: Double-sided t-test and O'Brien's F-test. † $p < .10$, * $p < .05$, ** $p < .01$

Appendix 2. Factor analysis of product development strategies

			Factor 1	Factor 2	Factor 3
	mean	s.d.	Engineering Integration	Technology Integration	Separated Technology Development
Alternative core technologies were compared and analyzed using prototypes in order to realize the product's concept and specifications.	3.56	1.05	0.09	0.73	-0.12
Alternative designs were prototyped and screened within a spcified search range in order to achieve the target product specification and performance.	3.39	0.92	0.11	0.64	0.23
Effective coordination and communication were made between advanced element technology development department and product development department.	3.63	0.97	0.10	0.51	-0.10
Period of core technology development was overlapped with period of product concept/specification development.	3.74	0.92	0.17	0.54	0.05
Core technologies were separately developed in advance of product engineering.	3.66	1.19	0.00	0.46	0.60
The components were developed separetely by component development groups.	3.33	0.96	0.14	-0.11	0.75
Intensive communication was made between members in element technology development stages.	3.49	0.84	0.11	0.30	0.47
Period of product engineering was overlapped with that of process engineering.	3.58	0.95	0.54	0.21	0.15
Effective coordination and communication were made within product engineering group.	4.01	0.76	0.84	0.03	0.00
Effective coordination and communication were made between product engineering department and process engineering/ production technology department.	3.84	0.83	0.76	0.20	-0.04
Intensive communication was made among members in test/experiment stages.	3.82	0.76	0.65	0.08	0.13

Note: n = 188. Factor loadings were varimax rotated.
The shaded cells indicate values larger than 0.4 or smaller than -0.4.

Eigen Value

	Eigen Value	Contribution Ratio	Cronbachα
Product Development Routine Factor 1	3.96	0.21	0.82
Product Development Routine Factor 2	1.41	0.07	0.71
Product Development Routine Factor 3	1.18	0.06	0.60

Appendix 3. Correlation analysis between development strategies and performances

	Mean	S.D.	Engineering Integration	Technology Integration	Separated Technology Development
Customer Satisfaction/Total Quality	4.41	0.62	0.10	0.14 †	−0.05
Product Development Cost	3.75	0.77	0.17*	0.11	−0.03
Product Development Lead time	3.81	0.86	0.23**	0.08	0.02
Specific Functional Performance	4.37	0.61	0.15*	0.16*	0.04
Sales/Market Share	4.22	0.79	0.26**	−0.03	−0.03
Profit	3.91	0.74	0.17*	0.10	−0.07

Note: *n* = 118 † p < .10, * p < .05, ** p < .01

Appendix 4. Correlation matrix between multiple regression model variables

	Mean	S.D.	1	2	3	4	5	6	7	8	9
1 Technology Integration	−0.18	0.94	1.00								
2 Separated Technology Development	0.25	0.87	0.04	1.00							
3 Necessity of Element Technology Development	3.62	1.30	**0.32	*0.19	1.00						
4 Quantity of Evaluated Product Functions	2.88	0.83	0.07	0.10	−0.04	1.00					
5 Decomposability into Independent Components	3.16	1.22	**−0.23	† 0.14	0.10	−0.08	1.00				
6 Elusiveness of Customer/Market Needs	2.54	1.25	−0.09	**−0.23	0.10	0.01	−0.09	1.00			
7 Model Change Cycle (MO.)	31.78	28.47	0.04	0.04	0.00	−0.10	−0.07	† −0.15	1.00		
8 Industry (dummy, 1 = electronics/0 = machinery)	0.53	0.50	−0.09	−0.03	0.02	0.07	−0.09	† 0.13	**−0.49	1.00	
9 Product Novelty (dummy, 1 = novel/0 = conventional)	0.22	0.42	0.08	−0.11	† 0.15	0.08	0.02	0.02	−0.02	0.09	1.00

Note: *n* = 118 † p < .10, * p < .05, ** p < .01

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