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Internal and External Integration for Product Development: The Contingency Effects of Uncertainty, Equivocality, and Platform Strategy

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ABSTRACT

Effective product development requires firms to unify internal and external participants. As companies attempt to create this integrated environment, two important questions emerge. Does a high level of internal integration lead to a higher level of external integration? In the context of product development, this study considers whether internal integration in the form of concurrent engineering practices affects the level of external integration as manifested by customer integration, supplier product integration, and supplier process integration. External integration, in turn, may influence competitive capabilities, namely product innovation performance and quality performance. Second, using contingency theory, do certain contextual variables moderate the linkages between integration strategy (external and internal) and performance? Specifically, this study considers whether uncertainty, equivocality, and platform development strategy change the relationships among internal integration, external integration, and competitive capabilities. Data collected from 244 manufacturing firms across several industries were used to test these research questions. The results indicate that both internal and external integration positively influence product innovation and quality and ultimately, profitability. With respect to contingency effects, the results indicate that equivocality moderates the relationships between integration and performance.

Subject Areas: Contingency Theory, Integration, New Product Development, and Structural Equation Modeling.

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INTRODUCTION

New product development (NPD) is a key strategic activity in many firms because new products contribute significantly to sales. When firms are able to develop distinctive offerings, they have opportunities to command premium pricing, at least in the short run until competitors create similar products. Even with this growing emphasis on product development, the proportion of product development failures continues at around 35% (Cooper, 1990). This pattern seems to subsist as in a more recent study Cooper and Edgett (2003) found that the average success rate of NPD projects was approximately 60%. Interestingly, they also found a sizable difference in the success rate between the top-performing firms when compared with the average firm. Specifically, they found that the top 20% of firms had a higher success rate at 79.5% and less than half the failure rate of average firms. Partly for this reason, there has been considerable interdisciplinary academic research to understand why some projects fail whereas others succeed.

There have been at least four meta-analytic studies that have reviewed and critically synthesized the existing work on NPD (Montoya-Weiss & Calantone, 1994; Brown & Eisenhardt, 1995; Kessler & Chakarabarti, 1996; Henard & Szymanzki, 2001). Yet, the findings from these reviews are paradoxical. Conducted across a variety of settings, the broad correlates of NPD project success reported in these reviews were not consistent, both in terms of a presence of a relationship and in terms of the strength of their impact. All four reviews call for an integrated examination of broad and new factors that affect NPD success. Similarly, Krishnan and Ulrich (2001) updated past meta-analytic reviews by offering a decision-making focus to group research on NPD and suggest new research directions. Henard and Szymanski (2001) specifically call for studies that depart from the typical "main-effects" models that seek to understand key drivers of NPD performance. They indicate a strong need for examining the effects of contextual variables that might enhance or mitigate the results of main-effects models. Consistent with the comments of Henard and Szymanski (2001), Gerwin and Barrowman (2002) in their meta-analytic review of the literature on integrated product development point out several contextual variables that may explain why certain relationships show up as being statistically significant in certain studies but not in others.

Another consistent finding across several of the cited meta-analytic reviews is the lack of a robust theory that explains patterns in the findings. This research seeks to address these gaps by offering a contingency view of the effects on product development performance. We also use extant theory to support our contextual view of NPD performance. More specifically, the objectives of this research are to test the paradigm of how structuring as a broad concept and integration as a manifestation of structuring can positively influence performance using the context of NPD. The focus is on internal integration (concurrent engineering) and external integration (both supplier and customer) that represent the overall strategy of integration. This is a departure from prior studies that have tended to examine either internal or external sources of integration but not both sources within the same study. In addition, past empirical research on external integration has focused on customer or supplier integration but did not assess the concurrent effects of these variables. The distinction between supplier product integration and supplier process integration did not receive much acknowledgment in past empirical research either. Ragatz, Handfield, and Petersen (2002) suggest that evidence supporting supplier integration is less clear than evidence on the positive contribution of customer integration. Performance is measured in terms of product innovation, product quality capabilities, as well as profitability. The second objective is to use contingency theory to evaluate the moderating impact of uncertainty, equivocality, and platform strategies.

THEORY DEVELOPMENT

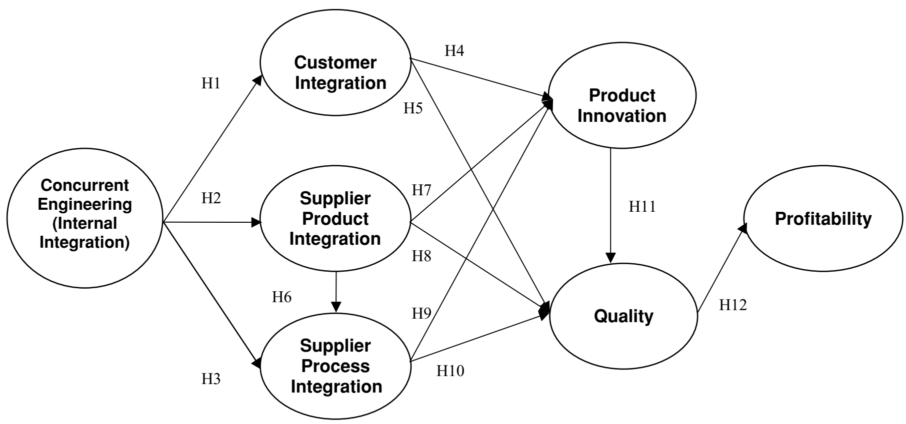
Successful firms employ organizational designs that enable them to deal effectively with their competitive environment. Such firms involve important constituents early in the product development effort, and those constituents become part of a cross functional team (Hartley, Meredith, McCutcheon, & Kamath, 1997; Hartley, Zirger, & Kamath, 1997; Liker, Sobek, Ward, & Cristiano, 1996).

The empirical literature supports this approach. Droge, Jayaram, and Vickery (2000) found in a recent study of NPD in the automotive supplier industry that synergistic integration, a construct that includes cross functional teams for innovation, tended to reduce NPD time and improve NPD performance. They also found that supplier closeness had similar impacts, which suggests that cross functional and boundary spanning integration provides ways to share understanding about the different tasks underlying product development and launch efforts.

Although theoretically the literature suggests that firms would employ integrative practices in the face of uncertainty, Song and Montoya-Weiss (2001) state that research in explaining how firms adapt to uncertain environments is sparse. Many firms are facing an environment that is replete with change and complexity. These changes affect product performance, quality, length of product life cycles, and frequency of new product introductions. Products and processes are also becoming more perplexing, creating a complex environment for firms to operate within. With each new source of change in the environment, firms realize that they do not possess adequate information for effectively dealing with change. This creates a sense of uncertainty. In addition, the complexity in the environment introduces equivocality because even with the availability of information, constituents find it difficult to cope with ambiguity. As uncertainty and equivocality increase, firms may refine their product development process to increase integration and knowledge sharing.

Researchers (e.g., Burns & Stalker, 1961; Lawrence & Lorch, 1967; Huber, O'Connell, & Cummings, 1975; Huber & Daft, 1987) have argued that environmental uncertainty and ambiguity have an important influence in structuring an organization. Daft and Lengel (1986) suggest that in order to reduce uncertainty, the organization needs to process more information and do so effectively. Information processing typically involves people from different functional specialties who share information and converge on a shared interpretation of what the project team ought to do (Daft & Lengel, 1986). Gupta, Raj, and Wilemon (1986) use uncertainty reduction theory to explain the perceived need for integration in product development. They maintain that uncertainty increases the need for interconnected product development practices that help product development teams cope with the

Figure 1: Hypothesized structure model.



fuzziness of their task environment and, thereby, enact a shared team vision more quickly.

This research examines the strategy of integration as a key predictor of success in NPD efforts. It uses arguments from organizational theory to propose integration as a structural mechanism that firms employ to deal with the information processing requirements for developing and launching new products. The study posits internal integration as an important precursor for effective external integration. External integration is expected to positively influence the competitive capabilities of product innovation and quality. Moreover, the study suggests that there may be contingency variables that affect these relationships (Galbraith, 1973).

Based on the previous discussion, we propose the research framework in Figure 1 which illustrates how a firm's key structural decision of internal integration, that is, concurrent engineering (Langowitz, 1988; Barkan, 1992; Millson, Raj, & Wilemon, 1992) facilitates external integration, that is, customer integration, supplier product integration, and supplier process integration. Parthasarthy and Hammond (2002, p. 79) suggest that external integration can impact innovation speed and frequency by facilitating coordination with boundary groups. These key practices expedite knowledge transfer and improve product innovation and quality capabilities. Supplier integration involves two separate constructs: supplier product integration and supplier process integration. This distinction is important as firms may integrate suppliers from a process and/or product point of view. This may explain some of the differential findings in the literature.

Internal Integration: Concurrent Engineering

Concurrent engineering is the early involvement of a cross functional team in a process to plan product design, process design, and manufacturing activities simultaneously. It has been operationalized to include cross functional teams, concurrent workflows, and early involvement (Koufteros, Vonderembse, & Doll, 2001). It may afford a firm a stream of integrative innovations that improve the value of products to customers, enhance quality, shorten time-to-market, and reduce cost. With early release of information, engineers can begin working on different phases of the problem, while final designs are evolving. The early release of information reduces uncertainty and promotes the early detection of problems, which enables firms to avoid time-consuming changes. Victor and Blackburn (1987) suggest that the team should identify the source of uncertainty and institute approaches to reduce it.

Concurrent development reduces uncertainty by improving communication between departments. Cross functional teams provide an avenue for constituents to express concerns, a mechanism for capturing learning, and an opportunity to reduce equivocality. A cross functional team brings together a carefully selected array of specialists who share information and make product, process, and manufacturing decisions, jointly and simultaneously. Early involvement empowers downstream participants in the sense that they have a say before decisions are finalized. This helps to achieve commitment and clarify product requirements before too much time and money has been invested and opinions have been formed (Gupta & Wilemon, 1990). Griffin (1997) reports that over 84% of the more innovative projects use multifunctional teams.

The interaction of functional representatives enables concurrent development to provide a rich information medium for reducing equivocality. Concurrent development reduces equivocality by facilitating an exchange of existing perspectives among functional representatives. As a team, they jointly define problems and resolve conflicts. By enabling the enactment of a shared team vision, concurrent development facilitates downstream coordination, enhances product integrity, and improves product development success. Through information sharing and computer technology, teams are able to develop customized products and design new features that enhance product performance (Barkan, 1992; Rosenthal & Tatikonda, 1992).

At the same time, internal constituents seek to integrate with external actors that can provide important information necessary to reduce uncertainty and equivocality. These internal constituents stand to benefit from working closely with customers and suppliers. They recognize that the logic that drives internal integration is equally relevant for integrating activities of external entities. McDermott and O'Connor (2002) point out that firms seek integration with external constituents to fill technical or market-based competency gaps. A broader product development team that includes both customers and suppliers may enact a shared interpretation of the competitive situation, market potential, and customer needs and thus develop a shared sense of purpose. This shared interpretation enables them to reach mutual agreement on key issues such as product definition, project targets, and strategic fit.

Customers have a vested interest in product development. Being integrated with the supplier firm ensures that their voice will be heard and their recommendations and suggestions would be incorporated in the design of new products. Information from the project can be useful to customers for planning purposes such as product features, pricing, and product release dates. Customer input has serious implications for the various internal constituents. Such information has to be incorporated in the project as early as possible to avoid costly mistakes later.

Information about customer requirements can lead to uncertainty reduction as information can be passed to the development team first hand and in real time.

Many suppliers are involved in the product development effort through what are called gray box and black box design approaches. In a black box design environment, suppliers carry out product engineering activities on behalf of their customers and even develop components or entire subassemblies. This is called supplier product integration. On the surface, it may look like suppliers are given basic functional specifications and are asked to complete all technical specifications and sometimes to include materials to be used. The likelihood is that this is more complicated, and indicative of a more intimate relationship between a supplier and a customer. The supplier is expected to have a sixth sense, reading what the customer has in mind. The supplier has to have a picture of expectations and the supplier has to connect with this picture. However, this picture is often latent and represents an amalgam of views produced by various constituents belonging to a concurrent engineering team. To produce this picture, internal constituents have to come together in order to generate a consistent depiction of their expectations. Unless the internal actors generate a consistent picture of functional expectations, it will be difficult for suppliers to meet expectations.

In a gray box environment, the supplier's engineers work alongside the customer's engineers to jointly design the product so the supplier's process can be effectively integrated with the design. We term this supplier process integration. Suppliers provide information about alternatives with regard to material specifications, material availability, material cost, and scheduling. The provided information is more of an impetus that calls for a concerted and integrated effort on the part of the product development actors. Obviously, the higher the level of supplier integration desired the more processes have to be in place to accommodate such integration. The product development team should have a sensory system that can detect stimuli provided by suppliers and then be able to interpret and act upon the information furnished. The preceding discussion suggests the following set of hypotheses:

H1: Concurrent engineering is positively associated with customer integration.

H2: Concurrent engineering is positively associated with supplier product integration.

H3: Concurrent engineering is positively associated with supplier process integration.

Customer Integration

Customer integration involves determining customer requirements and tailoring internal activities to meet these requirements. As a firm gets to know its customers better and becomes committed to understanding and meeting their needs, a strong linkage is forged between the company and its customers. This helps to ensure that the products and/or services the company is providing are what its customers are actually demanding. Customer integration ensures that the voice of the customer plays a vital role in the innovation process within the organization. A firm that places a strategic emphasis on closer customer relationships has moved beyond a mere customer orientation mindset to a customer partnership mentality. Stump, Athaide, and Joshi (2002) suggest that customer involvement includes obtaining reactions to the product design and securing "... feedback on desirable product modifications and alternative applications ..." (p. 443). Customers can evaluate the product's interface with existing operations and feedback can benefit supplying firms because such feedback "... alerts sellers to buyers' perceptions of salient product attributes and reduces market uncertainty ..." (p. 444).

Evans (1996) cites several case examples of companies that have successfully incorporated the voice of the customer into the NPD process. For example, at Ames Rubber Corporation, customers work directly with design engineers on NPD teams. At Whirlpool, when customers rate a competitor's product higher in customer satisfaction surveys, engineers take the product apart to find out why. They also have hundreds of consumers fiddle with computer-simulated products, while engineers record the users' reactions on videotape. When consumers reported that they wanted refrigerators to look clean, Whirlpool designed models with stucco-like fronts and sides that hide fingerprints.

The importance of customer integration can also be gauged from the fact that 23 of the 25 Best Plants finalists reported having direct customer involvement in product development (Taninecz, 1996). For example, Symbiosis Corp., a Miami manufacturer of disposable medical devices, goes right to the surgical theater to observe how physicians operate. This input is supplemented with focus group sessions involving physicians, and coordination with marketing partners to determine future technology needs. At U.S. Steel Corp., customers participate in product-development efforts via their Early Vendor Involvement Program where future steel requirements are identified. The required design performance for specific applications and the tooling needs for the material are identified to facilitate product development and enhance the steel conversion process. The Best Plants finalists frequently visit their customer sites, track customer rejects and deliveries cycles, and locate technical representatives within customer facilities.

By its very nature, customer integration should boost a firm's product innovation and quality capabilities as firsthand information from customers becomes available. As the voice of the customer is embedded in the product development effort, new products and features desired by customers should become available.

H4: Customer integration is positively associated with product innovation performance.

H5: Customer integration is positively associated with product quality performance.

Supplier Integration

Supplier integration may lead suppliers to operate as strategic collaborators. A partnership of this nature is characterized by a long-term commitment between the collaborators, an openness of communication, and mutual trust. Partners work together to ensure high product quality and low costs, with both companies sharing in the benefits. Supplier partnering seeks to bring participants early in the product life cycle so even suppliers and customers can provide input to each other's processes. Thus, the partnership relationship might entail early supplier involvement in product design or the acquisition of access to superior supplier technological capabilities (Narasimhan & Das, 1999). The close integration between the manufacturer and its suppliers afforded by partnership relationships provides a unity of effort in meeting customer requirements for products and in responding to changes in the marketplace. Supplier integration is intuitively appealing for many reasons. Ragatz et al. (2002) provide a list that captures the rationale for such integration (p. 392).

– Including suppliers on project teams adds information and expertise regarding new ideas and technology. This improves the quality of the final product, and ensures that it meets or exceeds the final customer's expectations.
– Supplier integration provides outsourcing and external acquisition possibilities that reduce the internal complexity of projects and provides extra personnel to shorten the critical path for NPD projects.
– It helps to better coordinate communication and information exchanges, which further reduces delays and ensures the project is completed on time.
– The strategy broadens the scope of tasks and issues because accessibility of parts can be considered early on, thus eliminating rework and reducing costs.
– It creates an improved relationship with the supply base, leading suppliers to internalize project concerns and allowing a smoother working relationship on future projects.

Supplier integration may be manifested through a direct assumption of responsibility for carrying out product engineering activities, the development of component parts or even the development of whole subassemblies. Such activities are referred to here as supplier product integration. Companies allocate to suppliers tasks, such as product engineering and the development of entire subassemblies, by capitalizing on the engineering expertise and background of suppliers. The premise is that many suppliers will work concurrently on various components and subassemblies, and thus expedite the development process. For a more "complete" integration of product development activities with suppliers, supplier product integration is frequently accompanied by supplier process integration. Once suppliers are charged with developing entire subassemblies or even certain parts for their customers, suppliers and customers may find it most conducive to also integrate suppliers in the customer's internal product development processes in order to gain a better understanding of the scope and nature of the project but also to contribute their own knowledge and expertise.

Suppliers can be integrated with the internal processes of their customers in an effort to improve quality, reduce costs, and speed up product development. Suppliers possess valuable information and expertise, which can be invaluable in the product development process. Their integration can begin early in the product development process in order to be more beneficial. Their suggestions can be incorporated with the commencement of detailed product development work.

Several empirical studies have examined the effects of supplier involvement on product development time although with no distinction between supplier product or process integration. Eisenhardt and Tabrizi (1995) found supplier involvement actually slowed the pace of product development when products had somewhat predictable designs and mature and stable markets. Clark (1989) used data from a study of the world auto industry to investigate lead-time differentials between Japanese and American automobile companies. The study found that supplier involvement (and strong supplier relationships) contributes four to five months of the lead-time advantage (of Japanese auto producers). Bonaccorsi and Lipparini (1994), reported the following benefits of early supplier involvement: lower development costs, standardization of components, consistency between design and suppliers capabilities, reduction in engineering changes, higher quality with fewer defects, improvement in supplier's manufacturing process, availability of detailed process data, and reduction in time to market.

In another interesting contrast, Swink, Sandvik, and Mabert (1996) found in a series of five NPD projects in high-tech companies, that early supplier involvement strategy was effective in reducing overall development time for highly innovative products. Hartley, Meredith, et al. (1997), suggest that the timing of supplier's involvement was significantly related to perceived contribution to product development success. In the same study, they also found a statistically significant relationship between NPD project success and supplier involvement. In a more recent study, Petersen, Handfield, and Ragatz (2003) found that supplier involvement in decision making pertaining to product and process design significantly affected NPD project outcomes.

Based on a series of case studies, Handfield, Ragatz, Petersen, and Monczka (1999) offer a process model that can be used by firms in appropriately involving suppliers in different aspects of the buyer's NPD project based on the presence and absence of structural characteristics. They found that most firms involved suppliers in the concept development stage of the buyer's NPD process suggesting that an early and extensive involvement of suppliers can greatly enhance the success of the buyer's NPD project success.

Supplier integration appears to be indispensable for product development, at least on an egalitarian level. Supplier talent and capabilities can bring a significant advantage to the product development process. Suppliers provide valuable information about materials, pricing, and process capability. The information provided by suppliers is cross functional in nature and may have a significant impact on the quality, performance, features, pricing, and timing. Suppliers can answer questions from the product development team and thus reduce uncertainty. Suppliers also provide suggestions for reducing complexity.

H6: Supplier product integration is positively associated with supplier process integration.

H7: Supplier product integration is positively associated with product innovation performance.

H8: Supplier product integration is positively associated with quality performance.

H9: Supplier process integration is positively associated with product innovation performance.

H10: Supplier process integration is positively associated with quality performance.

Product Innovation

Product innovation refers to the capability of organizations to introduce new products and features. The fast pace of technological change and the demands of customers for novel and better products require firms to innovate quickly and continually (Blackburn, 1991; Clark & Fujimoto, 1991). Continuing efforts in innovation fosters organizational learning and enables time-to-market to be shortened even further.

Innovation is expected to have an important impact on quality, as many of quality issues are determined during product development (Koufteros, Vonderembse, & Doll, 2002). Continuing efforts in product innovation foster improvements in process innovation, organizational learning, and time to market (Garvin, 1984). Reductions in product development time facilitate product innovations. Because of frequent innovation, products closely match current customer demands and expectations and firms can adopt technological advancements as they become available. Design or quality deficiency can be overcome quickly, resulting in more satisfied customers. Current and future needs of customers are incorporated into new products expeditiously (Koufteros et al., 2002).

H11: Product innovation is positively associated with quality performance.

Quality

Quality gauges the capability of the firm to design and produce products that would fulfill customer expectations (Hall, Johnson, & Turney, 1991; Doll & Vonderembse, 1991). Meta-analysis of Capon, Farley, and Hoenig (1990) identified 20 studies examining the relationship between the quality of products or services and business performance. They found 104 positive versus eight negative relationships between quality and firm performance. Because of the importance of quality, researchers have sought to identify potential contributors to quality performance. Quality is posited here to affect profitability, which is used as a firm performance measure. Buzzell and Gale (1987) while summarizing the extensive results that have examined Profit Impact of Market Share (PIMS) data, have found that product quality is a significant and most consistent predictor of both market share and overall firm profitability. Accordingly, we propose that:

H12: Quality performance is positively associated with profitability.

Impact of Uncertainty and Equivocality on the Adoption of Integrated Product Development Practices

Iansiti (1995) suggests that rapid change in the external environment promotes uncertainty in product development, whereas Song, Jinhong, and Di Benedetto (2001) suggest that the more potential sources of environmental change, the greater the uncertainty faced by the firm (p. 227). Environmental uncertainty reflects changes in environmental components (Daft, 1992; Duncan, 1972). Indeed, environmental uncertainty has been operationalized through measures of change (Waller & Weber, 1987; Sutcliffe & Zaheer, 1998; Song & Montoya-Weiss, 2001; Song et al., 2001). In a study of Fortune 500 manufacturers of industrial products, Calantone, Schmidt, and DiBeneditto (1997) found that the presence of environmental hostility magnified the positive influence of NPD activities on new product success. In this study, they recommended concurrent engineering for firms facing hostile environment conditions to simplify, speed up, and facilitate parallel processing of activities.

Firms are also experiencing varying levels of equivocality. Equivocality is the presence of multiple and conflicting interpretations about a phenomenon (Weick, 1979; Daft & Lengel, 1986). High equivocality implies confusion and lack of understanding. Many times this confusion stems from the presence of complexity. Complexity in products and processes gives rise to ambiguity within the context of product development. Equivocality is portrayed as being similar to uncertainty but equivocality presumes a messy, unclear field and an information stimulus that may have several interpretations (Daft & Lengel, 1986, p. 554). Some of the sources of uncertainty and equivocality are internal, whereas others are imputed from the external environment. Uncertainty and equivocality are more salient where new products capture market share rapidly, product quality and performance standards increase quickly, and product and process complexity expands substantially.

Varying levels of equivocality may contribute to a varying need for internal and external integration. Thus, firms that can cope with higher levels of equivocality are in a sense creating structural mechanisms internally and externally to provide consistency in interpretations about the environmental influences and how to cope with such influences. This consistency can facilitate implementations that span the boundaries of the firm. For example, in the context of NPD, integrative practices help the team members acquire information about the environment, exchange views, interpret the task environment, resolve cross functional conflicts, and reach a mutual understanding of the development task. Integration suggests seamless and joint consideration of issues and decisions across functional and organizational boundaries. Examples of integrative practices include the use of cross functional product development teams, early involvement of constituents, concurrent workflow, and supplier and customer involvement.

Firms facing equivocal and uncertain environments would adopt an organizational design that is efficient in acquiring and processing additional information as well as rich information. The reasons for richness differ according to media type, media's capacity for immediate feedback, the number of channels utilized, personalization, and language variety (Daft & Wiginton, 1979). Wheelwright and Clark (1992) describe such an organizational design as integrated problem solving, which includes the early involvement of constituents who belong to a cross functional team that works on different phases of product development concurrently. This integration includes internal and external participants, and it links upstream and downstream groups in time and in the pattern of communication (Wheelwright & Clark, 1992). Blackburn, Hoedemaker, and Van Wassenhove (1996) describe the need to manage both activity and information concurrency. They develop a model of information concurrency that includes the early involvement of constituents, preliminary information transfer, and intensive and rich communication among team members. Integrated product development practices seem to possess the characteristics needed for complex and changing environments. In another empirical study, Ragatz et al. (2002) found that uncertainty of technology in the environment moderated the effect of supplier integration processes on NPD performance measures such as product cost, quality, and cycle time. Similarly, Primo and Amundson (2002) found that NPD projects with high levels of technical difficulty favor the involvement of new suppliers. This is because established and critical suppliers tend to slow the NPD project and also assign lower priority to a specific buyer's NPD project. Thus, we propose the following hypotheses:

H13: Uncertainty in the environment will have a differential impact on the path coefficients specified in Figure 1.

H14: Equivocality in the environment will have a differential impact on the path coefficients specified in Figure 1.

Impact of Platform Strategy on the Structural Relationships

Another example of a contingency variable is the level of platform strategy. The idea behind a platform strategy is that a dominant product design forms the basis for all future extensions of the product within the same product family. The advantages to firms pursuing a high level of platform strategy are efficiency, lower costs, higher quality, and faster time to markets. Yet, the pressures to integrate for a firm pursuing a high level of platform strategy are quite different from the pressures to integrate for a firm pursuing a low level of platform strategy.

The platform concept is a strategy of planning multiple generations of products by designing a core product that can be modified to create derivative or enhanced variants. Each variant (or increment) optimizes particular design goals that are matched to a specific market segment (Muffatto, 1999). Product changes can be made quickly because technical and marketing uncertainties are lower. This incremental approach leverages a firm's existing capabilities (Zirger & Hartley, 1996) and it permits quicker consumer adoption (Czinkota & Kotabe, 1990).

The platform technique also enhances both social and technical learning. Participants learn how to work effectively together as a cross functional team. The team identifies coordination problems and learns how to deal with them in ways that are transferable to successive generations of products and platforms. Participants gain and share technical knowledge about the causal chain that links customer requirements, product design, process design, and manufacturing. This technical knowledge of cause and effect relationships enhances individual learning, builds the team's shared knowledge base, and enhances its capacity to innovate. Much of this technical learning is transferable to new design cycles. Working on the core or original product, a team develops a shared understanding of customer needs, specifies a product architecture that identifies common modules and interfaces, and designs a flexible manufacturing process that can make a family of products. This up-front work on the core or initial product reduces uncertainties concerning the work process, key module and interface designs, and manufacturing capabilities. By reusing established processing concepts, firms avoid or reduce typical start-up uncertainty and confusion.

H15: The use of platform strategies will have a differential impact on the path coefficients specified in Figure 1.

RESEARCH METHODS

The process of developing the measurement instrument involved several steps. An initial literature review was followed by structured interviews with ten practitioners. Several items were then generated for each construct. Next, the items were evaluated by several professors and practitioners. Participants at this formal pretest step included 14 practitioners representing product development and engineering managers with firsthand knowledge of the product development efforts for their firms and faculty from three universities with expertise in manufacturing management, engineering, marketing, and information technology. The next step consisted of a preliminary assessment of measurement properties employing a sample of 34 firms. The reliability of each construct was examined via Cronbach's (1951) alpha. All were above .80 and are indicative of internal consistency (Nunnaly, 1978). Tentative evidence attesting to the unidimensionality of the constructs was provided through exploratory factor analysis.

There were 32 items (Table 1) that emerged from the pilot study: ten for concurrent engineering, four for customer integration, six for supplier integration, four for product innovation, seven for quality, and one for profitability. The six items for supplier integration comprised two constructs: supplier product integration and supplier process integration, each baring three items. The items for all the scales were mixed throughout the instrument to make sure that the results were not an artifact of the sequence of the questions. The 20 items measuring concurrent engineering, customer integration, and supplier integration gauge the extent to which a practice is used by a firm. This is based on a five-point Likert type scale where 1 = *not at all* and 5 = *a great deal*. The product innovation, quality, and profitability construct items are measured on a seven-point Likert type scale where a firm is compared with the average in the industry and 1 = *much below* and 7 = *much above*. The next step involved the collection of data through a large-scale administration.

Research Design and Sample Characteristics

The research study received support from the Society of Manufacturing Engineers (SME). The society provided the mailing list and logistical support. SME sent a prenotification card to potential respondents 2 weeks prior to mailing the questionnaire. The questionnaires used envelopes and stationary from SME and the cover letter was co-signed by an SME executive. The cover letter identified the purpose of the study and indicated that summary results will be made available to respondents. The pool of respondents included executives of 2,500 discrete-part manufacturing firms with more than 100 employees each, which is consistent with Calantone, Garcia, and Droge's (2003) selection of firms with more than 100 employees. Four SIC codes (SIC 34: Fabricated metal products [except machinery and transportation equipment], SIC 35: Industrial and commercial machinery, SIC 36: Electronics; Electrical equipment and components, and SIC 37: Transportation equipment) were targeted. These specific SICs have been chosen because they

Table 1: Completely standardized loadings and *t*-values ($n = 244$)

Latent Variable	Items	Completely Standardized Loadings	*t*-Values
	X1. Much of process design is done concurrently with product design	.82*	–*
	X2. Product development activities are concurrent	.89	17.57
	X3. Product development group members share information	.72	12.71
	X4. Product development group members trust each other	.74	13.28
Concurrent	X5. Product development employees work as a team	.87	17.00
Engineering	X6. Product development group members seek integrative solutions	.83	15.73
	X7. Purchasing managers are involved from the early stages of product development	.67	11.58
	X8. Process engineers are involved from the early stages of product development	.72	12.82
	X9. Manufacturing is involved from the early stages of product development	.86	16.66
	X10. Various disciplines are involved in product development from the early stages	.82	15.55
	X11. In developing the product concept, we listen to our customer needs	.82*	–*
Customer	X12. We visit our customers to discuss product development issues	.78	13.62
Integration	X13. We study how our customers use our products	.78	13.62
	X14. Our product development people meet with customers	.81	14.43
Supplier	X15. Our suppliers do the product engineering of component parts for us	.82	–*
Product	X16. Our suppliers develop component parts for us	.88	14.90
Integration	X17. Our suppliers develop whole subassemblies for us	.68	11.09
Supplier	X18. Our suppliers are involved in the early stages of product development	.85	–*
Process	X19. We ask our suppliers for their input on the design of component parts	.87	17.24
Integration	X20. We make use of supplier expertise in the development of our products	.84	16.16
	X21. Our capability of developing unique features is	.67	

Table 1: (continued)

Latent Variable	Items	Completely Standardized Loadings	*t*-Values
Product Innovation	X22. Our capability of developing new product and features is	.82	11.33
	X23. Our capability of developing a number of new features is	.91	12.24
	X24. Our capability of developing a number of new products is	.84	11.58
Quality	X25. Our capability of offering products that function according to customer needs over a reasonable lifetime is	.63	–*
	X26. Our capability of offering a high value product to the customers is	.71	9.44
	X27. Our capability of offering safe-to-use products that meet customer needs is	.79	10.30
	X28. Our capability of offering reliable products that meet customer needs is	.87	11.00
	X29. Our capability of offering durable products that meet customer needs is	.81	10.50
	X30. Our capability of offering quality products that meet customer expectations is	.85	10.82
	X31. Our capability of offering high performance products that meet customer needs is	.86	10.93
Profitability	X32. What is your profitability relative to the average in the industry	1.0	–*

Note: * indicates a parameter fixed at 1.0 in the original solution. The items for the first four constructs measure the extent a firm employs the practices using a five-point scale: 1 = not at all, 2 = a little, 3 = moderately, 4 = much, 5 = a great deal. The items for capabilities compare the firm to the average in the industry using a seven-point scale: 1 = much below, 2 = moderately below, 3 = slightly below, 4 = about average, 5 = slightly above, 6 = moderately above, 7 = much above.
Fit indices: Chi-square = 802.75 (p = .00), 444 df, chi-square/df = 1.81, NNFI = .93, CFI = .94, PGFI = .70, PNFI = .79, standardized RMR = .048, RMSEA = .058.

have gained popularity as key segments in much of the reported manufacturing research.

Out of 253 responses received in a single mailing, 244 were usable resulting in a response rate of 10%. Such response rate is not unusual when the unit of analysis is the firm and the survey involves an extensive organizational level survey (the study included four major parts measuring product development practices, manufacturing practices, competitive capabilities, and contextual variables and demographics). Response by SIC code is SIC 34: 35%, SIC 35: 30%, SIC 36: 12%, SIC 37: 15%, and miscellaneous: 8%. Response by position is President/CEO: 12%, Vice President: 31%, Director: 11%, Manager: 19%, miscellaneous: 27%. Response by number of employees is 100–499: 69%, 500–999: 16%, 1000 or more: 15%. The majority of respondents were executives from firms with fewer than 500 employees. There were no statistically significant mean differences of product development practices by firm size. High and middle level executives were targeted because they would have knowledge of product development practices as well as knowledge of their competitive environment. As the majority of the firms are small in size (i.e., fewer than 500 employees), it is reasonable to presume that even high-level executives, such as presidents and CEOs, would have an adequate knowledge of product development practices.

To evaluate response/nonresponse bias of the sample, a chi-square test of differences between observed and expected (population) frequencies for two digit SIC codes and firm size was carried out. The chi-square test showed that the distribution of the sample fits very well with the distribution of the population for SIC codes ($p > .527$), whereas the sample seems to include more large firms than the population would imply ($p < .000$). In addition, we examined for differences in the mean responses between late respondents (i.e., last 25%) and the rest of the respondents. This is the same approach taken by Calantone et al. (2003) who used similar substantive and contextual variables in their research. There were no statistically significant differences in the mean responses on any of the variables we are testing.

Measurement and Structural Model Methods

The measurement model is tested first, followed by the testing of the structural model. This should be done in order to avoid the possible interactions between the measurement and structural models. In addition, confirmatory factor analysis (CFA) is performed on a covariance matrix using maximum likelihood estimation and on the entire set of items simultaneously (Anderson, Gerbing, & Hunter, 1987). Convergent validity is assessed by examining the significance of individual item loadings through t tests. The overall fit of a hypothesized model can be assessed using fit indices such as the ratio of chi-square to degrees of freedom, Bentler and Bonnet's (1980) nonnormed fit index (NNFI), Bentler's (1980) comparative fit index (CFI), James, Mulaik, and Brett's (1982) parsimony goodness-of-fit index (PGFI) and parsimony normed fit index (PNFI), standardized RMR (Joreskog & Sorbom, 1993), and Steiger and Lind's (1980) root mean square error of approximation (RMSEA). Criteria for evaluation of model fit can be found in Byrne (1998) and Hu and Bentler (1995). Potential misspecifications in the measurement model can be examined by reviewing each item's completely standardized expected change in Λ_x (i.e., potential cross loadings). Items exhibiting change in Λ_x greater than .4 should be investigated for their lack of unidimensionality and possible misspecifications in the model. Discriminant validity can be assessed by comparing the average variance extracted (AVE) to the squared correlation between constructs (Fornell & Larker, 1981). Discriminant validity can also be assessed by developing a confidence interval of $\phi \pm 2\sigma e$ (Marcoulides, 1998) for each pair of constructs and examining whether one is included. In other words, the confidence interval is constructed by the correlation between two constructs plus or minus twice the standard error. If one is not included, there is evidence of discriminant validity. Reliability estimation is left for last because in the absence of a valid construct, reliability may not be relevant (Koufteros, 1999).

To test hypotheses H1–H12, a structural model was evaluated. If a model fits the data adequately, the *t*-values of the structural coefficients (i.e., γ and β) can be used to test the research hypotheses. To assess the role of uncertainty (H13), equivocality (H14), and platform strategy (H15), the method used amounted to testing for moderator effects. Our methods for testing moderator effects are reflective of the work in Schumacker and Marcoulides (1998) and follow Byrne's (1998) paradigm where measurement invariance, in terms of loadings matrices, is tested before assessing invariance for path coefficients. For each of the three moderators, two groups were formed such as low uncertainty and high uncertainty groups. The two-group methodology is followed here as Calantone et al. (2003) have shown that it is a more appropriate device than an approach where environmental effects are posited as direct effects.

The low and high groups were formed based on the mean score on the respective moderator scale. Firms scoring below the mean score were classified as belonging to the low group and firms scoring above the mean score were classified as belonging to the high group. This was followed by tests for measurement and structural coefficient invariance. Naturally, the first step involved developing a baseline model with two groups (Model 1). This was followed by imposing equality constraints on both the λ_X and λ_Y matrices (Model 2). The chi-square difference between the baseline model and the model in which the equality constraints were imposed can indicate whether the loadings are invariant between the two groups. To further test for invariance of the measurement model, additional constraints of equality were placed on θ_δ and θ_ε coefficients (Model 3), the error terms for the X and Y models. A nonstatistically significant difference in chi-square between this model and the previous one would indicate invariance in error terms between the two groups. Finally, additional structural coefficient equality constraints (i.e., β and γ) are imposed (Model 4). If, there is no statistically significant chi-square difference between the former (Model 3) and latter model (Model 4), then this is taken as evidence that the structural coefficients do not differ. This is an overall test similar to the ANOVA test for mean differences. If, however, there is a statistically significant difference in chi-square, then a search for identifying which particular coefficients differ takes place. This is accomplished by testing whether there is a significant chi-square difference between Model 3 and a model that specifies invariance for a given structural coefficient, that is, β or γ, at a time. Measures of uncertainty, equivocality, and platform strategy appear in Appendix A. The scales appear to be unidimensional and have satisfactory Cronbach's alpha, respectively.

MEASUREMENT AND STRUCTURAL MODEL RESULTS

Measurement Model

The posited measurement model appears to be supported by various fit indices. The fit indices, along with *t*-values, provide evidence of convergent as well as discriminant validity (Table 1). The chi-square was 802.75 with 444 degrees of freedom, which results in a ratio of 1.81 of chi-square per degrees of freedom. The CFI was .94 and NNFI was .93, whereas the PGFI and PNFI values were .70 and .79, respectively, and are not unexpected (Mulaik et al., 1989). The standardized RMR was .048 and RMSEA was .058. All of the items have statistically significant relationships with their factors. All factor loadings are above .63 and most above .80. The significance of the *t*-values (Table 1) associated with factor to item loadings exceeds the critical value at the .001 significant level.

None of the completely standardized expected changes in Λ_x were greater than .40. Table 2 provides descriptive statistics, composite reliabilities, average variance extracted (AVE), and correlations among the constructs. Evidence of discriminant validity is provided by comparing the squared correlation of two constructs against their individual AVE. The highest squared correlation, was observed between the supplier product integration and the supplier process integration constructs (i.e., .41). This was lower than the AVE for the latent variables, which were .64 and .73, respectively. Evidence provided through confidence intervals also attests to discriminant validity as there are no intervals that contain the value of 1.00 (Table 2).

The composite reliabilities and AVE estimates for each construct exceed customary acceptable levels (Table 2). Overall, there is comforting support for the models to allow us to proceed with an evaluation of the structural model and hypotheses testing.

Overall Structural Model

The overall structural model fit appeared to be reasonable (e.g., chi-square = 824.38, 453 df, chi-square/df = 1.82, CFI = .94, NNFI = .93) and we proceeded with testing of hypotheses H1–H12. Hypotheses H1, H2, and H3 stated that internal integration will have a positive effect on external integration. The results support these hypotheses (Table 3, Fig. 2). Specifically, higher levels of concurrent engineering were associated with higher levels of customer integration ($t = 12.10$) and higher levels of both supplier product integration ($t = 6.90$) and supplier process integration ($t = 8.21$). This supports hypotheses H1, H2, and H3 that posited that internal integration has positive effects on external integration. Internal integration may be necessary if external integration is to materialize at significant levels. Although all concurrent engineering effects were statistically significant, it is important to note that the effects on supplier product integration practices were weaker.

Customer integration was hypothesized to affect competitive capabilities such as product innovation (H4) and quality (H5). The results indicate that customer integration had a statistically significant and positive relationship with product innovation ($t = 4.43$). The contributions of customer integration towards product innovation cannot be ignored. Customers are an important source of information that can aid the product development process. Interaction with customers can improve understanding of their needs and can lead to avoidance of time consuming and costly change orders later in the product development process. On the other hand, customer integration did exhibit only a statistically moderate effect on quality. The coefficient was positive ($t = 1.94$). It was expected that customer integration would lead to higher levels of quality as customers are the source of valuable information and they could have an input in many of the parameters that can affect quality.

Hypothesis H6 suggested that supplier product integration has an impact on supplier process integration. The data supports this assertion and indicates that

Table 2: Descriptive statistics, correlations, composite reliability, and discriminant validity ($n = 244$).

Factors	No. of Variables	Mean	SD	1	2	3	4	5	6	7
(1) Concurrent engineering	10	33.40	8.13	.95[a], .64[b]						
(2) Customer integration	4	15.18	3.25	.58[c]**, .34[e]	.88, .64					
				(.59, .99)[f]						
(3) Supplier product integration	3	7.22	2.85	.24**, .06	.26**, .07	.84, .64				
				(.27, .59)	(.30, .62)					
(4) Supplier process integration	3	8.94	2.79	.51**, .26	.44**, .19	.64**, .41	.89, .73			
				(.54, .90)	(.48, .84)	(.57, .93)				
(5) Product innovation	4	21.05	4.49	.31**, .10	.38**, .14	−.04, .00	.15[d]*, .02	.89, .66		
				(.19, .47)	(.23, .51)	(−.07, .17)	(.09, .37)			
(6) Quality	7	41.46	5.81	.25**, .06	.35**, .12	−.02, .00	.05, .00	.60**, .36	.92, .63	
				(.13, .33)	(.13, .33)	(−.01, .15)	(.02, .22)	(.28, .56)		
(7) Profitability	1	4.73	1.40	.10, .01	.03, .00	−.05, .00	.05, .00	.20**, .04	.27**, .07	NA
				(−.05, .39)	(−.17, .27)	(−.33, .17)	(−.11, .33)	(.19, .63)	(.19, .51)	

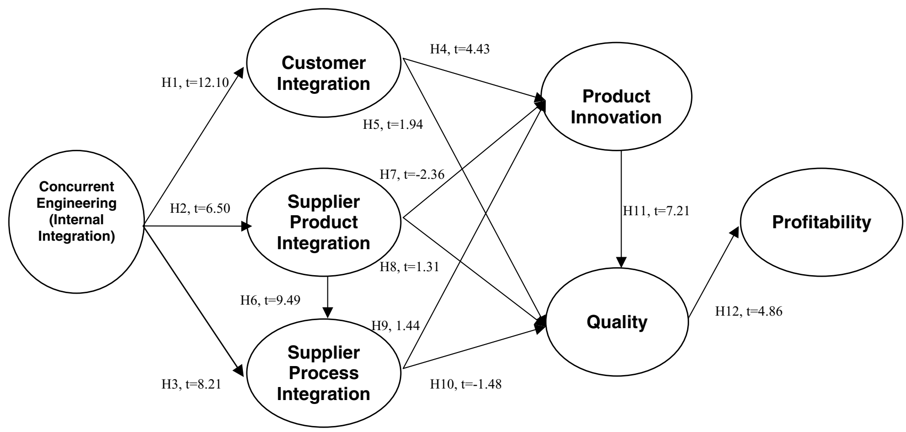
[a]Composite reliabilities are on the diagonal.
[b]Average variances extracted are on the diagonal.
[c]Correlation is significant at .01.
[d]Correlation is significant at .05.
[e]Squared correlation.
[f]Confidence interval for correlation (Phi) in parentheses.

Table 3: Summary table of structural model across environments (standardized coefficients).

Path	Concurrent Engineering	Customer Integration	Supplier Product Integration	Supplier Process Integration	Product Innovation	Quality
Customer integration	H1					
	.81 (12.10)[a]					
	—[b]					
	.81 (12.10)[c]					
Supplier product integration	H2					
	.45 (6.50)					
	—					
	.45 (6.50)					
Supplier process integration	H3		H6			
	.45 (8.21)		.57 (9.49)			
	.26 (5.71)		–			
	.70 (10.80)		.57 (9.49)			
Product innovation		H4	H7	H9		
	–	.40 (4.43)	.30 (−2.36)	.21 (1.44)		
	.32 (5.35)	–	.12 (1.42)	–		
	.32 (5.35)	.40 (4.43)	−.17 (−2.39)	.21 (1.44)		
Quality		H5	H8	H10	H11	
	–	.15 (1.94)	.14 (1.31)	−.18 (−1.48)	.48 (7.21)	
	.19 (4.63)	.19 (4.14)	−.15 (−2.48)	.09 (1.41)	–	
	.19 (4.63)	.29 (4.50)	−.06 (−1.18)	−.02 (−.22)	.48 (7.21)	
Profitability						H12
	—	–	–	–	–	.84 (4.86)
	.16 (3.64)	.24 (3.57)	−.05 (−1.16)	−.02 (−.22)	.40 (4.56)	–
	.16 (3.64)	.24 (3.57)	−.05 (−1.16)	−.02 (−.22)	.40 (4.56)	.84 (4.86)

Model fit: Chi-square = 824.38 ($p = .00$), 453 df, chi-square/df = 1.82, CFI = .94, NNFI = .93, Standardized RMR = .054, RMSEA = .058.
[a]Direct effect.
[b]Indirect effect.
[c]Total effect.

Figure 2: Hypothesized structure model results.



higher levels of supplier product integration are related to higher levels of supplier process integration ($t = 9.49$). The effects of supplier integration on both product innovation and quality performance were speculated through Hypotheses H7, H8, H9, and H10. The effects of supplier product integration on product innovation (H7) were statistically significant, but interestingly they were negative ($t = -2.36$). The effects on quality (H8) were positive ($t = 1.31$) but not statistically significant. What the analysis suggests is that assigning more product developing responsibilities to suppliers may be having a negative effect on the ability of the organization to offer new products and features. It may lead to deterioration in product innovation capabilities.

Supplier process integration was expected to have a positive influence on product innovation (H9). However, the study found a nonstatistically significant link ($t = 1.44$). On the other hand, the effects of supplier process integration on quality (H10) were negative, but still not statistically significant ($t = -1.48$). It is possible that supplier integration in NPD projects in the U.S. is still in its infancy stage, which may have contributed to the aforementioned results.

Hypothesis 11 argued for a positive relationship between product innovation and quality. This hypothesis was strongly supported. Higher levels of product innovation were associated with higher levels of quality ($t = 7.21$). This suggests that product innovation may be indispensable in the quest for improvements in quality. Finally, quality levels were expected to have an impact on profitability (H12). Indeed, the path coefficient was statistically significant and positive ($t = 4.86$) and points to the important role of quality in impacting profitability.

Contingency Effects of Uncertainty

As a first step in testing for the effects of uncertainty (H13), a baseline model was compared against a model that specified invariant loadings matrices (i.e., LX and LY). The chi-square for the base model with 906 degrees of freedom was 1430.07 (Table 4). The chi-square for a model that specified invariance for LX and

Table 4: Invariance tests across uncertainty environments: Hypothesis 13.

Hypothesis Description	Chi-square	df	Chi-square/df	RMR	NNFI	CFI	Nested Models	ΔChi-square	Δdf	Significance Level
1. Base model	1430.07	906	1.58	.066	.90	.91				
2. Equal item loadings	1454.16	931	1.56	.071	.90	.91	2–1	24.09	25	.514
3. Equal item loadings, measurement error	1699.68	962	1.77	.072	.87	.87	3–2	245.52	31	.000
4. Equal item loadings, measurement error, structural coefficients	1715.85	974	1.76	.079	.87	.87	4–3	16.17	12	.184

LY was 1454.16 with 931 degrees of freedom. The difference of 24.09 in chi-square for 25 degrees of freedom was not statistically significant ($p = .514$). This implies equivalency of loadings across the two groups. Next, invariance for loadings and error terms (i.e., TD and TE) was specified. The chi-square was 1699.68 with 962 degrees of freedom. The difference in chi-square was 245.52 for 31 degrees of freedom with a $p = .000$. This suggests that error terms are not invariant across low and high uncertainty environments. Finally, we proceeded with the overall testing of invariance for loadings, error terms and structural coefficients (i.e., β and γ). The chi-square for the latter model was 1715.85 with 973 degrees of freedom. The difference in chi-square was 16.17 with 11 degrees of freedom and was not statistically significant ($p = .1349$). Thus, no differences in path coefficients were detected. In other words hypothesis 13 is rejected, the structural model appears to be the same for companies operating under low and high uncertainty environments.

Contingency Effects of Equivocality

Hypothesis H14 called for a differential effect on the pattern of linkages in Figure 1 according to the levels of equivocality. The chi-square of a baseline model with 906 degrees of freedom (chi-square = 1426.87) was compared against the chi-square for a model (Table 5) that specified invariance for LX and LY matrices with 931 degrees of freedom (chi-square = 1451.84). The difference of 24.97 in chi-square for 25 degrees of freedom was not statistically significant ($p = .464$). The loadings appear to be the same for low and high equivocality environments. Next, factorial invariance for loadings and error terms (i.e., TD and TE) was specified. The chi-square was 1692.76 with 962 degrees of freedom. The difference in chi-square was 240.92 with 31 degrees of freedom and a $p = .000$. There is evidence that the error terms are not equivalent across the two groups. In the last test, invariance of loadings, error terms, and structural coefficients (i.e., β and γ) was specified. The chi-square for the latter model was 1716.94 with 974 degrees of freedom. The difference in chi-square was 24.18 with 12 degrees of freedom. The difference was statistically significant ($p = .019$) and thus differences in path coefficients were detected. A search procedure followed to identify which path coefficients were different for the two groups.

This involved the testing of two models at a time: model 3 and one in which a given path coefficient is specified as invariant (Table 5). Thus, the difference in degrees of freedom was one. Chi-square differences greater than 3.84 are statistically significant at an alpha of .05. This was the case for five coefficients. The β coefficient that describes the relationship between customer integration and product innovation was different (chi-square difference = 6.10). It appears that customer integration was more conducive for product innovation in a high equivocality environment. Customer integration is a stronger predictor of product innovation in a high equivocality environment ($t = 4.88$) but was a weak predictor of product innovation in a low equivocality environment ($t = 1.57$).

The effects of supplier product integration on product innovation were also sample specific (chi-square difference = 6.27). They were statistically significant and negative only for the low equivocality environment. In a low equivocality environment, assigning more product related responsibilities to suppliers resulted in lower product innovation capabilities ($t = -2.75$). Though a negative coefficient

Table 5: Invariance tests across equivocality environments: Hypothesis 14.

											Low Equivocality		High Equivocality	
Hypothesis Description	Chi-square	df	Chi-square/ df	Standardized RMR	NNFI	CFI	Nested Models	Δ Chi-square	Δ df	Significance Level	Standardized Coefficient	*t*-Value	Standardized Coefficient	*t*-Value
1. Base model	1426.87	906	1.57	.067	.90	.91								
2. Equal loadings	1451.84	931	1.56	.071	.90	.91	2–1	24.97	25	.464				
3. Equal loadings, measurement error	1692.76	962	1.76	.071	.87	.87	3–2	240.92	31	.000				
4. Equal loadings, measurement error, structural coefficients	1716.94	974	1.76	.077	.87	.87	4–3	24.18	12	.019				
5a. Concurrent engineering → customer integration	1692.78	963	1.76	.071	.87	.87	3–5a	.02	1	.655	.77	9.37	.84	10.07
5b. Concurrent engineering → supplier product integration	1693.99	963	1.76	.071	.87	.87	3–5b	1.53	1	.216	.51	5.45	.34	3.44
5c. Concurrent engineering→ supplier process integration	1694.18	963	1.76	.072	.87	.87	3–5c	1.42	1	.233	.39	5.44	.51	6.79
5d. Customer integration → product innovation	1698.86	963	1.76	.075	.87	.87	3–5d	6.10	1	***.013***	***.19***	***1.57***	***.69***	***4.88***
5e. Customer integration → quality	1692.96	963	1.76	.071	.87	.87	3–5e	.20	1	.655	.16	1.65	.28	1.93
5f. Supplier product integration → product innovation	1699.03	963	1.76	.072	.87	.87	3–5f	6.27	1	***.012***	***–.59***	***–2.75***	***–.01***	***–.06***
5g. Supplier product integration → quality	1698.63	963	1.76	.071	.87	.87	3–5f	5.87	1	***.015***	***–.15***	***–.90***	***.47***	***3.31***
5h. Supplier process integration → product innovation	1698.54	963	1.76	.071	.87	.87	3–5f	5.78	1	***.016***	***.55***	***2.32***	***–.15***	***–.80***
5i. Supplier process integration → quality	1696.96	963	1.76	.071	.87	.87	3–5f	4.20	1	***.040***	***.09***	***.48***	***–.51***	***–2.95***
5j. Supplier product integration → supplier process integration	1694.30	963	1.76	.071	.87	.87	3–5f	1.54	1	.215	.62	7.76	.53	6.70
5k. Product innovation → quality	1693.29	963	1.76	.071	.87	.87	3–5f	.53	1	.467	.64	5.85	.63	4.84
5l. Quality → profitability	1692.76	963	1.76	.072	.87	.87	3–5f	.00	1	1.00	.37	3.96	.28	2.89

was also present in the high equivocality environment, it was not statistically significant. The supplier product integration effects on quality were specific to the environment as well (chi-square difference = 5.87). Efforts to assign more product-related responsibilities to suppliers seem fruitful for quality in a high equivocality environment ($t = 3.31$) but not in a low equivocality environment ($t = -.90$). This is suggestive of a contingency relationship.

Supplier process integration appears to be important for product innovation and quality in select environments. The chi-square difference for the relationship with product innovation was 5.78, whereas for quality 4.20. Specifically, involving suppliers in the product development process was important in a low equivocality environment as the effects on product innovation were positive ($t = 2.32$). On the other hand, the effects of supplier process integration in product development in a high equivocality environment were not significant ($t = -.80$). Supplier process integration in a high equivocality environment has not resulted in the expected positive contributions toward quality. Though the contribution was statistically significant ($t = -2.95$), it was nevertheless negative. This suggests that supplier process integration in a high equivocality environment is risky for quality. The effects in a low equivocality environment were negligible ($t = .48$). Overall, there were clearly contingency effects that should be accounted for.

Contingency Effects of Platform Strategy

Hypothesis H15 suggests that the use of platform strategies will have a differential effect on the pattern of linkages in Figure 1. The chi-square of a baseline model with 906 degrees of freedom (chi-square = 1491.40) was compared against the chi-square for a model (Table 6) that specified invariance for LX and LY matrices with 931 degrees of freedom (chi-square = 1548.75). The difference of 57.35 in chi-square for 25 degrees of freedom was statistically significant ($p = .000$) implying no equivalency in loadings between the two groups. Next, factorial invariance for loadings and error terms (i.e., TD and TE) was specified. The chi-square was 1700.33 with 962 degrees of freedom. The difference in chi-square was 151.58 for 31 degrees of freedom with a $p = .000$. This suggests that the error terms for the two groups are different. In the last test, invariance of loadings, error terms, and structural coefficients (i.e., β and γ) was specified. The chi-square for the latter model was 1713.84 with 973 degrees of freedom. The difference in chi-square was 13.51 with 11 degrees of freedom. The difference was not statistically significant ($p = .2613$) implying hypothesis 15 is not supported and thus differences in path coefficients were not detected.

DISCUSSION, CONCLUSIONS, FUTURE RESEARCH, AND LIMITATIONS

The results of this study indicate that internal integration is an important enabler of external integration, that is, customer and supplier integration. Internal integration had a significant effect on the level of external integration. Internal integration, which is important for external integration, also leads to higher levels of competitive capabilities. Companies that reported high levels of adopting practices, such as early involvement, concurrent workflow, and the team approach, also reported

Table 6: Invariance tests across platform environments: Hypothesis 15.

Hypothesis Description	Chi-square	df	Chi-square/ df	RMR	NNFI	CFI	Nested Models	Δ Chi-square	Δ df	Significance Level
1. Base model	1491.40	906	1.65	.070	.88	.89				
2. Equal item loadings	1548.75	931	1.66	.085	.87	.88	2–1	57.35	25	.000
3. Equal item loadings, measurement error	1700.33	962	1.77	.086	.85	.86	3–2	151.58	31	.000
4. Equal item loadings, measurement error, structural coefficients	1713.86	974	1.76	.091	.85	.86	4–3	13.53	12	.332

high levels of adopting supplier integration and customer integration practices. Organizational theory suggests that internal integration is conducive for external integration as there is a timely exchange of critical information amongst supply chain partners. Internal actors quickly understand that for the supply chain to be more effective, it is necessary to not only integrate internally but also externally. External integration probably would not be realized in the absence of an internal system that not only advocates it but also facilitates it. Efforts to integrate suppliers without an internal integrated sensory and interpretive system may be futile.

Though there were no direct paths specified between internal integration and competitive capabilities, the total effects of (which include indirect effects; Table 3) internal integration on competitive capabilities were statistically significant when testing the overall model. The effects of internal integration on product innovation ($t = 5.35$) and on quality ($t = 4.63$) were positive and indicative of strong indirect effects. Further investigation revealed that the modification indices for γ (exogenous to endogenous coefficients) between internal integration and product innovation and quality were statistically nonsignificant. What this points to is that internal integration has an indirect and significant influence on competitive capabilities and not necessarily a direct influence. This is an interesting finding and calls for additional research. In addition, internal integration has a significant impact on profitability ($t = 3.04$), albeit indirect.

Customer integration appears to be vital for product innovation, especially in high equivocality environments. Customers can provide access to information and their integration can lead to mutual understanding. This could result in products that meet customer expectations and higher capability levels in introducing new products and features in the marketplace. Contrary to expectations, higher levels of customer integration were not strongly associated with higher levels of quality. This was equally true across environmental levels. It was postulated that since customers have an active role in the product development process, it would lead to higher levels of quality. The effects were primarily positive but never mustered enough strength to be statistically significant. A more detailed examination of the overall results shows that customer integration does indeed have an impact on quality, but such impact is indirect through the effects on product innovation. The indirect path coefficient was statistically significant ($t = 4.28$) (Table 3).

There is considerable evidence that the effects of supplier integration on competitive capabilities and firm performance are mixed. Some studies report positive, whereas other studies present negative correlations with such variables as NPD cycle time and costs. Eisenhardt and Tabrizi's (1995) research revealed that supplier integration may have a negative impact on product development time, particularly in uncertain environments. Corswant and Tunalv (2002), citing the work of Littler, Leverick, and Bruce (1995), state that over 40% of the respondents expressed the view that collaboration makes product development more costly, more complicated, less efficient, more time consuming, and more difficult to control and manage. They conclude that there must be a point where the value of product development collaboration should be questioned. Liker et al. (1996) also note that the "use of outside suppliers increases the organizational complexity of coordinating design decisions" (p. 168). Many of the supplier integration practices now employed in the U.S., were adopted from the Japanese. It is also possible that such supplier integration practices may still be in their relative infancy in the U.S. and thus their contribution negligible if not negative as of yet. As Liker et al. articulate, “Japanese companies have a comparatively long history of assigning greater responsibility for product development” (p. 168).

The effects of supplier product integration on product innovation are negative. Assigning more product engineering tasks to suppliers may have detrimental effects in the ability of the firm to introduce new products and features and it is especially true in a low equivocality environment (Table 5). On the other hand, allocating such tasks to suppliers leads to higher levels of quality. The coefficients were positive but not statistically significant for the overall results (Table 3) but they were statistically significant and positive in a high equivocality environment (Table 5). It is possible that in those environments, the product engineering expertise of suppliers is valued as complexity increases.

Supplier process integration was expected to have a positive impact on product innovation. The overall results suggest a positive contribution which was however, statistically nonsignificant. Involving the suppliers in the product development process contributed significantly and positively in the low equivocality environment only (Table 5). It was expected that the integration of suppliers in the product development process would be more conducive in the high equivocality environment. This did not materialize and it may signal that such integration of suppliers in high equivocality environments does not provide any substantial benefits, especially when compared against the contributions of customer integration toward product innovation in those same environments. Involving suppliers in the process in those environments may increase the level of complexity and any potential benefits may diminish (Corswant & Tunalv, 2002).

The integration of suppliers in the product development process had adverse effects on quality, especially for a high complexity environment. It was expected that the integration of suppliers in the process would lead to higher levels of quality. Integration of suppliers in the process in those environments may have complicated the effort even further and added more coordination headaches, instead of being decisively positive. Firms may reconsider such integration of suppliers as the negative implications cannot be neglected. Overall, firms should pursue supplier product integration in high equivocality environments as this improves quality. Firms should seek supplier process integration in low equivocality environments as this enhances product innovation capabilities.

Firms that achieved higher levels of product innovation also achieved higher levels of quality. This was invariably the case for all environments examined. As long as product innovation capabilities improve, quality capabilities will improve as well. Finally, quality levels were associated with levels of profitability, irrespective of environment. Both Capon et al.’s (1990) meta-analysis of the effects of product quality on firm performance and Buzzell and Gale’s (1987) summary of studies using PIMS data strongly confirm this result. Moreover, in this research, it is interesting to point out the indirect influence of external integration and innovation on profitability (Table 3).

The data analyses suggest that equivocality may be important in understanding relationships between product development processes, structures, and performance. Understanding the contextual impact of these variables in the product development environment may be useful. The evidence in this study corroborates recent findings and suggestions. For example, McDermott and O'Connor (2002) state, "we know considerably less about the effective management of product development process in a radical innovation context compared with an incremental innovation context" (p. 424). They comment that a great amount of research has taken place studying a cross functional and integrated approach. They further note, "these common cross functional and integrative practices may be detrimental in some environments. In the search for speed to market, researchers and practitioners may have been too quick to generalize the utility of these practices across very diverse environments" (p. 425).

Environmental uncertainty and platform strategy levels do not appear to moderate the relationships as suggested in the model. There are two possibilities: First, we may have failed in our efforts to correctly operationalize the two contextual variables. For example, we considered uncertainty as a unidimensional construct based on exploratory factor analysis work. It is possible that there are numerous manifestations of uncertainty. Miller and Friesen (1978) posit that uncertainty may be related to changes in technology, customer demand, and/or competitive strategies. Similarly, Sutcliffe and Zaheer (1998) define three kinds of environmental uncertainty: primary, competitive, and supplier. In terms of the platform strategy, perhaps we operationalized the strategy too vaguely. Second, the model may be invariant across environmental uncertainty or platform strategy environments. In more practical terms, internal integration, for example, may have a substantive effect on external integration whether the environment exhibits low or high uncertainty. Customer integration may have positive effects on product innovation under low or high uncertainty levels.

There are obviously numerous other variables that can impact performance. For example, the employment of information technology as a tool for product development activities and as a means of communication and integration has not received adequate attention in the literature including the present study. Another important variable is the proficiency (Calantone et al., 1997) with which NPD activities are carried out. In the present study, we only measured the extent of use of certain product development practices. Usage of such practices alone, however, may not be the best predictor of performance. It is important to measure the proficiency with which practices are carried out. This is important for many reasons. Given the same usage of practices, the company with higher proficiency can deliver products in a shorter period of time. It could also deliver those products at a lower cost and better quality. Olson, Walker, Ruekert, and Bonner (2001), citing Henard and Szymanski (1999), state that increasing the level of integration alone may not be adequate to result in new product success. The quality, focus and timing of integration may prove to be critical. Thus, future research should incorporate such measures that go beyond mere usage of certain practices.

The sample used here includes a fair number of smaller firms (i.e., firms with fewer than 500 employees). We have found no statistically significant differences in mean levels of practices or performance across firm size. It is possible, however, that small firms may employ more informal approaches and practices in their product development efforts. Such informal efforts were not captured in this research. Future research should identify and take them into account.

Our study used a set of contingency variables that could affect integration strategies. Future research can expand on this list and examine the role of product life cycle and country of origin effects (e.g., U.S. vs Europe vs Japan) on the integration to performance relationships. Another avenue might be to examine the role of Internet and virtual technologies such as virtual prototyping as a mode of integration between the NPD team and suppliers.

This research study makes several contributions. First, it is rare to find research studies in the product development arena where both internal and external integration variables are included in the same study. This is relevant as there is a coexistence of internal and external integration for product development in many firms. We provide answers to the important question of how external and internal integration strategies affect each other as well as performance. Our results provide managerial insights about specific practices that work in product development projects. Second, few studies have incorporated both customer and supplier integration as manifestation of external integration in a single study. The research studies we have found in the literature focus on either supplier integration or customer integration. It is imperative that we study product development performance in the presence of both effects. Third, very few studies have examined the impact of contextual environmental variables as moderators. Our study is distinctive in employing SEM to accommodate moderators and in this sense it goes beyond the prototypical assessment of a measurement and structural model via SEM. We test for measurement model invariance as well as structural model invariance to assess the potential impact of moderator variables such as uncertainty, equivocality, and platform strategy. To this extent, we believe that our study makes contributions to research methodology as well.

This study has limitations. For example, it is desirable to have multiple respondents providing data as opposed to a single respondent in order to improve data quality. However, collecting data from several sources significantly increases the time and cost of data collection. Consistent with prior research (Ernst & Teichert, 1998; Lynn & Akgun, 1998) we have used the most knowledgeable (or key) respondent to provide data to maximize the chance of highly reliable data. In addition, we have used perceptual measures for both exogenous and endogenous variables and those were provided by the same individual. This is a limitation that should be noted as there is a possibility for common methods bias. [Received: November 2003. Accepted: July 2004.]

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APPENDIX A: FACTOR LOADINGS FOR CONTEXTUAL ITEMS

Item	Uncertainty	Equivocality
What best describes the % of products in your industry whose *performance* has improved over the last 2 years due to technological change?	.82	
In this industry, what best describes the degree of improvement in product performance within the last 2 years?	.78	
In this industry, how quickly do new products capture market share from existing products?	.76	
In this industry, what best describes the frequency of product change within the last 2 years by you or your competition?	.73	
What best describes the % of products in your industry whose *quality* has improved over the last 2 years due to technological change?	.72	
What best describes the % of products in your industry whose manufacturing practices have been substantially improved over the last 2 years due to technological change?	.71	
In this industry, how extensive is the typical product change?	.67	
What is the degree of process complexity in your dominant product line?		.91
In your dominant product line, what best describes the complexity of your most complex process?		.88
What is the degree of product complexity in your dominant product line?		.80
Eigen value	4.40	1.86
Percent of variance extracted	44.0	18.6
Cumulative percent of variance extracted	44.0	62.6

All ten Likert type items (measured on a five-point scale) were factor analyzed with oblimin rotation. The first factor, interpreted as *uncertainty*, consists of seven items, it has a Cronbach's reliability α of .87, and it measures change in technology, products, and market conditions. The second factor was interpreted as *equivocality* and consists of three items. The three items measure both product and process complexity and have a Cronbach's reliability alpha of .84. Only loadings $\geq$ .30 are shown.

APPENDIX A: (continued)
Platform Product strategy:

Item	Factor Loading
Our core products are designed as platforms for multiple generations of products to come	.77
Our product designs enable us to accommodate several generations of products	.90
Our product designs are drawn to accommodate future generations of products	.91

The items measure the extent to which a firm employs the strategy using a five-point scale: 1 = not at all, 2 = a little, 3 = moderately, 4 = much, 5 = a great deal. The Cronbach's reliability α for the scale was .90.

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