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Ravi Patnayakuni  
*Temple University*

Nainika Patnayakuni  
*Temple University*

Arun Rai  
*Georgia State University*

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# A MEDIATED IMPACTS MODEL OF DEMAND VOLATILITY ON INVENTORY FLOW INTEGRATION IN SUPPLY CHAINS

**Ravi Patnayakuni**

Fox School of Business and Management  
Temple University  
Philadelphia, PA USA  
[ravi@temple.edu](mailto:ravi@temple.edu)

**Nainika Patnayakuni**

Fox School of Business and Management  
Temple University  
Philadelphia, PA USA  
[naina@temple.edu](mailto:naina@temple.edu)

**Arun Rai**

Robinson College of Business  
Georgia State University  
Atlanta, GA USA  
[arunrai@gsu.edu](mailto:arunrai@gsu.edu)

## Abstract

*We develop a theoretical model about how organizations cope with the bullwhip effect created by consumer demand uncertainty through product modularity and information sharing across the supply chain. Unpredictability of consumer demand is likely to accentuate inventory flows in the supply chain. Information sharing and product modularity can be used by organizations to mediate the impact of uncertain product demand on inventory flow integration. An organization's success in coping with the bullwhip effect is reflected in the degree to which inventory flows are integrated across the supply chain. Our results suggest that (1) information sharing is essential for achieving integration of inventory flows irrespective of the demand environment, and (2) the strategy of modular product design can help organizations enhance inventory flows under conditions of consumer demand uncertainty.*

**Keywords:** Supply chains, information sharing, demand uncertainty, inventory flows

## Introduction

Getting the right product to the right customer at the right time, or in other words effective order fulfilment, is the hallmark of effective supply chain management in the current competitive environment (Hintlian and Mann 2001). Integration of inventory flows across the supply chain is central to achieving such capabilities (Enslow 2000). The level of cooperation required to realize such integration underscores the new model of competition where organizations increasingly compete with each other as part of a network of organizations or supply chains rather than as individual enterprises (Evans and Wurster 1999). This highlights the importance of effective fulfilment strategies to link all trading partners to ensure delivery of goods and services to the final consumer at acceptable service levels.

The capabilities required for effective fulfilment vary by product market context (Fisher 1997). Markets characterized by innovative products are complex, uncertain, and information rich. Organizations try to meet customer demand with increased product variety, faster response times, greater customization, and more fine-grained market segmentation (Bovet and Martha 2000; Magretta 1998). With rapid changes in technology and the market environment, product life cycles are becoming shorter. In

many cases, new products may be offered even before retiring existing products from the market, which inevitably leads to successive generations of products overlapping each other (Lee et al. 2000). Predicting product demand in rapidly changing consumer environments creates an order of magnitude increase in the complexity of the supply chain planning and coordination processes.

Demand signals often get distorted as they travel upstream in the supply chain (Lee et al. 1997a, 1997b). The distorted demand signals result in excess inventory, high procurement, warehousing, and shipping costs, and the high cost of product returns. It has been analytically demonstrated that the amplification of order variation, also known as the bullwhip effect, gets progressively worse as it travels upstream in the supply chain (Sterman 1989). From the perspective of a firm's product environment, the bullwhip effect is aggravated in unpredictable consumer demand contexts due to the inherent variability in the demand signals. Near real-time sharing of key information indices across the supply chain has been advocated as an essential capability to cope with the bullwhip effect.

The challenges of supply chain management are heightened by the market shift toward mass customization from mass production. Modular product design enables the implementation of mass customization strategies designed to better meet the demand for variety in products by customers (Feitzinger and Lee 1997; Kotha 1995). Standardized product modules are sent across the distribution channel and assembled as and when product orders are received (Zipkin 2001). Modular product designs may enable organizations to cope with the bullwhip effect by enabling rapid reutilization of existing components, and reduce inventory holding and obsolescence costs (Baldwin and Clark 1997). Such product strategies are especially relevant to demand chains where volatility is high (Baldwin and Clark 1997). There is, however, limited empirical evidence, aside from case studies and examples (van Hoek 1998) on the impact of product modularity in coping with the bullwhip effect.

The objective of this study is to develop a theoretical model about how organizations cope with the bullwhip effect created by consumer demand uncertainty through product modularity and information sharing across the supply chain. An organization's success in coping with the bullwhip effect is reflected in the degree to which inventory flows are integrated across the supply chain. Our results suggest that (1) information sharing is essential for achieving integration of inventory flows irrespective of the demand environment, and (2) modular product design can help organizations cope in volatile consumer demand environments by improving their inventory flows.

The remainder of this paper is organized as follows. In the next section, we develop the research model by drawing upon research in supply chain management and transaction cost economics. We then describe details about the empirical study, including research method, data collection procedures, statistical analysis, and results. Finally, we discuss our findings and offer some implications for managers and future research.

## The Bullwhip Effect in Supply Chains

Information sharing across organizations is critical to supply chain integration (Daugherty and Stank 1995; Premkumar 2000). Traditional demand forecasting is of limited use when demand patterns vary significantly over time (Lowson et al. 1999). Organizations need real-time information about changes in demand signals that can be interpreted to assess changes in customer demand patterns. When actual sales information is unavailable, organizations rely on sales forecasts that are likely inaccurate due to their excessive reliance on historic information. This approach is especially problematic when consumer demand volatility is high and resultant inaccurate sales forecasts cause stock outs or excess inventory that is then cleared by using costly sales promotions, markdowns, and discounts.

Supply chain pipelines consist of both information flows and material flows. Focusing only on material flows and ignoring information flows will result in suboptimal performance (Braithwaite 1993). With developments in information technology for interorganizational information sharing, it is now feasible to decouple information flows from material flows and manage information flows as a resource that provides critical information for the coordination of business processes and material flows. New mass customization and postponed manufacturing approaches make it imperative that all companies in the supply chain have direct access to real-time or near real-time demand information (Mason-Jones and Towill 1999). In contrast to the near real-time stream of demand information shared across the supply chain just discussed, existing practices rely on order batching often promoted by embedded incentive schemes and established materials resource planning cycles. The resultant inaccuracy of the demand signals due to such practices promotes the bullwhip effect and creates excessive or inadequate inventory, poor utilization of production and capacity planning, and declined customer service levels.

To respond to the bullwhip effect, organizations may share information across the supply chain such as actual point of sale data, data on inventory holdings, and capacity utilization and delivery schedules. Information about inventory can substitute for actual inventory in the supply chain (Milgrom and Roberts 1988), creating the opportunity for integration of inventory flows across the supply chain. Collaborative forecasting allows manufacturers and suppliers to enhance their forecasting accuracy. This would involve downstream suppliers sharing forecast information with upstream suppliers because they have access to more accurate market information. Sharing production schedules across the supply chain enables better production planning for manufacturers and suppliers. Information on performance metrics can also be shared across the supply chain, so as to enable identification of bottlenecks in the supply chain and design of joint actions and governance mechanisms for their improvement (Lee and Whang 1998). Wal-Mart and Procter & Gamble have for over a decade constantly worked to leverage information technology by sharing data across their shared supply chain to reduce need for inventories and to better coordinate channel activities (Grean and Shaw 2002). Inventory flow integration approaches such as vendor managed inventory and continuous replenishment rely on both critical supply-side inventory information and demand-side information on specific requirements from downstream customers. In summary, both inventory flow integration and information sharing are critical elements that should be part of an organization's strategy to cope with the bullwhip effect across the supply chain.

### ***The Impact of Product Environment***

Supply chains need to be optimized differently for innovative and functional products (Fisher 1997). Functional products satisfy basic needs, don't vary over time, and have long life cycles with a stable and predictable demand. They are characterized by intense competition, low profit margins, low number of product variants per category, and high lead times for manufacturing and delivery. In contrast, innovative products have short life cycles, high contribution margins, high product variety, and uncertain product demand. Innovative products may also be based on modular designs to enable postponed differentiation. The implications for supply chain management are different for functional and innovative products. Given their consumer demand predictability and low margin structures, functional products require physically efficient processes with high inventory turnover and low supply chain costs.

In contrast to functional products, the uncertain consumer demand for innovative products creates tension against the integration of physical flows of materials and products. The traditional, but inefficient response has been to increase safety stocks and buffer capacity as a response to demand fluctuations. The objective of mass customization strategies is to balance efficiency and flexibility so that inventory flow integration strategies can be pursued for products with a high proportion of customization. Organizations may adopt modular product design for responding to demand shifts associated with innovative products while pursuing inventory flow integration strategies.

### ***Organizational Information Processing***

Organization information processing theory argues that volatile demand environments are information rich (Galbraith 1973). To cope with information abundance, organizations pursue information hedging, information focus, and capacity-enhancing strategies. Capacity-enhancing strategies can be implemented with infrastructure-focused IT initiatives that expand processing, networking, and database capacities. Hedging strategies include mass production, inventory buffers, and localization of inventory storage to respond to uncertain demand. Poorly crafted hedging strategies result in unnecessary slack and cost inefficiencies that work against tight linking of processes across supply chain partners and further exacerbate the bullwhip effect. Modular product design constitutes an information focus strategy, by way of simplifying product design; common product platforms and shared product components create embedded information in the product that reduces the need for explicit information sharing. Focus strategies reduce information overload by reducing the number of activities performed and the number of sources from which information is processed. In the supply chain context, modularity enables organizations to combat uncertainty by reducing the number of different parts purchased. Past research notes that an information sharing approach increases an organization's capacity to process information in dynamic environments (Mendelson and Pillai 1998).

### ***Transaction Costs in the Supply Chain***

According to transaction cost theory, the governance structures of organizations are determined by a combination of production and transaction costs (Williamson 1985). High uncertainty is associated with higher transaction costs, and hence a hierarchical form of organization. When uncertainty is lower, organizations can enter into short-term spot market transactions. Traditional

transaction cost economics has focused on pure markets and hierarchies at the expense of underemphasizing hybrid forms of governance such as partnerships and other supply chain relationships. Such relationships are characterized by frequent transactions such as automatic replenishment programs and mutual asset-specific investments. They exist in industries where product innovativeness and uncertainty are high (Fisher 1997). Transaction cost theory would predict that such situations are best suited to vertical integration. When a supplier invests in relationship-specific assets, it increases the manufacturer's power and the supplier's vulnerability in the relationship (Joshi and Stump 1999). This increases the risk of opportunism by the manufacturer, making hierarchy more suitable under conditions of consumer demand volatility. Empirical research has shown that organizations invest in supply chain management when recurrent transactions require specialized assets and uncertainty is high (Ellram 1991). One approach to reducing uncertainty and the risk of opportunism in environments characterized by high uncertainty has been to share information across the supply chain.

## **Research Model**

### ***Inventory Flow Integration***

Inventory flow integration is the degree to which materials and finished good flows are coordinated across the supply chain for the purpose of reducing costs, downtime, and inventory. Downstream physical flows consist of the flow of raw materials, subassemblies, and finished goods to the customer. Upstream physical flows consist of returns and products to be repaired. The objective of coordinating physical flows is to reduce inventory holdings, minimize costs, synchronize supply and demand, and manage risks, such as inventory obsolescence. Coordinating physical flows requires planning and management of distribution centers, manufacturing sites, and distribution networks for optimizing the tradeoffs between customer delivery and costs. Inventory management strategies such as postponed purchasing, postponed manufacturing, just-in-time deliveries, and automatic replenishment programs can be used to manage physical flows (Anderson and Narus 1995; Pagh and Cooper 1998; Schneidrijans 1993). Inventory flow integration approaches the entire supply chain as a system, coordinating customer service, transportation, warehousing, production planning, and other activities across the supply chain, rather than as a set of different activities. Integration reduces inventory holdings and improves asset utilization and customer service (Gustin et al. 1995).

### ***Product Modularity***

Industries with innovative products that have short life cycles are early adopters of modular production (Starr 1965). Product modularity has been identified as an important product characteristic that is likely to influence supply chain management (Baldwin and Clark 1997). The objective of modular product design is to be able to offer increasing product differentiation without increasing product complexity (van Hoek and Weken 1998), and by using standardized interchangeable components (Lampel and Mintzberg 1996).

Modular production can be applied at a product, product group or process level. At the product group level, the level of commonality across product groups and within product groups can vary (Sheu and Wacker 1997). Modular production at a process level involves establishing commonality in cross-functional and interorganizational processes (van Hoek and Weken 1998) and can be coordinated with procurement and manufacturing to synchronize the flow of product with consumer demand. Postponed purchasing implies that suppliers hold inventory until the product or material is actually needed in the manufacturing process, reducing the complexity of the inbound logistics process. Similarly, postponed manufacturing is linked with the outbound flow of goods to the customer and can be coordinated with outbound processes to differentiate products at later stages in the distribution channel (van Hoek and Weken 1998). With modular product design, organizations can coordinate procurement, production, manufacturing, and distribution to increase alignment between physical flows and demand in uncertain consumer demand contexts.

Implementing modular production requires coordination of inventory flows across the supply integration. Modular products can decrease total transportation and inventory costs by reducing the variety of products transported or held in inventory. Requisite product variety is introduced in the distribution channel when assembly takes place proximate to the space and time of delivery. From a transaction cost perspective, modular production increases supplier asset specificity as suppliers are drawn further and further into the manufacturing process. It can also increase manufacturer control on downstream delivery and assembly. Thus, a modular production strategy is likely to positively impact the integration of physical flow in the supply chain

### Information Sharing in the Supply Chain

Downstream information flows consist of exchange of information about capacity, delivery schedules, and product information. Upstream information flows consist of orders, demand forecasts, point-of-sales information, and performance metrics. The objective of sharing information is to minimize physical flow delays and better match supply and demand information (Milgrom and Roberts 1988). Coordination and integration of supply-chain-wide processes enables organizations to sense and respond rapidly to changing customer demand. Information sharing can help firms move from local optimization of subunit level processes to global optimization of supply-chain-wide processes. For example, careful consolidation of distribution centers can reduce inventory costs, while at the same time achieving desired service levels. Information sharing about customer orders can enhance value by enabling organizations to capture and interpret demand signals in accurate and timely manners, providing critical information about product demand that best fits the needs of their customers. Similarly, plans for resource capacities and flows can be coordinated across suppliers, manufacturers, and distributors by sharing planning information. Finally, improvement efforts and capability development initiatives can be coordinated by sharing of performance-related data across the supply chain.

The research model is presented in figure 1. The model will be used to test if product environments characterized by consumer demand volatility are associated with modular product designs and information sharing in the supply chain. Consumer demand volatility is measured in terms of forecast errors and length of product life cycle, key metrics that contrast functional and innovative products (Fisher 1997). Product modularity reduces the need to share embedded information, while information sharing enables organizations to better manage information overload resulting from consumer demand uncertainty by making the information on actual sales and inventory visible across the supply chain. In addition, we argue that information sharing reduces transaction costs associated with uncertain product environment by reducing the risk of opportunism in the supply chain. Information sharing and modularity, in turn, enable the integration of inventory flows across the supply chain.

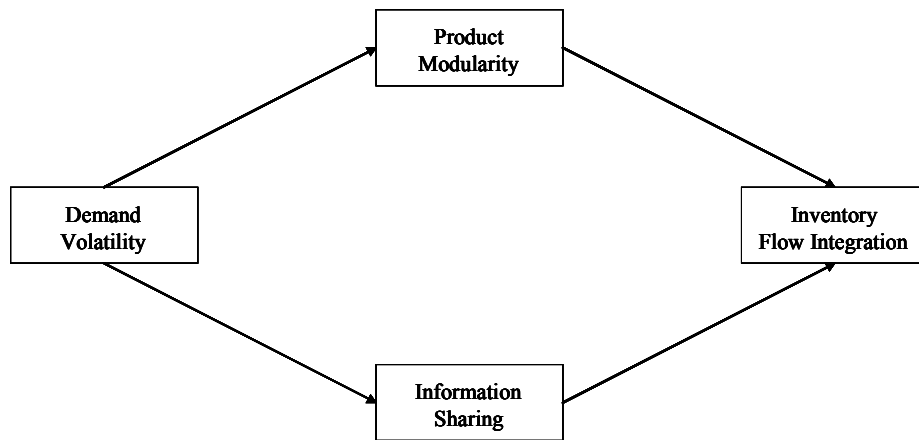


Figure 1. Research Model

## The Empirical Study

### Instrument Development

Data were collected using a self-report survey instrument, which was carefully developed using guidelines and exemplars in the IS literature, for example, Straub (1989) and Sethi and King (1991). Survey items associated with each construct are shown in Table 1. Measures for the study were systematically developed and validated. Past literature was reviewed to enable specification of a meaningful set of items that ensured content and face validity and minimal overlap between constructs (Cronbach 1971). Items associated with these constructs used a seven-item Likert-type scale where respondents were asked to state their agreement with a given statement on a scale that ranged from “strongly agree” to “strongly disagree.”

Great care was taken to assess content validity; the items were first evaluated by each of the researchers independently and subsequently in joint meetings where each construct and its items were discussed until there was unanimous agreement of the content validity. Subsequently, experts in the field evaluated the measures in order to enhance content validity as suggested by Cronbach (1971). Two well-established IS researchers with significant experience in survey-based empirical research and with

relevant domain expertise evaluated the draft instrument. After incorporating their suggested changes, the first phase of the pilot test was conducted with nine faculty members in the information systems area who are actively researching this area. In addition to asking them to comment on items and instructions, they were also asked to respond to semi-structured questions designed to obtain their assessment of the content validity of each measure. Based on their feedback, the instrument was modified. The instrument was then tested using a similar approach with 10 supply chain and logistics managers in the greater Philadelphia region. This resulted in a final set of refinements to the survey, such as modifying or deleting items and clarifying instructions. Items from the questionnaire used in the analysis are listed in Table 1.

**Table 1. Construct Definitions, Items, and Measurement Properties of the Scales**

Survey Items		Item Loading
<b>Inventory Flow Integration</b>		
<i>The degree to which the flows of materials and finished goods between a firm and its supply chain partners are coordinated.</i>		
IF1	Inventory holdings are minimized across the supply chain.	.712
IF2	Supply chain wide inventory is jointly managed with suppliers and logistics partners (e.g. UPS, FedEx).	.792
IF3	Suppliers and logistics partners deliver products and materials just in time.	0.622
IF4	Distribution networks are configured to minimize total supply chain –wide inventory costs.	0.712
Internal Consistency: .808		Average Variance Explained: 51.4%
<b>Information Sharing</b>		
<i>The extent of operational information content that is shared and the timeliness of such exchange between a firm and its supply chain partners.</i>		
IS1	Production and delivery schedules are shared across the supply chain.	.785
IS2	Performance metrics are shared across the supply chain	.800
IS3	Supply chain members collaborate in arriving at demand forecasts.	.711
IS4	Our downstream partners (e.g., distributors, wholesalers, retailers) share their actual sales data with us.	.757
IS5	Inventory data are visible at all steps across the supply chain.	.731
Internal Consistency: .872		Average Variance Explained: 57.7%
<b>Product Modularity</b>		
<i>The degree to which products share common and standardized components and are designed on common product platforms.</i>		
PM1	Uniqueness in product parts and designs has been minimized.	0.619
PM2	Product parts and subassemblies are shared across many products.	0.746
PM3	Production processes are shared across many products.	0.81
PM4	Products have a modular design.	0.682
Internal Consistency: .822		Average Variance Explained: 53.8%
<b>Consumer Demand Volatility</b>		
<i>The degree of forecasting uncertainty associated with products.</i>		
DV1	There is a high margin of error in product forecasts.	.824
DV2	Products have a short life cycle (< 1 year).	0.644
Internal Consistency: .767		Average Variance Explained: 62.6%

**Data Collection**

A mailing list of supply chain and logistics managers was compiled from the list of attendees of the Annual Conference of Council of Logistics Management (CLM) in the year 2000. Target respondents for the survey were considered to be senior or middle managers with direct responsibility for the supply chain management or logistics function in the organization. Approximately

1,800 names were randomly selected from the list. All organizations that did not belong to manufacturing or retail industries (the first two digits of SIC codes 20 to 39 and 52 to 59) were removed from our sample. The final list consisted of 432 manufacturing and retail organizations. The survey was first mailed out and then subsequently made available on a Web site; the address of the Website was sent only to people on the mailing list. Two electronic reminders followed the initial mailing. After accounting for undelivered and invalid mail and incorrect e-mail addresses, the effective mailing was 360 surveys. We received a total of 110 combined responses via return mail, Web, and e-mail. The effective response rate was 30.55 percent, which is considered as an acceptable response rate for survey-based research.

The median organization size was 4,000 employees and the median organization revenue was \$1.5 billion. We tested for nonresponse bias using analysis of variance techniques. Considering the last group of respondents as most likely to be similar to nonrespondents, a comparison of first and last quartile of respondents provides a test of response bias in the sample (Armstrong and Overton 1977). The first and last 25 percent of respondents were compared on revenue, organization size, and other key study variables. The tests did not indicate any response bias across these variables. Similar comparisons were made across participants who responded by regular mail and those who completed the survey online. The analysis indicated that the two groups were statistically similar on all demographic and key study variables.

### Analysis and Results

Constructs used in research gain meaning from their definition, their measures, and the theoretical context in which they are embedded (Barclay et al. 1995). We use partial least squares (PLS) as it is considered appropriate for predictive research models where the emphasis is on theory development while linear structural relationship (LISREL) modeling is recommended for confirmatory analysis and requires adherence to a stringent set of distributional assumptions (Joreskog and Wold 1982). We chose PLS for data analysis, because of our emphasis on theory development.

The PLS method does not directly provide significance tests and confidence interval estimates of path coefficients in the research model. In order to estimate the significance of path coefficients, a bootstrapping technique was used. Bootstrap analysis was done with 500 subsamples and path coefficients were reestimated using each of these samples. The vector of parameter estimates was used to compute parameter means, standard errors, path coefficient significance, indicator loadings, and indicator weights. This approach is consistent with recommended practices for estimating significance of path coefficients and indicator loadings (Löhmoeller 1984) and has been used in prior IS studies (Chin and Gopal 1995; Compeau and Higgins 1995; Ravichandran and Rai 2000).

All of the constructs in this study are modeled as reflective. Reflective indicators are those that are viewed as being affected by the same underlying construct. For reflective indicators, a rule of thumb is to accept loadings of .707 or more which implies more shared variance between the construct and its measures than error variance. A few of the items have loadings less than the norm, but are retained if the internal consistency of the construct is adequate. Table 1 presents the results of the measurement model analysis, along with the definitions of constructs, the items from the survey included for each construct, and internal consistency and average variance extracted. We specified organization size as a control variable as larger organizations may be able to achieve better integration of inventory flows by virtue of having better access to resources. The number of full-time employees was considered as an indicator of size in the study. Table 2 presents analysis of discriminant validity among the constructs in the research model. Constructs are considered to have adequate discriminant validity if they share more variance with the items belonging to the construct than with other constructs in the model. Values in the diagonal are the square root of the average variance extracted (AVE) while the off-diagonal values represent correlation between variables. Constructs are considered to have adequate discriminant validity if the square root of the AVE value exceeds its correlation with other constructs in the model.

**Table 2. Assessment of Discriminant Validity**

	<b>Inventory Flow Integration</b>	<b>Information Sharing</b>	<b>Product Modularity</b>	<b>Demand Volatility</b>
Inventory Flow Integration	.716			
Information Sharing	.535	.759		
Product Modularity	.258	0.095	.733	
Demand Volatility	.193	0.101	.288	.791

*The values in the diagonal are the square root of average variance extracted*



The results provide support for the research model. One indicator of the predictive power of path models is to examine the explained variance or  $R^2$  values (Barclay et al. 1995; Chin 1998).  $R^2$  values are interpreted in the same manner as those obtained from multiple regression analysis; they indicate the amount of variance in the construct that is explained by the path model (Barclay et al. 1995). The results (Figure 2) indicate that the model explained 32.9 percent of the variance in inventory flow integration. Three of the four path coefficients were significant, providing additional evidence in support of the research model. Interestingly, the hypothesized path from consumer demand volatility to information sharing is not detected to be significant. The implications of these results are discussed next.

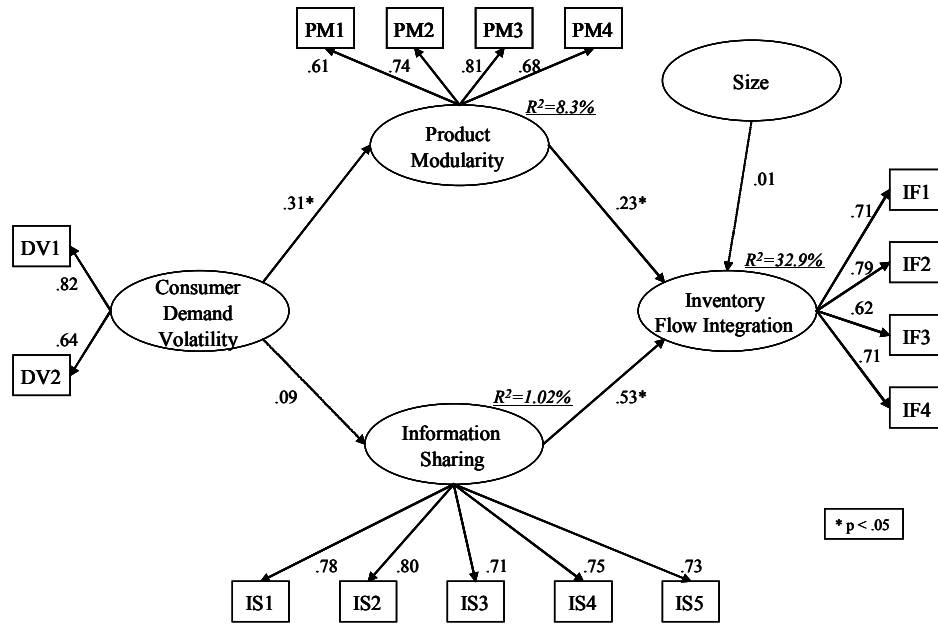


Figure 2. Results of the PLS Analysis

## Conclusion

Product modularity and information sharing provide organizational capabilities for integrating inventory flows across the supply chain. Customer demand volatility, however, does not directly impact information sharing, and explains only a small proportion of the variance in product modularity. Information sharing and product modularity assist organizations to cope with the bullwhip effect by enabling the coordination of inventory flows and minimization of inventory through close collaboration with suppliers. While modularity enables organizations to alleviate the pressures created by consumer demand volatility, it appears that information sharing does not. It may be argued that information sharing may be a prerequisite to coping with the bullwhip effect, irrespective of the level of consumer demand volatility. For example, Fisher (1997) discusses the case of Campbell soup which sought a physically efficient supply chain with its continuous replenishment program to achieve a nearly perfect level of service for meeting the demand for its products. To cope with uncertain demand for new products, Campbell would stock its supply chain based on the most optimistic forecast for the first month without an adverse effect on the overall inventory levels for all its products in the supply chain. Thus, while consumer demand volatility by itself may not drive information sharing, it is essential for Campbell to achieve integrated inventory flows in its supply chain. Sharing of demand and supply information and visibility of inventory are primary concerns in coping with the bullwhip effect, whether we are dealing with diapers or microprocessor chips.

Our results suggest that consumer demand volatility promotes modular product designs, suggesting that modularization of product design reduces the need for explicit information sharing about the inner design of modules and subsystems. Product modularity enables organizations to simplify procurement, reduce inventory holdings, assemble products in the distribution channel, and create shared processes for procurement, manufacturing, and distribution. National Bicycle of Japan adopted this strategy to increase its share of the sports bicycle market from 5 percent to 29 percent (Fisher 1997). National Bicycle is in an innovative product segment selling sports bicycles to affluent customers who buy them purely for recreational purposes. It put together a responsive supply chain where its made-to-order system allowed it to match supply with demand as it occurred at retailers. Our findings are also consistent with Clark's (1989) work on modularity and its significant impact on the coordination capability of the information technology industry's supply chains. These findings also support the information-focus strategy to manage

information processing in organizations (Tushman and Nadler 1978). Modular product designs imply that architectural information, such as interface specifications, is shared among partners. Such embedded sharing of information among partners reduces the transaction-by-transaction coordination complexity. To the extent that variety of product configurations possible in orders is high, the efficient coordination of tasks and resources across supply chain participants can be enhanced by a modular product design strategy.

Consumer demand volatility itself may not have a direct effect on information sharing in the supply chain, suggesting that the practice and behavior of supply chain information sharing is shaped by firm- and supply-chain strategies, policies, and capabilities. It is quite likely that product uncertainty, in and of itself, does not encourage information sharing behavior in organizations. A strong relationship is noticed between information sharing and inventory flow integration, suggesting that information sharing enables the efficient management of the stocking and flow of materials and products from the suppliers toward customers. From a transaction cost perspective, it appears that information sharing and shared governance of processes and resources do, in fact, improve transaction efficiencies. In summary, as firms move into complex and uncertain demand environments, they need to embrace a dual strategy—sharing of information that reduces transaction inefficiencies and information-focus strategies that reduce the need for explicit transaction-by-transaction information exchange.

### ***Implications for Research***

Coping with the bullwhip effect calls in question a variety of organizational capabilities such as managing the supply and demand chain, rationing, volume pricing, and return policies, and information sharing. Many of these are organizational initiatives are aided by information technology in as much as they impact the quality, accuracy, and timeliness of information shared across the supply chain. Information sharing in the supply chain is a key determinant of the contribution of information technology in enabling organizations to cope with the bullwhip effect. The measures of information sharing identified in this study deal with operational, tactical, and strategic information that enables the effective matching of supply and demand information. The impact of sharing other information attributes, such as expected lead times, status of order backlogs, ordering policies, and promotion and discount plans, on inventory holdings should be examined.

While the role of information sharing in enabling organizations to cope with the bullwhip effect is well accepted, we need to further investigate the role of modularity in matching demand and supply signals. The basic concepts of product modularity, standardization of loosely held components that may be recombined to fashion a variety of different products, is also applicable to other aspects of organizational design. Modular procurement (van Hoek and Weken 1998), modular manufacturing (Baldwin and Clark 1997), and modular organizational designs (Sanchez and Mahoney 1996) can, in principle, enable organizations to cope with the bullwhip effect. Theoretical and empirical inquiry needs to be directed toward the implications of different types and levels of modularity on the design and performance of supply chains.

Inventory flow integration was used as a surrogate for an organizations' ability to cope with the bullwhip effect. Future studies may develop more refined measures of success in coping with the different types of demand and supply uncertainty. In addition, the relationship between consumer demand volatility and information sharing, or lack thereof, needs to be further investigated. Information sharing may be of equal significance in both volatile and stable product demand environments; it is also likely that factors such as trust in the supply chain and information and communication technologies may mediate the relationship between demand uncertainty and information sharing.

### ***Implications for Practice***

Firms should evaluate their information-focus and information-sharing strategies that are being used for supply chain coordination. Sharing of architectural information about products can be very useful from a supply chain coordination standpoint, and the timing of such sharing with suppliers should be carefully managed as intergenerational product changes are introduced into the market. A systematic strategy for information sharing needs to be developed. The content of information shared should span not just transactional activity level information but should encompass operational, tactical, and strategic information. The sharing of managerially relevant information enables firms to plan their activities and resources synergistically and allows for the adaptive execution of operations and responsive handling of exceptions. Finally, it is critical for firms to evaluate how well their operational processes use available information associated with the stocking and flow of materials and products. The processes may be optimized under assumptions of unavailability of information, and as these constraints are reduced, these processes should be reconfigured and re-optimized.

## Limitations

We hope that our study triggers related investigations by the IS research community. There are specific limitations to our work. First, the unit of analysis of this study is not a specific supply chain for a given product line but a firm. This results in aggregation across supply chains for products. On the other hand, this unit of analysis allows us to paint a broader picture of organization-wide patterns in information sharing, product modularity, and inventory flow integration. Second, the study focuses on manufacturing and retail organizations, and as such the model and relationships should be examined in other industrial sectors. Third, variables such as structure of specific supply chains, number of tiers in the chain, types of supply chain applications, and types of business processes integrated, which have not been examined, should help us develop a better understanding of organizational mechanisms to cope with the bullwhip effect.

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