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Oliver Lin

University of Maryland - College Park, olin@rhsmith.umd.edu

Sunil Mithas

University of Maryland - College Park, sunil.mithas@gmail.com

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INFORMATION TECHNOLOGY AND INVENTORIES: SUBSTITUTES OR COMPLEMENTS?

Technologie de l'information et inventaires : Substituts ou Compléments ?

Completed Research Paper

Oliver Lin

Robert H. Smith School of Business
University of Maryland
College Park, MD
olin@rhsmith.umd.edu

Sunil Mithas

Robert H. Smith School of Business
University of Maryland
College Park, MD
smithas@rhsmith.umd.edu

Abstract

Is information technology (IT) a substitute or complement for inventories? This study answers this question by understanding substitution and complementarity of IT and inventories insofar as they impact profitability of a firm. We use data on IT expenditures and inventories of U.S firms and find support for the substitution between IT and overall inventories. Because overall inventories comprise raw-material, work-in-process and finished goods inventories, should we take this result to imply that substitution argument applies uniformly to all types of inventories? The answer is no. Our disaggregated analyses indicate that while IT can be a substitute for raw material inventories, IT is a complement for finished goods inventories. We discuss implications of these findings for research and practice.

Keywords: Information technology, inventories, inventory turnover, profitability, substitutes, complements, supply chain management

Résumé

La technologie de l'information (TI) est-elle un substitut ou un complément aux inventaires ? Nous exploitons des données sur les dépenses en TI et les inventaires des entreprises américaines. Nous constatons un effet de substitution entre les TI et les inventaires globaux. Bien que les TI puissent substituer les inventaires de matières premières, elles sont complémentaires aux inventaires de produits finis.

Introduction

Information technology (IT) investments can allow firms to become more agile and carry less inventory in their supply chain (Cachon and Fisher 2000). Previous research has noted a general upward trend in IT investments both at the economy level and in firm-level IT expenditures (Brynjolfsson and Hitt 1996; Dewan, Michael and Min 1998; McAfee and Brynjolfsson 2008; Mithas et al. 2007). Parallely, Chen, Frank, and Wu (2005) find that the inventory levels of US firms decreased from 1980 to 2000. The general trend of increasing IT investments and decreasing inventories is consistent with the argument that more IT might allow firms to carry less inventory, while improving other supply chain efficiencies and related business processes (Ho, Au and Newton 2002; Mithas and Jones 2007; Rai, Patnayakuni and Patnayakuni 2006; Sambamurthy, Bharadwaj and Grover 2003; Whitaker, Mithas and Krishnan 2007). Business press and academic studies using case examples and analytical models suggest that IT investments in enterprise planning, demand and forecasting, and replenishing systems allow firms to decrease their inventory holdings. For example, Dell Computer systems has one of the highest inventory turnover rates because of its efficient supply chain as well as transparency of information in its supply chain (Rai, Patnayakuni and Patnayakuni 2006). In short, there appears significant anecdotal support for the view that IT and IT-enabled information flows can be substitutes for physical inventories.

Against the backdrop of the substitution view, recent research implies an intriguing possibility that IT (and associated increased information flows) and inventories could be complements as well. Generally speaking, this work suggests that firms may be in a better position to accommodate a sudden change in demand using physical inventories if they also have higher information endowments typically associated with higher IT expenditures (Anand 2007).

To our knowledge, few studies have used actual data to test whether IT investments and inventories are substitutes or complements. While some studies have examined effect of IT on inventories (Barua, Kriebel and Mukhopadhyay 1995), these studies do not address the question whether IT is a substitute or a complement to inventories. This is because a resolution of substitution versus complementarity argument necessarily requires that we consider how IT and inventories jointly impact some measure of firm performance.

This paper evaluates the validity of substitution versus complementarity by using data on IT investments and inventories of U.S. firms, insofar as they impact profitability of a firm, a key metric that concerns managers. We first describe several mechanisms by which IT and inventory levels of a firm are related. Then, we examine whether or not IT and aggregate inventories are substitutes or complements of each other. To gain further insights, we do not treat all inventories in the same way. Therefore, we disaggregate inventories into raw materials, work-in-process, and finished goods inventories to understand how IT and disaggregated inventory levels affect profitability of a firm.

Theoretical Framework

We begin by synthesizing prior literature to identify three mechanisms that link IT expenditures and inventory levels: information integration, collaborative planning, and workflow coordination. Information integration refers to the sharing of information between members in a supply chain. Collaborative planning defines how to use the information that is being shared or integrated, and allows for the joint design and execution of product introduction, forecasting, and replenishment. Workflow coordination refers to the streamlined and automated workflow activities between supply chain partners (Lee and Whang 2003).

Information Integration

Information integration refers to the sharing of information by allowing better communications among members in a supply chain (Lee and Whang 2003). Vlosky (1994) describes information integration as a sharing of business data between or within firms in a structured format, which allows both parties to easily and quickly assimilate the other's information. Chopra and Meigham (2000) argue that IT allows information to be quickly and easily accessed in a central store so that information travels to the partners in a timely manner. Swaminathan and Tayur (2003) cite an example of providing information at a central store through the use of Enterprise Resource Planning (ERP) systems. This central store or repository enabled partner firms to access data throughout their entire supply chain.

How does information integration affect inventory turnover? First, information integration with upstream supply chain partners can expedite movement of goods to the locations where they are needed most. For example, Wal-Mart's Retail Link program shares its point-of-sales (POS) data with its suppliers to facilitate quicker replenishment of its shelves at its 4,000 stores (Sahin and Robinson 2002). Likewise, Zara, a Spanish apparel manufacturer and retailer, has been successful in integrating the use of demand data into operations across its supply chain. Because of the transfer of real time information, products are delivered quickly and reliably when and where they are needed (Frohlich 2002).

Second, information integration with downstream channel partners can affect inventory turnover through timely and targeted promotions that shape customer expectations regarding availability of goods. Alternatively, customer locations can also use appropriate pricing schemes to manage demand to suit the delivery schedule conveyed in advance. This also allows for dynamic revenue management where prices can reflect actual demand and inventory positions (Chopra and Mieghem 2000).

Third, information integration is not limited to business-to-business partners. Firms can also use the Internet and customer relationship management systems to interact with end consumers (Mithas, Almirall and Krishnan 2006; Peppers, Rogers and Dorf 1999). By allowing integration between customers and business partners (see Mithas, Krishnan and Fornell 2005), the firm is better poised to react to the changes in the market. When firms are able to better forecast the demand of their customers, they are able to react to market change and adjust their inventory more accurately.

How do IT applications facilitate information integration? Through the use of technology, firms have immediate access to data and information about their suppliers and buyers which allows decisions to be made in real-time, specifically regarding inventory levels. For example, Electronic Data Interchange (EDI) systems have allowed firms visibility into the supply chain and have allowed them to communicate with both their consumers and suppliers to shape their expectations regarding product availability and deliveries. Firms are also using these systems to collect demand information from consumers-centralized inventory.

Collaborative Planning

Collaborative planning refers to the joint design and execution of plans for product introduction, forecasting, and replenishment (Lee and Whang 2003). In contrast to information integration, collaborative planning describes what needs to be done once the information has been shared. Vlosky (1994) defines collaborative planning as the strengthened structural bonding in the relationship that closely ties partners together economically, strategically, and organizationally. By tying partners together, firms achieve unified global objectives and ultimately become more profitable (Sahin and Robinson 2002). Collaborative planning allows firms in the market to align their business goals so that they are able to more effectively work together. Transparency of information between firms allows unprecedented access to the partner's supply chain and with collaborative planning, firms are able to act upon this knowledge.

How does collaborative planning affect inventory turnover? First, collaborative planning allows companies to improve planning for capability issues such as warehousing, distribution, and transportation. By anticipating these changes, companies are able to reduce inventory because they are able to replenish their lost stock quickly. For example, Adaptec has utilized IT-collaborative software to communicate in real time to its suppliers to transfer production and shipment schedules (Lee and Whang 2001). By synchronizing schedules between different members in the supply chain, firms are able to better plan for unexpected problems in the supply chain.

Second, collaborative planning allows companies to set similar business goals in order to create synergies that would benefit both companies. By setting similar business goals, companies are better suited to combine synergies in order to offer a better product to the end consumer. For example, Cisco has embarked on a project to create an e-Hub, which will help identify potential demand and supply problems (Lee and Whang 2003). This system and collaborative planning allows firms to quickly communicate with one another in case of supply problems by linking multiple tiers of suppliers.

How do IT applications facilitate collaborative planning? IT systems facilitate the collaborative planning of firms by allowing them to match goals and align processes with their partners. For example, commercial tools, such as Microsoft Forecaster, enable users to organize projects and activities such as project management tools and discussion. This mixture of project management, group management and collaborative software allows several

firms to coordinate and complete sophisticated projects. By making use of IT, firms are able to work closely with their supply chain partners to jointly design and execute aligned plans.

Workflow Coordination

Workflow coordination refers to the streamlined and automated workflow activities between supply chain partners (Lee and Whang 2003). Johnson and Whang (2002) define it as an integration of players within the supply chain and an organization with vendors and customers based on shared forecasts. These coordination mechanisms seek to align available information and incentives such that decision makers act in the best interests of the firm (Sahin and Robinson 2002). Activities such as procurement, order fulfillment, engineering change, design optimization, and financial exchanges all fall under the category of workflow coordination. The main difference between collaborative planning and workflow planning is in the scope and timing of the supply chain coordination. Collaborative planning involves long term objectives and goals, whereas workflow coordination involves the detailed day-to-day operations of a firm. Viewed in this way, workflow coordination can also be considered a subset of collaborative planning.

How does workflow coordination affect inventory turnover? First, it allows companies to manage the complexities of the procurement process, which generally involves making buying decisions under conditions of scarcity. By matching workflow coordination among several firms, a firm's profitability can be increased. For example, Longs Drug Stores, a retail pharmacy chain, uses the service of Nonstop Solutions to manage its ordering and replenishment processes at their distribution centers and stores (Lee and Whang 2003).

Second, firms are able to coordinate workflows to improve its daily order processing accuracy. By utilizing the information that is being exchanged between partners, firms are able to work together to automate the delivery of items and products with more accuracy. For example, Chrysler Corporation was able to increase its cost savings by using EDI to coordinate daily workflows with its suppliers and partners (Mukhopadhyay, Kekre and Kalathur 1995).

Finally, workflow coordination decreases the time that it takes for a product to reach the market or to replenish a product. Too little product leads to stock outages, while too much can require the use of promotions and discounts to move inventory or risk having it returned to the manufacturer. Satisfaction by the retailer and customer can be obtained simply by improving the time it takes to get a product to the market. For example, Wal-Mart partners with Wrangler jeans through their Vendor Managed Replenishment (VMR) system. Even though the daily sales of Wrangler jeans through the Wal-Mart outlet are almost one million pairs, Wrangler is able to cope with this volume by using real-time retail data to determine when to replenish the stock of jeans at Walmart. This predetermined workflow coordination is based from history of sales as well as the company's ability to work well together (Hamid and Keith 2000).

How do IT applications facilitate workflow coordination? IT plays a major role in facilitating workflow coordination. By using technology to align the processes of different companies, firms are better able to react to the market and supplier on a daily basis. For example, Sharepoint allows firms to coordinate scheduling to assure customers that their products will arrive on time. In other words, workflow coordination allows an automation to be effectively deployed and thus, increase the efficiency and profitability of the business.

Table 1 provides a summary of the three mechanisms outlined above and how these mechanisms relate to the substitution versus complementarity arguments referred earlier. It also points to similarities and distinctions among these mechanisms. For example, one can categorize these mechanisms based on whether they focus on short-term versus long-term or whether they are tactical or strategic. Tactical goals are short-term initiatives that generally encompass the day-to-day operations of a firm. Strategic goals look at the long-term planning between partners in a supply chain. Information integration is categorized as both tactical and strategic because visibility into the supply chain aids in both the immediate planning and the future planning abilities of the firm. The scope of information integration covers the short-term and long-term initiatives of a supply chain. Collaborative planning refers to the day-to-day operations of partners within a supply chain and is considered more tactical short-term goal. Workflow coordination looks at the long term collaboration between partners in a supply chain and is geared more towards shaping the overall strategy of the firms.

IT and Inventory: Substitutes or Complements

As noted earlier, while some researchers have argued that investment in IT and inventory are substitutes for each other (Cachon and Fisher 2000; Lee and Whang 2003; Zhu and Kraemer 2002), others have argued that IT and

inventory can be complements to each other (Anand 2007; Hitt and Snir 1999; Zheng and Zipkin 1990). We briefly review and elaborate these arguments, before presenting empirical results to test these alternative views.

Table 1: Definition and Role of the Mechanisms

	Definition	Type	Role in Substitutes Argument	Role in Complements Argument
Information Integration	The sharing of information by allowing better communications among members in a supply chain.	Short-Term Tactical & Long-Term Strategic	As more information is available, a firm can reduce the amount of inventory in store because they have real-time demand information.	The more information that is available, the more a firm will match demands which would lead to higher inventories.
Collaborative Planning	The joint design and execution of plans for product introduction, forecasting, and replenishment.	Short-Term Tactical	Firms can reduce inventory because they have collaborative mechanisms in place to replenish inventory when levels decrease.	Because firms have collaborative planning mechanisms in place, firms will order new inventory immediately which can lead to high inventory levels.
Workflow Coordination	The streamlined and automated workflow activities between supply chain partners.	Long-Term Strategic	By increasing workflow coordination, accuracy and processes can be managed better which results in lower inventory.	Workflow coordination forces firms to stock on inventory in order to meet their joint inventory goals.

Researchers have studied linkages between IT and inventory using analytical models, case studies and empirical work. Prior research using analytical models suggests that investment in IT can lead to improvements in inventory turnover (Zhu and Kraemer 2002). Cachon and Fisher (2000) argue that IT can be a substitute for inventory in supply chain by showing substantial savings from lead time and batch size reduction through the use of IT. Additionally, researchers have argued that information transparency would lead to a diminishing of the bullwhip effect and have proposed several IT-based mechanisms to counter these effects. For example, Lee and Whang (2003) have argued that communication of demand information through the use of IT is one way to counter the bullwhip effect. Moreover, Agile Software is able to decrease their inventory by collaboratively managing product design and engineering changes through the use of IT (Johnson and Whang 2002). While analytical studies, which typically make several simplifying assumptions, have enhanced our understanding of how information can act as a substitute for inventory, these studies are silent about the implications of IT and inventory turnover for firm performance.

Several case studies shed some light on the connection between IT and inventory turnover. For example, Lee and Whang (2003) argue that one of the reasons for success of Seven-Eleven Japan (SEJ) is the multi-channel model in which SEJ is able to utilize an IT-based supply chain system that has allowed them to integrate with seven of Japan’s largest industry giants. Likewise, trade press and academic researchers have argued that IT has played an important role in supply chain efficiency at Dell and Sport Obermeyer. Dell has leveraged IT synergies in order to manage its supply chain to the point where they only need to maintain four days of inventory (Rai, Patnayakuni and Patnayakuni 2006). Sport Obermeyer has used IT to form a joint venture with its supplier to source raw materials, cut and sew garments, and coordination shipping which has been beneficial to both firms (Narayanan and Raman 2004). While these case studies provide useful insights, it is problematic to generalize from case studies and therefore we reviewed prior empirical studies that study linkages between IT and inventory.

Among early empirical studies, Barua, Kriebel and Mukhopadhyay (1995) linked IT spending with inventory turnover at the business unit level using data collected by the Strategic Planning Institute (SPI) as part of the “Management Productivity and Information Technology” (MPIT) program for the period from 1979 to 1984. They found IT has a significant impact on inventory turnover. Other studies have surveyed supply chain managers and found that integrated IT infrastructures enable firms to develop the higher order capabilities of supply chain process integration. For example, Cisco Systems has created a digital platform through the use of IT to create a system that transfers information in near real time (Rai, Patnayakuni and Patnayakuni 2006). Finally, other studies have related specific IT systems such as Electronic Data Interchange (EDI) to positive performance improvements when the system is used for inter-firm process reengineering (Lee, Clark and Tam 1999).

Collectively, the above body of work points to IT and inventories as likely substitutes of each other. Although case study examples and analytical models argue why increased use of IT will lead to reduced inventory turnover, they do not test how IT and inventories jointly affect firm performance to validate the substitution arguments empirically.

While arguments for IT and inventory as substitutes are a dominant theme in the supply chain management research, an alternative view suggests the possibility of IT and inventories complementing each other. For example, Zheng and Zipkin (1990) examined the inventory position and tested the performance of a supply chain system with and without this information. They found that the performance of the system is better with inventory position as an information marker. Hitt and Snir (1999) studied 400 firms and found that IT and other firm level inputs could potentially be complements or substitutes depending on the organizational structure of the firm. They further discuss that as the price of IT continues to decrease, they expect firms that have the ability to capitalize on complementing IT with other inputs to become more profitable.

Although intuitively, it would seem that lower inventories would yield higher profitability, higher profitability can also arise with higher inventories and more IT. For example, higher inventories can prevent stockouts and thus potential loss of profitability. A stockout occurs when a firm runs out of inventory of a particular product to service their customers. Stockouts have been shown to affect the current and future orders (Anderson, Fitzsimons and Simester 2006), order quantity and purchase incidence (Campo, Gijsbrechts and Nisol 2003). Consumers that suffer a stockout situation do not purchase the same quantity from the seller and may be less trusting of this seller in the long term. This decrease in purchasing leads to a decrease in overall firm profitability. IT systems can allow firms to have greater visibility to demand information, distribution needs and demand variance of consumers. For example, Smaros et al. (2003) found that vendor-managed inventory systems give managers access to more accurate demand data. Increased visibility allows for better and more precise information about demand from the distributors (Karaesman, Liberopoulos and Dallery 2004). Better demand information reduces the possibility of stockouts because increased information leads to better service to customers in the form of higher fill rates (Bourland, Powell and Pyke 1996). Toktay and Wein (2001) find that forecasting and inventory levels were more accurate when demand information was known and stationary. By having better demand information and higher inventories, firms can prevent stockout conditions during times when consumer demand has a lot of variance which can increase customer satisfaction and future purchase behavior (Fornell et al. 2006).

In summary, in contrast to prior research which focuses on impact of IT on inventories (e.g., Barua (1995) and Rabinovich (2003)), our focus here is on how IT and inventory turnover jointly influence firm performance. While previous research has argued that IT and inventory can be complements or substitutes, few empirical studies have tried to resolve this issue. Specifically, while prior studies have conjectured that increased spending in IT coupled with improved inventory turnover may influence profitability, none have empirically validated these conjectures with actual data.

Hypotheses

Based on the foregoing discussion related to substitution arguments, we posit IT and aggregate inventories can be substitutes of each other in overall profitability due to three mechanisms. First, IT systems in the supply chain increase the visibility of inventories across the entire production system. This allows managers to see where potential problems may arise and to take steps to avert problems. Secondly, the collaborative planning between firms and their partners allow firms to set long-term goals in order to increase productivity. Finally, workflow coordination allows firms to implement day-to-day processes in order to better fulfill inventory needs. Therefore,

firms with higher IT investments and lower inventories will have higher profitability if IT and inventories are substitutes of each other.

Hypothesis 1. A firm's investment in IT systems and overall inventories will be a substitute for each other in their joint impact on profitability.

Although we hypothesize that IT and total inventory will be a substitute for each other, we divide inventory into its components in order to get a clearer picture of IT's interaction with inventory. Total inventory consists of three types of inventories: raw materials, work-in-process, and finished goods. Raw materials inventory generally requires communication and interaction with different firms in a supply chain. The more efficient these firms are in communicating with their partners, the higher the profitability of the firm. Therefore, firms with higher IT spending and lower raw materials inventory will have higher profitability if they are substitutes of each other.

Hypothesis 2a. Greater IT spending within a firm is a substitute for raw materials inventory in their impact on profitability.

Unlike raw material inventory, work-in-process inventory generally does not depend on the interaction with other members in the supply chain. Because the three mechanisms that have been described in this paper are concerned with the interaction between different firms of a supply chain, we are unsure of whether or not work-in-process inventory is a substitute or complement for IT. Therefore, we do not posit a specific hypothesis whether higher IT expenditures and lower work-in-process inventory will be substitutes or complements of each other.

Finally, finished goods inventory depends on the interaction between a firm and its distributors. To avoid stockouts and any customer dissatisfaction or lost sales arising therefrom, firms may keep higher inventories compared to their competitors, despite higher visibility into the supply chain. Therefore, higher IT spending and greater finished goods inventories will be complements of each other as measured through firm profitability.

Hypothesis 2b. Greater IT spending within a firm is a complement for finished goods inventory in their impact on profitability.

Methodology

This research utilizes an empirical investigation using secondary data. We study the effect of IT and inventory levels on profitability of manufacturing firms from the year 2000 to 2004. We focus on firms in the manufacturing sector for several reasons. First, IT has traditionally had a very high impact on the manufacturing firms. Numerous firms have made IT investments in their supply chain in order to reap the benefits of speed and innovation that cutting-edge technology offers. Second, the manufacturing firms use inventory as one of their baseline metrics to assess how well the firm is doing. Limiting the study to manufacturing firms also allows us to better interpret the results of our analysis because it is hard to interpret the notion of inventories in the context of service firms.

We obtained the data collected by the *InformationWeek* surveys in the United States during the period of 2000 to 2004. *InformationWeek* is considered to be a source of reliable information, and previous academic studies have also used data from *InformationWeek* surveys (Bharadwaj, Bharadwaj and Konsynski 1999; Rai, Patnayakuni and Patnayakuni 1997; Santhanam and Hartono 2003; Tafti, Mithas and Krishnan 2007). We match the IT investment data on manufacturing firms in the *InformationWeek* sample with the data available from the Wharton's Research Data Services (WRDS). WRDS is a compilation of many comprehensive sources of financial, accounting, economic, management, marketing, banking, and insurance data. We used the Standard and Poor's CompuStat Annual database which includes firm-level financial measures. After matching, our final data for this study consists of a total of 440 firm-year observations for overall inventory models and 291 observations for disaggregated inventory models.

Table 2 provides a summary of the variables used in this study.

Variable Definition

OPINC: OPINC refers to the operating income of a firm before depreciation. This value was obtained from CompuStat's Annual database. Operating income is a measure of a company's earning power from ongoing operations, equal to earnings before deduction of interest payments and income taxes.

ITINV: This variable refers to the level of IT investment of a firm in millions of dollars.

INVTURN: This variable refers to the cost of goods sold (COGS) divided by the average inventory.

INVTURNRM, INVTURNWIP, INVTURNFG: These variables refer to the inventory turnover in each of the different stages of inventory. They represent raw materials, work-in-process, and finished goods, respectively.

FIRMSIZE: This variable refers to the revenue of the firm standardized using the Consumer Price Index (CPI). This is constructed by taking the log of the revenues a firm generates as a proxy for the firm size.

Y2000 – Y2004: This is an indicator variable for each of the year the data was collected. A time variable is introduced so that the trends from year to year can be captured.

Table 2: Variable Definitions and Operationalization

Variable Name	Definition and Operationalization	Source
OPINC	Operating Income before depreciation in millions of dollars.	CompuStat Annual
ITINV	IT Investment in millions of dollars.	Information Week Survey
INVTURN	Inventory Turnover defined by Cost of Goods Sold (COGS) divided by Inventory.	CompuStat Annual
INVTURNRM	Inventory Turnover of Raw Materials defined by total COGS divided by Raw Materials Inventory.	CompuStat Annual
INVTURNWIP	Inventory Turnover of Work-In-Process defined by total COGS divided by Work-In-Process Inventory.	CompuStat Annual
INVTURNFG	Inventory Turnover of Finished Goods defined by total COGS divided by Finished Goods Inventory.	CompuStat Annual
FIRMSIZE	Log of revenue from CompuStat. This variable is standardized using the Consumer Price Index (CPI).	CompuStat Annual

Table 3 provides summary statistics for the manufacturing firms in our sample. On average, manufacturing firms have an inventory turnover that ranges from about 1 to 91 or from 325 days to 4 days. The inventory range and average is consistent with prior studies that have looked at large public firms (Gaur, Fisher and Raman 2005; Stratopoulos and Dehning 2000). In addition, the operating income of the firms' average about \$1.85 billion and range from negative \$500 million to \$27.4 billion. Finally, the IT investment of these manufacturing firms range from \$0.98 million to \$10.0 billion with an average of \$343 million.

Table 4 provides correlations among variables. As one would expect, IT investments have a positive correlation with profitability, while inventory turnover variables have a negative association with profitability. IT has negative zero-order correlation with inventory turnover variables, providing some support for the substitution arguments. However, these correlations are low and alleviate concerns in studying the moderating effect of IT and inventories on profitability (Sharma, Durand and Gur-Arie 1981).

Table 5 provides trends in key variables by year. Inventory turnover (INVTURN) has generally trended up from the year 2000 to 2004. Average IT spending (ITINV) by firms decreased from 2000 to 2003, when the dot-com bubble began to deflate, but then steadily increased in 2003 and 2004. Operating income (OPINC) showed no consistent pattern and has varied from 2000 to 2004.

Table 3: Descriptive Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
OPINC	440	1855.86	3507.38	-567.41	27475.00
FIRMSIZE	447	8.22	1.16	4.90	11.83
ITINV	440	343.79	766.11	0.98	10009.20
INVTURN	447	8.71	10.72	1.12	91.45
INVTURNRM	356	40.59	66.01	3.13	816.21
INVTURNWIP	304	57.96	99.74	1.89	812.62
INVTURNFG	359	17.88	38.61	2.86	532.45

Table 4: Correlations Among Variables

	OPINC	ITINV	INVTURN	INVTURNRM	INVTURNWIP	INVTURNFG	FIRMSIZE
OPINC	1						
ITINV	0.49	1					
INVTURN	-0.08	-0.05	1				
INVTURNRM	-0.08	-0.06	0.29	1			
INVTURNWIP	-0.10	-0.08	0.36	0.17	1		
INVTURNFG	-0.07	-0.02	0.68	0.16	0.04	1	
FIRMSIZE	0.75	0.48	0.02	-0.18	-0.07	-0.08	1

Table 5: Trends in Key Variables

Year	Observation	OPINC	ITINV	INVTURN	INVTURNRM	INVTURNWIP	INVTURNFG
2000	Mean	2206.59	440.50	7.94	31.68	42.80	13.24
	N	94	94	96	78	66	75
2001	Mean	1827.21	338.36	8.59	34.25	53.04	17.00
	N	96	96	97	82	68	79
2002	Mean	1598.57	293.43	9.23	49.57	59.15	21.89
	N	122	122	123	95	81	96
2003	Mean	1974.24	315.91	9.14	42.75	56.16	19.43
	N	102	102	103	82	71	86
2004	Mean	1436.46	359.82	7.97	50.31	133.84	13.47
	N	26	26	28	19	18	23
Total	Mean	1855.86	343.79	8.71	40.59	57.96	17.88
	N	440	440	447	356	304	359

Empirical Models and Economic Issues

To test if IT and inventories are substitutes or complements, we look at the interaction between IT and inventory turnover as it affects operating income. A positive coefficient on the interaction implies that there is a

substitution effect because as a firm increases its IT spending and increases its inventory turnover (i.e., decreases its inventories), it will have greater firm profitability. On the other hand, if the coefficient is negative on the interaction between IT and inventory turnover, it implies a complementarity effect because as a firm spends more on IT and decreases its inventory turnover (i.e., higher inventory) or vice versa, it is able to generate greater profits.

We specify the following empirical model:

$$Y_{it} = X1_{it} \beta_1 + X2_{it} \beta_2 + X1_{it} X2_{it} \beta_3 + a_i + \varepsilon_{it} \quad (1)$$

Where Y represents the dependent variable operating income (OPINC), $X1$ represents the investment in IT (ITINV), $X2$ represents the inventory turnover (INVTURN), the β 's are the parameters to be estimated, subscript i indicates firms and subscript t indicates time, a_i represents unobserved time invariant fixed factors associated with a firm i , and ε is the error term associated with each observation.

Because of the panel nature of our dataset, the residuals across time for the same firms may be correlated, hence the ordinary least squares approach for estimating equation 1 may not be appropriate. Since firms in our sample may be considered as a draw from a larger population of firms, we estimate the parameters more efficiently through random effects models. Random effects models allow correlations among residuals of firms across time periods and also account for unobservable firm specific effects (Baltagi 2001). We estimated models represented by equation 1 by allowing the intercept to vary across individual firms (Greene 2000; Wooldridge 2002).

Table 6 presents the results. We checked for multicollinearity and found that the highest variance inflation factor (VIF) value of 2.87 is well below the threshold specified in the literature. To check robustness of our results, we estimated our models including a dummy variable for SIC codes and physical capital intensity and these specifications yielded broadly similar results. To alleviate any concerns due to endogeneity, we also estimated the random effect models by instrumenting the IT and inventory variables and although, as one would expect, these specifications had higher standard errors, we obtained qualitatively similar results.¹

Results

Hypothesis 1 predicted that a firm's investment in IT systems and their inventory would be a substitute for each other as measured by the profitability of the firm. As shown in **Table 6**, Column 1, the hypothesis is fully supported. We find evidence for a substitution effect between IT and inventory ($\beta = 0.07$, $p < 0.001$). The results show that manufacturing firms are more profitable when they spend more on IT and decrease their inventory which implies that IT and inventory are substitutes.

Hypothesis 2a looked at the substitution between IT and raw materials inventory and its impact on firm profitability. Column 2 of **Table 6** shows the results of disaggregated inventory for manufacturing firms. We find that operating income is greater in those firms where decreased raw material inventory ($\beta = 0.02$, $p < 0.01$) is coupled with greater IT investment.

Finally, hypothesis 2b looked at the complementation between IT and finished goods inventory. We find that operating income is greater in those firms where increased finished goods inventory is coupled with greater IT investment ($\beta = -0.03$, $p < 0.05$).

Among other results, because the interaction term involving the work-in-process inventory and IT is statistically insignificant ($\beta = -0.01$, $p = 0.255$), we fail to find support for either substitution or complementarity for IT and WIP inventories. IT investments show a positive and statistically significant impact on profitability at the mean values of aggregate inventories in Column 1 of Table 6. This suggests that IT investments after 1995 are associated with firm profitability (see Dedrick, Gurbaxani and Kraemer 2003; Lucas 1993; Mithas et al. 2007). While aggregate inventories do not appear to affect profitability at the mean value of IT investments, higher inventory turnover of raw-materials but lower inventory turnover of finished goods inventories is associated with profitability at the mean value of IT investments (see Column 2 of Table 6).

¹ We used lagged values of IT investments, inventories and profits as instruments. These instruments are far from perfect (see Mithas and Krishnan 2009 for a discussion) and we interpret the results as a sensitivity analysis only.

Table 6: How IT Investments and Inventory Turnover Show Substitution or Complementarity in their Effect on Profitability

	(1)	(2)
ITINV	0.48***	0.51*
	(0.11)	(0.31)
INVTURN	-12.42	
	(11.07)	
ITINV * INVTURN	0.07***	
	(0.02)	
INVTURNRM		6.97***
		(1.69)
ITINV * INVTURNRM		0.02***
		(0.00)
INVTURNWIP		-1.36
		(2.69)
ITINV * INVTURNWIP		-0.01
		(0.01)
INVTURNFG		1.46
		(5.09)
ITINV * INVTURNFG		-0.03**
		(0.02)
Constant	-14,295.72***	-12,811.82***
	(1,019.34)	(1,081.92)
Observations	440	291
Number of Firms	162	107

Standard errors in parentheses, * significant at 10%; ** significant at 5%; *** significant at 1%
 All models include an intercept, dummies for years and a control variable for firm size.

Discussion

The goal of this study was to conduct an empirical test of substitution versus complementarity arguments related to IT and inventories, in their impact on profitability. We find support for a substitution effect between IT and overall inventories, consistent with conjectures in the prior literature. However, substitution effect does not apply to all types of inventories. Our disaggregated analyses reveal that while IT is a substitute for raw-material inventory, it is a complement for finished goods inventories. The support for the complementarity argument for the finished goods inventories is consistent with the nascent and emerging analytical literature in the supply chain management area (Anand 2007).

Before turning to implications of these findings, we discuss the limitations of this study. This being the first study to examine how IT and inventories jointly impact firm performance, our results are associational and do not imply causality (Mithas and Krishnan 2009). Despite the associational nature of our study, the findings are informative given the goal of this study, that is, to test the substitution versus complementarity arguments.

These findings have important implications for further research. For example, ours is perhaps the first study to give empirical content to a long-standing claim in the supply chain management literature that equates IT with inventories, in a novel way. We bring to the fore the idea that substitution versus complementarity arguments

can not be evaluated without specifying a metric that firms may be trying to maximize. Further research can evaluate this template to examine substitution versus complementarity arguments in other contexts.

Second, this study highlights the need to make a distinction between different types of inventories and associated information flows in analytical work in supply chain management area. We find that the IT-enabled inventory substitution applies only to raw materials inventory, but we find evidence for complementarity between IT and finished goods inventory. While we fail to find evidence for either substitution or complementarity between IT and work-in-process inventory, there is need for further research to explain why this might happen. Is it that WIP inventories are completely unrelated to IT-enabled supply chain efficiencies? Or, is it because substitution and complementarity effects cancel each other out in our dataset and it is possible to find evidence for substitution or complementarity in WIP inventories depending on the extent to which such inventories are similar to RM or FG inventories in a given context. Clearly, there is a need for further research to answer this question. On the whole, the evidence in this study suggests that IT-enabled supply chain efficiencies affect only those inventories that benefit from supply chain or downstream coordination and not the ones that are largely within the control of a firm. In addition, firms achieve higher profitability for keeping a low raw materials inventory level and a high finished goods inventory level when coupled with greater IT investment.

Though our study provides evidence of a substitution and complementation effect between IT investments and different types of inventories, there are several opportunities to extend this work. First, this study uses a sample of firms in the U.S. The generalizability of our results needs to be confirmed with studies in other geographic areas. Second, although we have identified and articulated several mechanisms (information integration, workflow coordination, and collaborative planning) that relate IT expenditure and inventory turnover, but we do not directly measure and test these mechanisms. Future research should operationalize and test the relative explanatory power of these mechanisms. Finally, we use operating income as the dependent variable. An interesting extension to this study would be to use measures such as shareholder value and stock returns as alternative dependent variables.

This study also has important managerial implications. First, the finding that IT and overall inventory levels are substitutes for each other suggests that firms that are looking to decrease their inventory levels could invest in IT, with increased profitability. In addition, firms that have relatively high spending in IT should look at their inventory levels in comparison to their peers. Those with high spending in IT and high inventory levels can decrease their inventory levels by using their IT and supply chain processes more efficiently. Second, managers need to discriminate among raw materials, work-in-process and finished goods inventories. These inventories behave very differently as far as their interaction with IT spending affects profitability. By paying close attention to the three underlying mechanisms outlined in this paper, firms can better understand the interactions between IT and supply chain initiatives.

To conclude, this study conducts one of the first empirical tests to resolve whether IT and inventories are substitutes or a complements in their impact on profitability. Using data on IT, inventories and profitability of U.S. firms, we find support for the substitution between IT and overall inventories. Further analyses indicate support for the substitution argument in raw materials but for the complementarities argument in finished goods inventory. Overall, these results show that IT spending of a firm has implications for tailoring supply chain initiatives and inventory decisions for improved firm performance.

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