Assessing Information Technology Moderating Effects on Outsourcing Strategy and Inventory Levels in the Manufacturing Sector

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This paper studies the current growing utilization of contract manufacturing and how IT systems coupled with the outsourcing strategy can impact inventory performance. Contract manufacturing has been a strategic tool for manufacturing sectors to operate the manufacturing systems. A growing number of original equipment manufacturers have shifted a section of the entire line of production to contract manufacturers located either in the U.S. or around the world. While contractual arrangements may provide integrative inter-firm governances, it is the supply chain information technology (IT) systems that facilitate information sharing between supply chain members and in turn lead to better operational performance. We performed a cross-industry study on the effects of contract manufacturing-IT interaction on inventory performance. Our primary findings suggest that contract manufacturing may result in higher inventories in the supply chain; however, the combination of manufacture outsourcing and IT investment can reduce industry-level inventories of finished goods and raw materials.

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I. INTRODUCTION

The research objectives are: 1) to assess IT moderating effects on the outsourcing strategy and inventory levels in the entire U.S. manufacturing sector; 2) to seek the convergence of the contract manufacturing and IT research streams and theorize outsourcing's impacts on efficiencies of inventory management.

Outsourcing has been a strategic tool for manufacturing sectors to operate the manufacturing systems (Cheng, 2010; Schilling and Steensma, 2001; Sturgeon, 2002). A growing number of original equipment manufacturers (OEMs) have shifted their production to contract manufacturers (CMs) located either in the U.S. or around the world. OEMs utilize manufacturing outsourcing for several reasons. First, OEMs leverage the external economies established by contract manufactures and specialize their core competencies to reach their own scale economies (Fine, 2000; Langlois and Robertson, 1995; Plambeck and Taylor, 2005). In addition, through combining resources with CMs, OEMs can obtain flexibilities in terms of production capacities, product varieties, and new product development, among others. The increasing use of contract manufacturing has lead to the rise of OEM-CM networks, vividly suggested by researchers that bring forth a new American paradigm of organizing manufacturing supply chains (Sturgeon, 2002).

As witnessed in textile, computer, electronics, and semiconductor industries, practitioners and researchers have observed multiple industries that have developed OEM-CM production networks (Langlois and

Robertson, 1995). In 2000, Motorola contracted out approximately 15% of its production to electronics contract manufacturer Flextronics. Other electronics CMs also established close ties with large electronics OEMs. Jabil Circuit generates 18% of its revenue by serving for Philips Electronics and 12% for Cisco Systems, respectively. Another prominent instance is the emergence of semiconductor contract manufacturers, or foundries. Many semiconductor OEMs have adopted a "fabless" (i.e. no fabrication facilities) model and contract out parts or the whole of their foundries (Fabless Semiconductor Association, 2003). For instances, Philips uses Taiwan Semiconductor Manufacturing Company, and Broadcom hires Chartered Semiconductor Manufacturing. In addition, in the computer industry, Dell and HP forward their orders to a PC contract manufacturing firm in China to producing customized computers (Dean and Tam, 2005). Lastly, in the aircraft manufacturing industry, large manufacturers, e.g. Boeing, have outsourced the production of aircraft components to General Electric's air engines for the final assembly (Shy and Stenbacka, 2003).

Inventory performance has been employed by OM researchers as a critical operational performance indicator in the manufacturing supply chain network (Gaur, Fisher, and Raman, 2005; Rajagopalan and Malhotra, 2001). Logistics management plays a key role in integrating the expanded supply chain between OEMs and CMs (Cavinato, 1989; Mason, Cole, Ulrey, and Yan, 2002). After OEMs and CMs determine the production responsibilities of different parties, it is necessary to utilize logistics management to coordinate the flows of finished goods, work-in-process components, and raw materials (Rabinovich, Dresner, and Evers, 2003). Research on the inventory performance has suggested that the U.S. manufacturers have performed significantly better on their inventory turnovers and streamlined their logistics systems (Lieberman, Helper, and Demeester, 1999; Lieberman and Asaba, 1997). The improvements are the results of the increasing use of Just-in-Time (JIT) production systems, supply chain management, and inter-organizational information systems.

Information technology (IT) systems facilitate information sharing between supply chain members and in turn lead to better operational performance (Jitpaiboon, Vonderembse, Ragu-Nathan, and Asree, 2010; Lee, Clark, and Tam, 1999). The spreading use of IT to facilitate supply chain management initiatives, such as electronic data interchange (EDI), material requirements planning (MRP), enterprise resource planning (ERP), Quick Response/Efficient Customer Response (QR/ECR), etc., enhances supply chain coordination, production quality, and inventory performance (Gaur, Fisher, and Raman, 2005; Huson and Nanda, 1995; Radovilsky and Hegde, 2011).

Poorly managed logistics systems in the outsourcing context can lead to disruption of product lines, high stockpiles, stockout of inventories, and ultimately lost sales. While contract manufacturing arrangements between OEMs and CMs may provide inter-organizational coordination governances, we take the view that the inventory performances under production outsourcing need be assessed together with IT investment levels. Albeit the extensive discussion on contract manufacturing in the literature (Fine, 2000; Langlois and Robertson, 1995; Parker and Anderson, 2002), surprisingly, no systematic empirical study has been conducted to examine the inventory performance pertinent to the utilization of contract manufacturing, as pointed out by Rajagopalan and Malhotra (2001). Further, although IT's role in enhancing supply chain operations has been documented, how it can facilitate the OEM-CM supply chain's inventory efficiencies is not fully investigated.

Observing the aforementioned gaps in contract manufacturing literature, we are motivated to conduct an economy-wide research to assess the roles of IT systems for manufacturing industries' inventory management in an outsourcing context in the U.S. manufacturing sector. This paper intend to address the following questions: How does the utilization of contract manufacturing affect the inventory levels in the U.S. manufacturing industries? To what extent does IT investment level facilitate the OEM-CM dyads' integration and management of inventory levels?

We first utilize the Square Root Law and Bullwhip effect theories to theorize contract manufacturing's direct impacts on inventory levels. We proceed to apply supply chain IT literature to establish that IT investments will help firms to improve inventory efficiencies in the contract manufacturing context. The present research contributes to the outsourcing literature by empirically attest that in addition to contractual relationship, OEMs and CMs need to implement integrative IT systems to achieve inventory efficiencies.

We organize the remainder of this paper as follows. In the next section, we review literature on driving forces for inventory performance, contract manufacturing, and the function of IT in inventory management. The literature review section concludes with hypotheses predicting the impacts of contract manufacturing and IT's moderating effects on contract manufacturing and inventory performances. Next, data and methods for hypotheses testing are detailed. Finally, we discuss the implications of using contract manufacturing in the emerging global OEM-CM production networks.

II. LITERATURE REVIEW AND HYPOTHESES.

2.1. Inventory Allocation among OEMs and Contract Manufacturers

The emerging outsourcing phenomenon has transformed a manufacturing industry's structure from vertically integrated systems to clusters of value-added activity specialists operating at various stages of value systems (Jiang, Yao, and Feng, 2008). While OEMs and CMs belong to the same manufacturing industry, they function at respective downstream and upstream stages of the supply chain (Langlois and Robertson, 1995; Sturgeon, 2002). This change in industry structures affects the operations in supply chain processes, especially the inventory management.

2.2. Inventory Groups

OM literature has suggested inventory can be grouped into three general categories – finished goods (FG), work-in-process (WIP), and raw materials (RW) (Lieberman, Helper, and Demeester, 1999; Rajagopalan and Malhotra, 2001). While some researchers use the generic term "component" to describe WIP, Hsuan (1999) include components, modules, sub-systems, and systems to the WIP inventory category. The subsequent discussion applies the FG, WIP and RW categorization of inventories in the manufacturing sector.

2.3. Finished Goods Inventory under Outsourcing

OEMs' outsourcing decisions are driven by the supply chain capabilities as well as the low-cost production advantages developed by CMs (Sturgeon, 2002). Increasingly, OEMs outsource most supply chain processes to CMs, including R&D, FG manufacturing, inventory management, and physical distribution (Mason, Cole, Ulrey, and Yan, 2002). The OEMs' role can transform from manufacturing to marketing or supply chain coordination for the FG distributed to the marketplace (Cavinato, 1989). Nike and Reebok in the footwear industry are well-known leaders of production networks adopting this model (Schilling and Steensma, 2001). As CMs assume the responsibilities of managing more supply chain processes, OEMs can minimize FG inventories in their downstream stages.

In addition, OEMs have utilized the postponement strategies to delay the assembly of finished products and store WIP inventories at the upstream supply chain stages (Van Hoek, 2001). More WIP inventories are stored before custom orders arrive for final assembly, allowing higher-valued FG inventory levels to be lowered. Dell Computers in the computer industry established a well-known Direct model that uses contract manufacturing and postponement for computer products (Magretta, 1998).

2.4. Work-In-Process Inventory under Outsourcing

Postponement strategy strongly impacts on WIP inventory levels. Postponement strategy can immediately reduce FG levels in OEMs; in the meantime, more WIP inventories are accumulated at or pushed upstream to CMs. Literature has not explored how the interplay of WIP increase – FG reduction influences total inventory level. The combination of modularity and postponement strategies can lead to fewer generic components and more product variations (Ernst and Kamrad, 2000). The utilization of these two strategies gives manufacturers the flexibility to assemble interchangeable parts on multiple standard platforms, creating higher degree of customization while minimizing inventory level.

By concentrating on the development of standardized modules and master platforms, partnering OEMs and CMs maintain minimum level of FG inventories, stock WIP inventories, and postpone final assembly for customization. Dell Computer develops generic production platform and modules that can postpone the manufacturing process for unique computer specifics until customized orders are received (Fine, 2000). This operation is facilitated by the outsourcing networks with supply chain partners. Dell leverages postponement for customization, and the overall inventory levels for Dell have been lower than those of other vertically integrated firms (Magretta, 1998).

2.5. Raw Materials Inventory under Outsourcing

Contract manufacturing causes changes in the scope of operation processes, the stocking of RM, and managing inbound logistics (Svensson, 2001). As OEMs outsource materials management to CMs and concentrate on parts of manufacturing, or solely on R&D and marketing, more RM inventories are allocated to CMs and/or upstream suppliers (Hsuan, 1999). In the electronics industry, Jubil Circuits, for instance, performs upstream supply chain processes, such as materials purchasing and inbound warehousing on behalf of their OEM customers. In Shanghai, Quanta Computer takes the full responsibilities of inbound supply chain activities for U.S. PC OEMs to perform manufacturing and value-added supply chain processes (Dean and Tam, 2005).

2.6. Consolidation as the Driving Force to Reduce Inventory under Outsourcing

One crucial feature affecting inventory management in the OEM-CM network is the increasing consolidation among large CMs in manufacturing industries. Lead CMs have increased their market shares because of their cost advantages and growing OEM demands (Langlois and Robertson, 1995). This consolidation trend leads to scale economies in production, procurement, and transportation. Examples of scale economies can be found in electronics and semiconductor industries (Sturgeon, 2002).

Inventory management can also display significant scale economies through consolidation as well. Supply chain researchers have established a Square Root Law (SRL) to examine the impacts of operational consolidation on inventory levels (Maister, 1976). SRL suggests that the fraction of the total inventory after consolidation to the entire inventories carried by the initial decentralized system is equal to the reciprocal of the square root of the initial number of storage locations (Evers, 1995; Zinn, Levy, and Bowersox, 1989). The inventory reduction effects by SRL are described as the statistical economies of scale (Evers and Beier, 1998).

As the current contract manufacturing sectors display higher concentration and scale economies in the upstream supply chain, a more consolidated sector may substantiate the SRL and thus reduce the level of industry-wide echelon FG inventories. In addition, OEMs strategically delay manufacturing FG products, stock fewer FG inventories, and allocate WIP to CMs (Salvador, Forza, and Rungtusanatham, 2002; Van Hoek, 2001). The consolidation among CMs may help the OEM-CM supply chain in preventing surging WIP inventory levels through the SRL effect. Moreover, the reduction of RM inventory levels in the supply chain is realized when a few large CMs manage RM on behalf of many OEMs (Cavinato, 1989; Mikkola and Skjøtt-Larsen, 2004). Excessive RM accumulation can be avoided, and RM inventory levels reduce because of the SRL effect as well.

SRL has not been applied to theorize the consolidation in the contract manufacturing industry. That said, mathematical proofs of the SRL effect on reducing inventory levels have been documented in literature (Evers, 1995; Evers and Beier, 1993; 1998; Zinn, Levy, and Bowersox, 1989) . Moreover, Ballou (1981) discovers empirical evidence for SRL – decreasing inventories resulting from consolidation. Hence, we propose that the consolidation among the contract manufacturing industries will display SRL effects and lower OEM-CM inventory levels. Therefore,

Hypothesis 1a: Other things being equal, the higher the level of contract manufacturing the focal industry utilizes, the lower the focal industry's: 1) Finished goods inventory level; 2) Work-in-process inventory level; and 3) Raw materials inventory level.

2.7. Bullwhip Effect as the Driving Force to Increase Inventory under Outsourcing

Supply chain management research has witnessed that upstream supply chain members may incur higher inventory level variations than downstream members due to the Bullwhip effect (Lee, Padmanabhan, and Whang, 1997a). The reason of this effect is that the operational complexities may be greater at upstream supply chain stages in terms of forecasting, demand fluctuation, lead time variations, warehousing efforts, and packaging. The increasing complexities and uncertainties also result in higher inventories (Hui, Davis-Blake, and Broschak, 2008).

Bullwhip effect has not been applied to assess the inventory efficiencies under the outsourcing context. As OEMs relinquish the management of supply chain processes to CMs, OEMs in the meantime transfer uncertainties upstream. CMs may be more isolated from actual demand in the marketplace when they perform FG, WIP, and RM management (Lee, Padmanabhan, and Whang, 1997b). For the entire OEM-CM supply chain, uncertainties can be amplified in matching production capacities, managing supply chain lead time, processing orders, etc.,. These uncertainties may lead to consequences such as the termination of manufacturing and logistics processes, poor customer services, and ultimately lost sales for the entire chain.

Given the fact that most manufacturing industries are still operating multiple-echelon distribution channels, upstream CMs need to absorb higher variations from downstream supply chain stages than OEMs (Jiang, Talluri, Yao, and Moon, 2010). Without proper coordination between OEMs and CMs, maintaining higher inventory levels are the typical logistics strategies to accommodate the higher level of uncertainties. Specifically, CMs may be less accurate in matching FG with actual market demand than OEMs. The FG and WIP inventories upstream might be higher because of the higher safety stock needed to buffer the aforementioned uncertainties consequences in supply chains. Conceivably, Bullwhip effect demonstrated in FG and WIP inventories can result in higher RW inventories (Cachon, Randall, and Schmidt, 2007).

Compared to the SRL prediction, the Bullwhip effect literature offers a contrasting view regarding the effects of contract manufacturing on inventory levels. As such, we propose the following alternative hypothesis:

Hypothesis 1b: Other things being equal, the higher the level of contract manufacturing the focal industry utilizes, the higher the focal industry's: 1) Finished goods inventory level; 2) Work-in-process inventory level; and 3) Raw materials inventory level.

2.8. Supply Chain Information Technology and Contracting Mechanisms

IT systems implemented within individual manufacturing firms and across the supply chain, together with contractual arrangements, can lead to better integration and reduce the costs of conducting supply chain transactions (Liang, Saraf, Hu, and Xue, 2007). The cost efficiency will translate into better operational performances (Bharadwaj, Bharadwaj, and Konsynski, 1999; Brynjolfsson and Hitt, 1996; Oh and Pinsonneault, 2007). Particularly, more integration between OEMs and CMs brought forth by IT systems implemented in the supply chain can lower uncertainties across the chain and thus reduce inventories in both parties (Levina and Su, 2008).

Intra-organizational IT can enhance manufacturers' value chain processes. First, IT improves firms' capabilities to develop the design rules of the engineering process and enhance customization (Sanchez and Mahoney, 1996). IT systems, such as Computer Aided Manufacturing (CAM), Computer Aided Design (CAD), etc., have been implemented by manufacturers to enhance the design of products (Hsuan, 1999; Liang, Saraf, Hu, and Xue, 2007). IT systems, combined with the prevalent modularity and postponement strategies, help firms to facilitate designs for components and platforms and, hence, WIP inventory management (Rai, Patnayakuni, and Seth, 2006). Furthermore, prevalent Enterprise Resource Planning (ERP) systems also enhance manufactures' capabilities to manage traditional logistics functions such as purchasing, transportation, order processing, distribution, customer management, etc. These enhancements can also harvest inventory efficiencies.

In addition, inter-organizational IT systems are necessary to integrate the supply chain (Jitpaiboon, Vonderembse, Ragu-Nathan, and Asree, 2010; Sia, Koh, and Tan, 2008). Inter-organizational IT, such as Internet and Electronic Data Interchange, can help OEMs and CMs jointly collect crucial information (Subramani, 2004). Accordingly, more precise information can be shared among OEMs and CMs to determine proper levels of postponement, which can translate into less uncertainties and lower WIP level (Fawcett, Osterhaus, Magnan, Brau, and McCarter, 2007). Manufacturing companies at upstream stages hence can match production outputs against real market demands, leading to reduction of excessive FG inventories (Zhou and Benton, 2007). As such, the need to accumulate FG inventories in CMs and OEMs separately is no longer required because of better coordination among CMs and OEMs (Angeles, 2009).

In particular, for CMs coordinating the entire supply chain processes on behalf of OEMs, integrative supply chain management can eliminate redundant inventories (Cachon and Olivares, 2010). As CMs gain more access to the actual demands of final markets, CMs can better align their production with real market conditions (Kearns and Lederer, 2003).

Accordingly, CMs can utilize the more precise information to minimize inventory inflation due to the Bullwhip effect (Dewan and Min, 1997).

Furthermore, inter-organizational IT initiatives among OEMs and CMs may facilitate Intra-organizational IT's functions. As an example, Internet may enhance supply chain partners to communicate respective firms' information relative to design and logistics processes generated by CAD and ERP (Frohlich, 2002). Once IT is implemented to enhance OEM-CM integration, supply chain members can more precisely determine the quantities of FG and WIP to be manufactured (Fawcett, Osterhaus, Magnan, Brau, and McCarter, 2007). Because variations in production and logistics processes can be better controlled or reduced, integrative inter- and intra-organizational IT systems can improve individual manufacturers' and the whole supply chain's efficiencies and value creation(Wang and Wei, 2007).

In sum, IT systems implemented in the CM-OEM supply chain can lead to efficiencies for inventory management. The following hypothesis concludes the discussion associated with IT as a significant variable moderating the relationship between contract manufacturing and inventories:

Hypothesis 2: Other things being equal, IT systems have negative and significant moderating effects on contract manufacturing levels' impacts regarding: 1) Finished goods inventory level; 2) Work-in-process inventory level; and 3) Raw materials inventory level.

III. DATA AND METHODS

3.1. Data

The unit of analysis of this paper is a manufacturing industry in a calendar year. The industry-level method has been implemented in the extant research streams in OM and management fields that examining industry-wide manufacturing issues (Brush and Karnani, 1996; Brynjolfsson, Malone, Gurbaxani, and Kambil, 1994; Rajagopalan and Malhotra, 2001; Schilling and Steensma, 2001). We utilize the 6-digit North American Industrial Classification System (NAICS) of the U.S. Bureau of Census to define a manufacturing industry (U.S. Bureau of Census, 2005). The Bureau of Census has used NAICS to conduct surveys relative to U.S. economies since 1997. There are 473 industries of the entire manufacturing sector in the NAICS.

We apply the methods documented in industry-level research to operationalize studied variables. The data sources used in the present research are consistent with the respective data sources in the literature. The data are collected from two archival data storehouses of the U.S. Department of Commerce. Data items to operationalize the IT investments are collected from the U.S. Bureau of Economic Analysis (BEA). Data items to operationalize inventory levels, contract manufacturing, and control variables are collected from the Economic Censuses of the Bureau of Census. In U.S., the Economic Census is performed by government every 5 years during years ending by 2 or 7. Economic Census data sets have been published in print and digital forms. Currently, the most disaggregate level of publicly available data is the 6-digit NAICS industry data. Details to measure the variables are discussed soon after.

We collect industry level data in 1997 and 2002 from Census Bureau's and BEA's data sets which contain complete data items necessary to operationalize variables for hypotheses testing. We first retrieve data from publicly accessible databases. Missing variables, ambiguous data values are then compared with printed publications of respective data series. Data items are organized and edited in spreadsheet format for analyses performed on the STATA statistical software.

3.2. Dependent Variables – Inventory Levels

We calculate the inventory levels for three inventory categories: FG, WIP, and RW.

We utilize formulas described by Rajagopalan and Malhotra (2001, p. 16) to measure three inventory levels: 1) FG inventory level is calculated as the ratio of FG inventory to the sum of materials costs and total value added of output for a manufacturing industry each year; 2) WIP inventory level is operationalized as the ratio of WIP inventory to the sum of materials costs and half of value added of output for a manufacturing industry each year; 3) RW inventory level is operationalized as the ratio of RW inventory to material costs in a 6-digit NAICS manufacturing industry in a year. By calculating inventory levels as ratios, the variables can be comparable across manufacturing industries. The data items are collected from 1997 and 2002 Economic Censuses by the U.S. Bureau of Census.

3.3. Independent Variables

Contract manufacturing. We employ Schilling and Steensma's (2001) method to measure the level of the contract manufacturing usage. In order to investigate how contract manufacturing are adopted across manufacturing industries over time, it is necessary to compare the extent to which each U.S. industry depends on contract manufacturers in each calendar year. This variable is calculated as the ratio of dollar value each industry spent on contract works to the dollar value of materials purchased in each year. The data items are collected from 1997 and 2002 Economic Censuses by the U.S. Bureau of Census.

IT investment. We utilize the methods developed by Brynjolfsson, Malone, Gurbaxani, and Kambil (1994) and Chun (2003) to measure the level of the use of IT system by a manufacturing industry. This research has used the aggregate value of Office, Computing and Accounting Machinery (OCAM) categories in the BEA's National Income and Product Accounts (NIPAs) database to measure industry level use of IT systems.

IT investment level is a composite measure (Brynjolfsson, Malone, Gurbaxani, and Kambil, 1994; Chun, 2003). Each year, BEA reports the NIPAs for each 3-digit NAICS industry. We first collect the dollar values of IT investments from the BEA and calculate sum of dollar value of the OCAM categories. Data items are collected from 1997 and 2002 NIPA databases of the U.S. BEA. We then collect the aggregate 3-digit NAICS industry sales dollar values from 1997 and 2002 Economic Censuses by the U.S.Bureau of Census.

The OCAM IT dollar values are divided by the industry sales at the 3-digit NAICS industry level to obtain comparable, overall IT investments ratios across industries in 1997 and 2002, respectively (Bharadwaj, Bharadwaj, and Konsynski, 1999; Dewan and Kraemer, 2000). Finally, the IT investments ratios at the 3-digit industry level are extrapolated to corresponding 6-digit NAICS industries to determine the approximate levels of use of IT systems at the 6-digit industry level.

3.4. Control Variables

The following discussion pertains to the measures of control variables included in our analysis.

Capital intensity. The rationale for including this control variable is that greater automation may grant capital intensive industries less need for inventories to buffer uncertainties. We use Brush and Karnani's (1996) method to measure this variable. Capital intensity is derived as the ratio of capital expenditure to the total number of employees in an industry each year. The data items are collected from 1997 and 2002 Economic Censuses by the U.S. Bureau of Census. In addition, we use the Implicit Price Deflators for Gross Domestic Product reported by BEA to convert the capital expenditure dollar values into real 1997 terms (Dewan and Min, 1997).

$$\text{Inventory Level} = \beta_0 + \beta_1 \text{Contract Manufacturing} + \beta_2 \text{IT} + \beta_3 \text{IT} * \text{CM} + \beta_4 \text{Capital Intensity} + \beta_5 \text{2002 Effect} + \text{error terms} \quad (1)$$

Effect of year 2002. This variable is to capture the lasting effects of September 11, 2001 (9/11) terrorist attack and the economic recession around 2002. Kim and Gu (2004) found that the 9/11 terrorist attacks resulted in significant financial risks for U.S. firms. Firms' perception of higher risks might result in higher inventory levels to absorb uncertainties in 2002. Conceivably, the recession effect might also cause less customer purchasing and consequently unsold inventories. We use one dummy variable for each observation of the year 2002 to capture the 9/11 effect.

3.5. Regression Models for Hypotheses Testing

In general, the model for regression runs for hypotheses testing is shown in (1). In (1) and the following tables, IT denotes the level of IT investments and CM denotes the level of contract manufacturing in a manufacturing industry. According to Hypothesis 1a, if SRL takes effect, β_1 shall be negative or significant. In contrast, if Bullwhip effect is prevalent, β_1 shall be positive and significant, as predicted in Hypothesis 1b. According to Hypothesis 2, β_3 shall be negative and significant.

IV. RESULTS

4.1. Hypotheses Testing Results

Our sample is a panel which includes cross-sectional and time series data. It is necessary to account for the heterogeneity and autocorrelation effects (Greene, 2003). We hence perform Generalized Least Squares (GLS) to account for the foregoing issues (Rajagopalan and Malhotra, 2001). Regression runs are executed on STATA to test the hypotheses. Table 1 shows the descriptive statistics and correlation coefficients of variables.

TABLE 1. DESCRIPTIVE STATISTICS AND CORRELATIONS.

	Mean	Std. Deviation	InvT Fin	InvT WIP	InvT mat	Contract Manufacturing	IT Ratio	Capital Intensity
InvT Fin	.052	.038	1					
InvT WIP	.042	.049	.097**	1				
InvT mat	.099	.063	.110**	.172**	1			
Contract Manufacturing	.034	.048	-.016	.214**	.038	1		
IT	.020	.018	-.059	.287**	.230**	.006	1	
Capital Intensity	.008	.009	-.083*	-.124**	-.110**	-.148**	.030	1
Year 2002	1	0	.041	-.045	.024	-.007	.261	-.029

** $p < 0.01$ (2-tailed); * $p < 0.05$ (2-tailed)

Tables 2 through 4 are the results of GLS regression analyses. Models 1-4 in the tables demonstrate consistent signs and significance levels for studied variables' coefficients, as variables are added incrementally into regressions. The full models include the interaction term between IT investment and contract manufacturing, which test the IT investment level's moderating effect on contract manufacturing and inventory levels (Schilling and Steensma, 2001).

In Table 2, the sign of the CM coefficients in model 3 is positive and significant, supporting Hypothesis 1b. We find support for Hypothesis 2. With reference to regression models 3 and 4, the coefficients of the IT-CM interaction term are negative and significant, as predicted by Hypothesis 2.

TABLE 2. RESULT OF GLS ANALYSIS OF CM ON FINISHED GOODS INVENTORY LEVELS.

	Model 1	Model 2	Model 3	Model 4
Constant	0.047*** (19.71)	0.047*** (19.49)	0.046*** (18.11)	0.047*** (17.43)
Contract Manufacturing	0.014 (0.51)	0.013 (0.50)	0.050+ (1.37)	0.046 (1.24)
IT Investment		–0.001 (– 0.01)	0.055 (0.79)	0.056 (0.80)
IT * CM			–1.895+ (– 1.47)	–1.876+ (–1.45)
Capital Intensity				–0.147+ (– 1.33)
Year 2002	0.003*** (3.55)	0.003** (3.03)	0.003** (3.08)	0.003** (2.90)
R^2 within	0.031	0.031	0.026	0.023
R^2 between	0.001	0.001	0.011	0.018
R^2 overall	0.001	0.001	0.008	0.014
Δ of R^2 overall			0.007	0.006
χ^2			2.16+	1.77+

+ p < .10; * p < .05; ** p < .01; *** p < .001; one-tailed test; z-statistic in the parentheses

TABLE 3. RESULT OF GLS ANALYSIS OF CM ON WORK-IN-PROCESS INVENTORY LEVELS.

	Model 1	Model 2	Model 3	Model 4
Constant	0.046*** (16.51)	0.045*** (16.24)	0.046*** (16.11)	0.047*** (15.53)
Contract Manufacturing	0.085** (2.86)	0.094** (3.14)	0.058+ (1.53)	0.063* (1.66)
IT Investment		0.091+ (1.56)	0.033 (0.46)	0.034 (0.48)
IT * CM			2.047+ (1.48)	2.009+ (1.45)
Capital Intensity				–0.122 (– 1.12)
Year 2002	–0.004*** (– 5.30)	–0.005*** (– 5.13)	–0.005*** (– 5.20)	–0.005*** (– 5.10)
R^2 within	0.054	0.039	0.036	0.034
R^2 between	0.049	0.095	0.097	0.103
R^2 overall	0.045	0.088	0.100	0.106
Δ of R^2 overall			0.012	0.006
χ^2			2.18+	1.25

+ p < .10; * p < .05; ** p < .01; *** p < .001; one-tailed test; z-statistic in the parentheses

TABLE 4. RESULT OF GLS ANALYSIS OF CM ON RAW MATERIALS INVENTORY LEVELS.

	Model 1	Model 2	Model 3	Model 4
Constant	0.095*** (22.66)	0.090*** (21.95)	0.086*** (20.05)	0.088*** (19.25)
Contract Manufacturing	0.019 (0.40)	0.032 (0.69)	0.172** (2.79)	0.167** (2.69)
IT Investment		0.830*** (8.43)	1.047*** (8.92)	1.047*** (8.93)
IT * CM			–7.347** (– 3.36)	–7.340** (3.36)
Capital Intensity				–0.252+ (– 1.36)
Year 2002	–0.003+ (1.60)	–0.005** (– 3.06)	–0.005** (– 2.95)	–0.005** (– 2.98)
R^2 within	0.004	0.112	0.123	0.120
R^2 between	0.004	0.040	0.051	0.059
R^2 overall	0.004	0.072	0.084	0.096
Δ of R^2 overall			0.012	0.012
χ^2			11.29***	1.86+

+ p < .10; * p < .05; ** p < .01; *** p < .001; one-tailed test; z-statistic in the parentheses (Explain the above Tables.)

According to Table 3, the signs of the CM coefficient in regression models for WIP are all positive and significant. These results support Hypothesis 1b. However, in regression models 3 and 4, the coefficients of the IT-CM interaction terms are positive and significant. These results are against Hypothesis 2.

In Table 4, the coefficients of CM in models 3 and 4 are positive and significant. The results support Hypothesis 1b. We find support for Hypothesis 2. With reference to regression models 3 and 4, the coefficients of the IT-CM interaction terms are negative and highly significant, as predicted by Hypothesis 2.

4.2. Complementary Statistical Analysis

The original dataset for hypothesis testing consists of two data points, i.e. the years of 1997 and 2002. The data collected are constrained due to the U.S. Bureau of Census' data publishing arrangements; therefore, the two discrete time points deviate from the typical panel data. In the current "clock-speed" competition, manufacturers may change strategies in a relatively long time interval (Fine, 2000). Researchers in supply chain management and strategic management found that changes in firms' strategic actions will lead to performance changes (Feitler, Corsi, and Grimm, 1998; Grimm, Corsi, and Smith, 1993; Smith and Grimm, 1987).

Accordingly, we examine whether any change in the 5-year time span relative to the level of contract manufacturing will result in change in inventory efficiencies. The additional regression runs below serve as complementary analysis to validate the data set and confirm prior hypotheses testing results.

A new set of data is calculated to measure changes in studied variables between 1997 and 2002. We perform OLS by regressing the changes of inventory levels on changes of other variables. The general model for regression runs of change variables is shown in (2).

$$\Delta \text{ Inventory Level} = \alpha_0 + \alpha_1 \Delta\text{Contract Manufacturing} + \alpha_2 \Delta\text{IT} + \alpha_3 \Delta\text{IT} * \Delta \text{ CM} + \alpha_4 \Delta \text{ Capital Intensity} + \text{error terms} \quad (2)$$

TABLE 5. DESCRIPTIVE STATISTICS AND CORRELATIONS.

	Mean	Standard Deviation	ΔInvT Fin	ΔInvT WIP	ΔInvT mat	ΔContract Manufacturing	ΔIT Ratio	ΔCapital Intensity
ΔInvT Fin	.003	.021	1					
ΔInvT WIP	-.005	.022	.116*	1				
ΔInvT mat	.003	.037	.124**	.050	1			
ΔContract Manufacturing	-.002	.020	-.089	-.025	.018	1		
ΔIT Ratio	.009	.012	-.038	-.097*	.269**	-.091	1	
ΔCapital Intensity	-.0004	.007	-.008	-.009	.009	-.012	-.005	1

** $p < 0.01$ (2-tailed); * $p < 0.05$ (2-tailed)

According to the previous hypothesis testing results, Bullwhip effect is prevalent. Therefore, in (2), α_1 shall be positive and significant. α_3 is expected to be negative and significant according to Hypothesis 2. Table 5 shows the descriptive statistics and correlation coefficients of change variables.

Table 6 shows that increasing level of CM will positively and significantly lead to increased FG inventory levels. In regressions models 3 and 4, the interaction of IT change and CM change is negative and significant. The results are consistent with previous findings relative to FG inventory levels.

TABLE 6. RESULT OF OLS ANALYSIS OF CM ON FINISHED GOODS INVENTORY LEVELS

	Model 1	Model 2	Model 3	Model 4
Constant	0.003*** (3.69)	0.002* (1.99)	0.002* (2.12)	0.002* (2.04)
ΔContract Manufacturing	0.085* (1.84)	0.092* (1.98)	0.163** (2.59)	0.161** (2.52)
ΔIT Investment		0.116+ (1.60)	0.079 (1.04)	0.080 (1.05)
ΔIT *Δ CM			–8.291* (– 1.67)	–8.227+ (– 1.64)
ΔCapital Intensity				–0.005 (– 0.04)
R^2	0.008	0.014	0.020	0.020
Δ of R^2			0.006	0.000
F			2.78*	0.00

+ $p < .10$; * $p < .05$; ** $p < .01$; *** $p < .001$; one-tailed test; t-statistic in the parentheses

TABLE 7. RESULT OF OLS ANALYSIS OF CM ON WORK-IN-PROCESS INVENTORY LEVELS

	Model 1		Model 2		Model 3		Model 4	
Constant	–0.004***	(– 5.53)	–0.003**	(– 3.05)	–0.003**	(– 2.96)	–0.003**	(– 2.82)
ΔContract Manufacturing	–0.021	(– 0.52)	–0.029	(– 0.73)	0.003	(0.06)	0.017	(0.30)
ΔIT Investment			–0.144*	(– 2.31)	–0.161**	(– 2.47)	–0.165**	(– 2.52)
ΔIT * ΔCM					–3.764	(– 0.88)	–4.203	(– 0.98)
ΔCapital Intensity							–0.016	(– 0.14)
R^2	0.001		0.013		0.015		0.015	
Δ of R^2					0.002		0.000	
F					0.77		0.02	

+ p < .10; * p < .05; ** p < .01; *** p < .001; one-tailed test; z-statistic in the parentheses

TABLE 8. RESULT OF OLS ANALYSIS OF CM ON RAW MATERIALS INVENTORY LEVELS

	Model 1		Model 2		Model 3		Model 4	
Constant	0.002+	(1.34)	–0.006**	(– 3.19)	–0.006***	(– 3.20)	–0.006**	(– 3.17)
ΔContract Manufacturing	0.031	(0.38)	0.080	(1.04)	0.063	(0.59)	0.061	(0.58)
ΔIT Investment			0.865***	(7.18)	0.874***	(6.93)	0.875***	(6.95)
ΔIT * ΔCM					2.068	(0.25)	2.016	(0.24)
ΔCapital Intensity							0.110	(0.50)
R^2	0.000		0.109		0.109		0.111	
Δ of R^2					0.000		0.002	
F					0.06		0.25	

+ p < .10; * p < .05; ** p < .01; *** p < .001; one-tailed test; t-statistic in the parentheses

With reference to Tables 7 and 8, coefficients of CM change and the interaction of IT change and CM change are not significant.

In brief, the complementary analyses indicate that an increased level of CM from 1997 to 2002 significantly increased FG inventory levels. The results are consistent with Hypothesis 1b. In Table 6, the interaction of IT change and CM change has negative and significant effect on FG inventory levels, further supporting Hypothesis 2 in terms of IT's moderating effect on FG inventory levels under contract manufacturing. The change of contract manufacturing between 1997 and 2002 did not significantly alter the WIP and RW inventory levels between 1997 and 2002.

V. DISCUSSION AND IMPLICATIONS

5.1. Managerial Implications on Integrating IT Systems and Contract Manufacturing Strategy

Conventional wisdom holds that by using contract manufacturing strategies, OEMs may easily reduce upstream inventory levels. The present research, however, indicates that contract manufacturing alone may otherwise cause echelon inventory levels to increase. Supporting mechanisms, therefore, needs to be implemented. Among the potential strategies, we identify that IT systems may ensure better coordination to achieve inventory efficiencies when they are combined with the contractual mechanisms.

Specifically, OEMs and CMs not only shall rely on contractual mechanisms but also need to institute inter-organizational IT systems to improve inventory efficiencies. For instance, OEM and CM managers can utilize technologies, such as Electronic Data Interchange, Bar Codes, Radio Frequency Identification, etc. These IT systems have been found to help supply chain partners coordinate inbound and outbound logistics processes in the value system.

Furthermore, OEM and CM managers may need to consider investing in intra-organizational IT systems to integrate procurement, design, production, and logistics processes. These IT systems may generate data that help supply chain members manage their respective value chains. As a result, lowered variations in lead time and market demand will translate into lower safety inventories which are used to buffer uncertainties among OEMs and CMs.

Ultimately, OEM and CM managers can integrate inter- and intra-organizational IT systems to share information on production & distribution plans and real demand. In doing so, upstream supply chain members, e.g. CMs, may be able to more accurately estimate inventory requirements to safeguard uncertainties from subsequent stages in the supply chain, e.g. OEMs or actual buyers. The supply chain as a whole can minimize uncertainties and accomplish efficiencies in inventory management (Lee, Clark, and Tam, 1999).

Our results on the IT-CM interaction also shed light on implementing IT in the outsourcing context. IT systems are used to enhance manufacturing productivity by increasing product outputs for scale economies (Brynjolfsson and Hitt, 1996). But the side-effect is the accumulation of speculation inventory (Rabinovich, Dresner, and Evers, 2003). Under a contract manufacturing arrangement, misalignments among IT implementation and organizations' strategic goals, together with the aforementioned Bullwhip effect, may result in higher inventory levels. Firms in the production network shall take into consideration the trade-off between scale economies and inventory levels.

In the semiconductor industry, the vendor-managed inventory (VMI) systems have been employed between semiconductor CMs with their OEM customers to facilitate the reduction of excess inventories (Fabless Semiconductor Association, 2003). In the computer industry, H-P utilizes real-time information systems to synchronize supply chain processes with its overseas CMs to manage its supply chain inventories (Dean and Tam, 2005). Furthermore, the well-known success story of Dell Computer's "virtual integration" offers a prominent demonstration of the successful incorporation of outsourcing and inter-organizational IT systems that keeps Dell's echelon inventories low (Magretta, 1998).

5.2. Managerial Implications on Managing Inventories under Outsourcing Strategy

The findings of the present research provide insights for cost-minimizing manufacturers who seek to outsource production processes to minimize supply chain costs. As OEMs contract out parts or the whole manufacture to CMs, inventory carrying costs resulted from the Bullwhip effects may offset cost savings in scale economies in production as well as the statistical scale economies in inventory consolidation as predicted by SRL. OEM and CM managers will need to factor in the trade-offs between efficiencies in production costs and increase in carrying more inventories. Otherwise, outsourcing strategies may ultimately lead to an increase in total supply chain costs.

Furthermore, in implementing the contract manufacturing strategy, managers also need to carefully evaluate the consequences relative to allocating FG and WIP inventories. In the presence of the Bullwhip effect, the postponement and customization strategies may be a two-edged sword. When OEMs attempt to increase product varieties for high level of customization, the increased varieties may in turn lead to the logistics and marketing complexities which can translate to higher FG and WIP inventory levels upstream. In the meantime, CMs may not be perfectly responsive to the needs of FG manufacturing and distribution. These uncertainties can prompt CMs to use higher WIP inventories as a cushion to minimize the negative impacts of potential FG and WIP stockouts (Lee and Hoyt, 2001; Plambeck and Taylor, 2005). Accordingly, OEM-CM network members need to trade off the advantages of product variety against FG and WIP inventory levels under a mass customization strategy.

The holding of excess inventories among the electronics OEMs and semiconductor CMs provides an example of the Bullwhip effect (Fabless Semiconductor Association, 2003). During the 2000-2004 period, the semiconductor industry has reported billions of dollars worth of excess semiconductor inventories in the supply chain. Electronics manufacturers utilized a broad variety of WIP modules for customized final assemblies. However, complex materials handling caused difficulties for CMs to precisely manage FG, WIP, and RW, causing total semiconductor inventory levels to increase.

5.3. Research Implications

A prevalent impression among researchers holds that contract manufacturing can directly result in OEM supply chains' efficiencies in operations and labor. Our regression analyses found otherwise that in a OEM-CM system, supply chain inventory may actually increase under outsourcing. This result sheds light on the seemingly straightforward outsourcing practice. According to literature, supply chain-wide inventory performances depend on a number of driving forces. In this paper, we identify the SRL and Bullwhip effect to be the forces causing inventory levels to go opposite directions. Bullwhip effect, per our empirical study, may be dominant in increasing inventory levels against the statistical economies of scale for inventory. A challenge for researchers is to probe whether there exist other driving forces to facilitate or prohibit OEM-CM perform inventory management under outsourcing.

The contractual relationship between OEMs and CMs is not a standalone strategy and needs other mechanisms' support to accomplish desired performance. It may require a complex coordination endeavor among OEMs and CMs to achieve inventory efficiencies in a contract manufacturing strategy context. In our model, the interplay between IT investment and contract manufacturing leads to efficiencies for inventory management. An additional challenge for researchers hereby is to identify critical strategies to be implemented simultaneously with outsourcing to achieve inventory performances.

Another counterintuitive finding pertains to the IT's moderating effect on outsourcing and performance. Interestingly, investing in IT under outsourcing could result in higher WIP inventories. IT may be implemented to carry out routine operations; yet, the implementation may not be synchronized with production or logistics systems (Rabinovich, Dresner, and Evers, 2003). This finding may challenge further research to identify the methods which facilitate IT implementation and help IT to be fully aligned with firms' strategic deployment, so that the coordination benefits from IT are substantiated.

5.4. Limitations and Future Research

There are several limitations with respect to our data sets. The first one pertains to the level of aggregation to measure IT. We utilize the 3-digit NAICS IT investment and extrapolate to 6-digit NAICS industries associated with the 3-digit set. Even though this measure is consistent with IT literature (Brynjolfsson, Malone, Gurbaxani, and Kambil, 1994; Chun, 2003), a more detailed, 6-digit NAICS IT may provide more in-depth information for our analysis. The latest Economic Census now contains a similar data item on 6-digit industry which discloses expenditures on computer hardwares. As such, the new data set may complement the objective data sets from BEA. Further research may need to identify whether these archival data sources are consistent. In turn, the new measures may give insights into industry's actions relative to IT implementation at a more disaggregate level.

In addition, this paper's primary research interest is to offer insights into the industry-level outsourcing and its impact on the overall industry inventories. More disaggregate research, e.g. at a firm-level, on the contract manufacturing can provide richer information on the outsourcing phenomenon. Supply chain initiatives such as Vendor-Managed-Inventory (VMI) and JIT may be implemented by OEMs and CMs together with outsourcing and inter-organizational IT systems so that the supply chain can enjoy higher inventory performance. Industry-level studies have constraints in providing sufficient details to address the above issues. Specifically, one direction for future research is to investigate the impact of using CMs on OEMs or the OEM-CM dyads inventory categories at the firm level or at the dyadic OEMs-CMs level.

In addition, researchers can extend this research stream by investigating additional performance aspects through the outsourcing strategies, such as financial performance, market growth, capacity utilization, etc. The performance metrics may need to be developed at various analytical levels, namely, a plant, a firm, an OEM-CM dyad, a supply chain, or an industry. In doing so, future research on contract manufacturing can greatly help researchers and managers to understand the contract manufacturing strategies' impacts beyond cost savings in production outsourcing.

Finally, further research questions may need to be addressed to theorize this emerging trend to globalize the supply chains. Specifically, what are the supply chain-level or industry-wide driving forces which enable or prevent OEMs and CMs from achieving operational and financial performances individually and jointly? What are the strategic actions OEMs and CMs can adopt jointly or individually to reinforce the contract manufacturing strategies? In implementing outsourcing strategies and complementary actions, what are the methods that can effectively integrate outsourcing and additional actions to enhance performances?

VI. CONCLUSION

As more OEMs outsource parts of or the whole manufacturing to CMs, OEMs' role can transform from manufacturing to reselling or even supply chain coordinating on behalf of the entire production networks. IT systems have been found to enhance supply chain efficiencies, but the effects of the use of IT systems on outsourcing are not fully studied. This paper studies the IT systems' moderating effects on outsourcing and inventory performances. The paper reviews literature on outsourcing, inventory management, and IT management to assess the contract manufacturing phenomenon and its influence in allocating industry level inventories. We apply the Square Root Law (SRL) and Bullwhip effect theories and develop alternative hypotheses relative to contract manufacturing strategy's direct impacts on inventory levels. Specifically, SRL effects will help outsourcing strategy to reduce inventory levels. In contrast, the Bullwhip effect will cause inventory levels to increase under outsourcing. Moreover, the use of IT systems is hypothesized to have significant moderating effects on outsourcing's inventory efficiencies.

The present research performs a cross-industry study of the effects of IT-contract manufacturing interaction on inventory performance. We collect archival, industry-level data in 1997 and 2002 from the U.S. Bureau of Census and Bureau of Economic Analysis. We use GLS regression technique to test hypotheses. The results first support hypotheses based on the Bullwhip effect theory that contract manufacturing may lead to higher FG, WIP, and RW inventories in the supply chain. In addition, our regression runs support the hypothesis that IT investment levels among OEMs and CMs have negative and significant moderating effects on the contract manufacturing-inventory performance relationship. This indicates that FG and RW inventory performances can be greatly facilitated by the integration of contractual mechanisms and IT systems in the supply chain.

This study gives insights into the burgeoning, oftentimes international, outsourcing phenomenon. Achieving operational performance under the outsourcing strategy may not be as straightforward as public opinion reflects. OEMs may attempt to reduce echelon inventories by outsourcing parts of or even entire supply chain activities to CMs. However, the contract manufacturing strategy alone may undermine inventory efficiencies in the CM-OEM supply chain and can potentially offset cost savings in production. A joint mechanism, namely IT systems and the contract manufacturing strategy, needs to be implemented among OEM and CM managers to achieve inventory efficiencies for the entire supply chain.

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