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Interdependence Among Inventory Types and Firm Performance

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ABSTRACT

Extant research on lean manufacturing has focused on the relationship between systemic inventory and performance. However, limited research, if any, has focused on dynamics between three main types of inventory – raw material, work-in-process, and finished goods – and firm performance. Drawing on the interdependence framework and a sample of 1,286 firms representing 41,067 firm-quarter observations from 2000 to 2013, when considering two types of inventory efficiencies jointly, higher efficiency in the subsequent inventory type must be accompanied by lower efficiency in the previous inventory type. In other words, lower raw material inventory efficiency and higher work-in-process inventory efficiency, or lower work-in-process inventory efficiency and higher finished goods inventory efficiency are associated with higher performance. High performance is also realized only when inventory efficiency is increasing across all three inventory types. The findings show that pursuing efficiency in one type of inventory requires lower efficiency in the previous inventory stage, and benefits of lean manufacturing could only be realized when all three inventory efficiencies are simultaneously high.

Keywords: *inventory efficiency, manufacturing firms, panel data models, interdependence*

1. INTRODUCTION

Operations management literature has two divergent views on inventory. One view is that inventory efficiency improves operational performance (Shin et al. 2015;Shah and Ward 2003). Excess inventories a form of waste and must be minimized (Babatunde and Arogundade 2011; Rawabdeh 2005). Supporting this view, a number of past studies have shown a positive correlation between inventory efficiency and financial performance (Chen et al. 2005; Fullerton and McWatters 2001; Fullerton et al. 2003; Gaur et al. 2005; Shah and Shin 2007).Related to a systemic notion of inventory efficiency, the just-in-time approach focuses on minimizing 'waste,' especially through improved flow of inventory at different stages in the manufacturing process. Increasing inventory efficiency improves financial performance Jone et al. 1999.

The opposing view proposes that inventory efficiency can impose significant costs to firms by making them more susceptible to risks such as supply chain disruptions Chopra and Sodhi 2004. Although inventory efficiency is central to lean operations, other studies have found no significant effect of lean inventories on financial performance (Balakrishnan et al. 1996; Cannon 2008). Gaur et al. (2005) and Rumyantsev and Netessine (2007) have shown that being responsive is more important than being efficient. Indirectly supporting lower returns from an inability to adapt to demand fluctuations, Steinker and Hoberg (2013) find that firms with higher within-year inventory volatility (i.e., matching inventory with demand, or responsiveness) had higher performance. In a related work, Modi and Mishra (2011) propose that inventory efficiency has decreasing returns, and significantly increasing inventory efficiency could "impose heavy costs on firms by making them brittle" (page 254).

In the current work, we focus on joint effects of individual inventory efficiencies on firm performance Capkun et al. (2009), and explore two research questions: (i) whether influence of efficiency in one inventory type on performances independent of efficiency of the other inventory type; and (ii) whether all three inventory efficiency types independently affect overall performance.

Related to the first research question, raw materials, WIP and finished goods inventories are interdependent in a manufacturing system. Although coordination among different inventory types is espoused to increase system performance, coordination failures occur more often than expected. In the context of variability in project management, Arashpour and Arashpour (2015) found that variability in work flow increases waste and rework. They state that such variability could increase "completion times, longer queues of uncompleted jobs, and excessive delays, resulting in productivity loss." Work in engineering management has focused on negative effects of variability on quality and inspection Arditi and Gunaydin (1999) and highlighted the need to lower variability in the environment to mitigate resulting decline in performance Rojas and Songer (1999).

The proposed model suggests that higher efficiency in inventory translates to increased performance when the previous inventory stage is less efficient, thus providing buffers necessary to manage variability in inventory in the current stage. Lower efficiency in the preceding stage is essential to maintain flow or lower variability in the next stage as it provides buffers to facilitate learning and make current inventory stocks flow smoother. This logic is in line with workflow-leveling strategies where the start rate of the first activity must be controlled for Walsh et al. 2007. Along similar lines, the preceding inventory type must provide buffers for the subsequent inventory type to improve. These insights from engineering management are pertinent to the proposed framework. Arashpour and Arashpour (2015) used manufacturing firm data to find empirical support that IT can be a driver for differentiation.

Similarly, we seek to find empirical support that manufacturing firms can rely on lower inventory efficiency in the preceding stage to facilitate efficiency in the next stage to improve their performance.

Related to the second research question, the systemic nature of inventory efficiency and interdependence among the stages of inventory is essential to realizing performance gains from inventory efficiency. Building a lean manufacturing system requires stage wise development of inventory efficiency, and the findings seem to suggest that possibly working backward – starting with finished goods inventory efficiency, while keeping lower efficiency in work in process inventory; then increasing work in process inventory efficiency while keeping lower focus on raw material efficiency – could be a potential approach to implementing lean manufacturing practices. The findings also suggest that focusing in improving inventory in 'pairs' (finished goods and work in process or work in process and raw material) may lead to performance decline.

2. CONCEPTUAL FRAMEWORK

Over the years, inventory has been considered a 'necessary evil,' and lean practices literature has increasingly called to minimize inventory throughout the system. A rival stream of literature has argued that low efficiency in inventory allows firms to manage demand variations. Efficient inventory management relies on highly structured, integrated, and coordinated systems, but renders operations less able to adapt to disruptions or demand variations. Drawing on differentiation-integration duality proposed by Lawrence and Lorsch (1967), an efficient system require stronger integration that lowers its ability to respond through differentiation.

Despite a greater focus on overall inventory dynamics Elrod et al. (2013) and prescriptions in the lean practices literature Eroglu and Hofger (2011a), there is limited, if any, empirical work focusing on how dynamics between or among the three types of inventory efficiency – raw material, work-in-process, and finished goods – must be managed. Understanding interrelationships among the three types of inventory is necessary to understand how firms can allocate operational resources and the efficacy of their efforts toward different inventory areas. **Figure 1** presents an overview of the different types of interdependence. Higher interdependence refers to greater intensity or degree of linkage.

Conditions for interdependence

- Fate control refers to the efficacy of activity B being contingent on how effectively activity A is conducted (assuming activity B is dependent on the output of activity A) (Lawrence and Lorsch, 1967)
- Behavior control refers to "requirements for joint action as dictated by the technological, environmental, organizational [sic] determinants of work flow specified by the division and assignment of labor" (Victor, and Blackburn, 1987 page 488).

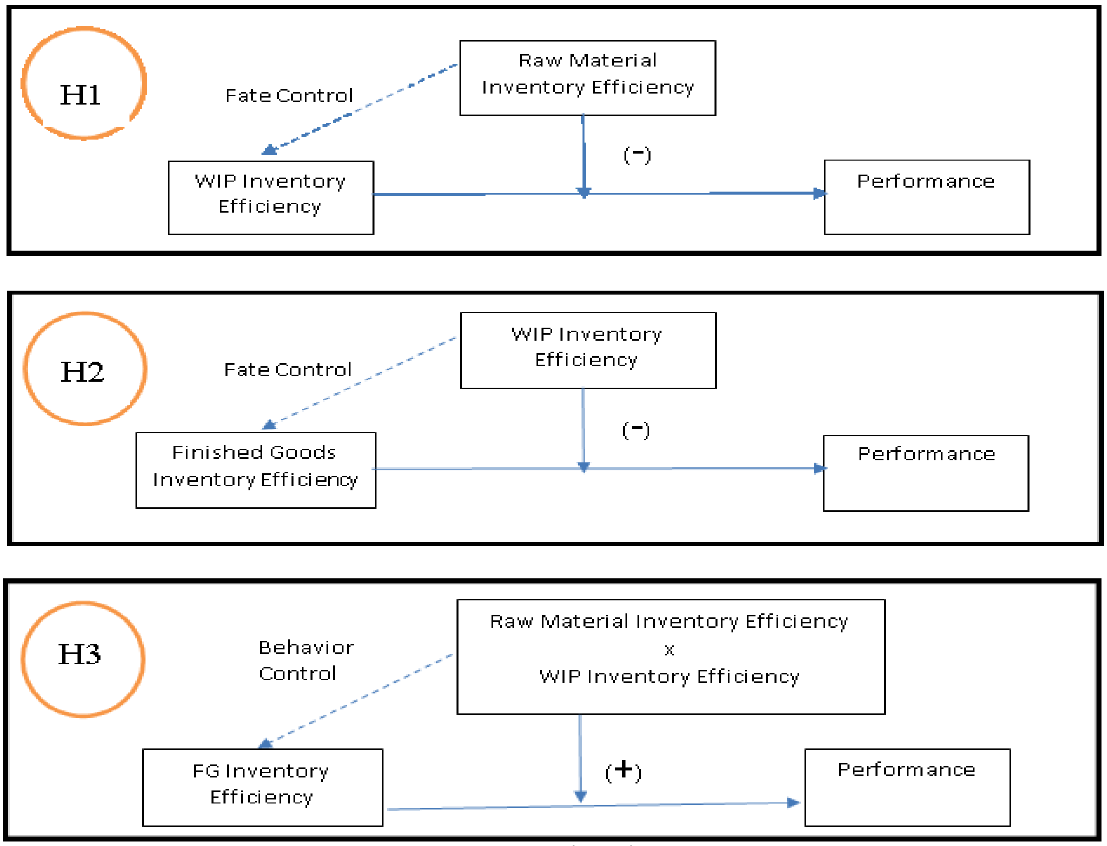

Figure 1 Interdependence Types

The implicit assumption in studies focusing on overall inventory management is pooled interdependence Thompson (1967), where management of individual inventory types aggregate into an overall increase in firm performance. Work focusing on the three types of inventory has not explicated the nature of interdependence Capkun et al. (2009), or has assessed interrelationships among the three but not how two or more types of inventory efficiencies jointly affect performance Eroglu and Hofger (2011b). We posit that the nature of interdependence among dyads of inventories – raw material inventory efficiency and work-in-process inventory efficiency, or work-in-process inventory efficiency and finished goods inventory efficiency – is based on fate control. The relationship among the three types of inventory efficiencies is based on behavior control.

2.1 Interdependence among inventory types

The interdependence framework in the context of inventory types is interpreted as follows. First, based on internal requirements of an activity (or, the first condition of interdependence), each type of inventory efficiency is conditional on internal actions within an activity. In other words, to improve raw material inventory efficiency, firms rely on forecasting systems, improving supplier relationships, managing procurement systems, and developing systems to store and distribute raw materials. Internal planning and scheduling systems, workforce human capital, and manufacturing process affect efficiency of work-in-process inventory. Finished goods inventory efficiency is improved by better forecasting, distribution, and customer relationships.

Second, the 'fate' control between two sequentially interdependent activities calls for coordination with other directly interdependent activities. Fate control refers to the efficacy of activity B being contingent on how effectively activity A is conducted (assuming activity B is dependent on the output of activity A) Victor and Blackburn (1987). Raw material (RM) inventory has fate control over work-in-process (WIP) inventory, and, in turn, WIP has fate control over finished goods (FG) inventory. For brevity, we refer to RM inventory as RM, WIP inventory as WIP, and FG inventory as FG. Raw material are the components or raw commodities brought into a firm. Once the manufacturing processes begin to add value to turn the raw material towards the final finished good form, it is considered WIP, The finished automobile would be the FG for a car company, while WIP would be the car not in its finished form as it goes down the line having pieces added (raw materials or their converted forms).

We posit that due to fate control in dyads of inventory efficiency, high RM and WIP efficiency (H1) will lower performance, and high WIP and FG efficiency (H2) also will lower performance. However, based on behavioral control, higher efficiency in the efficiencies of all three inventory types (RM, WIP, and FG) simultaneously increases overall performance (H3).

3. HYPOTHESES DEVELOPMENT

Continuing from earlier arguments on interdependence and fate control, the effect of WIP inventory efficiency on performance is conditional on the degree to which raw material stocks can meet varying demands of a WIP inventory system. WIP efficiency has a direct effect on performance as the level and variation in WIP efficiency not only increases direct and indirect manufacturing costs but it also indirectly affects sales. Excess WIP inventory increases inventory holding costs, lowers machine utilization, and overloads the operational resources. Higher WIP inventory efficiency results in lower costs, better quality, and a higher reliability in the delivery of finished goods.

RM efficiency could significantly increase fate control on the WIP efficiency-performance relationship. Raw material efficiency requires optimizing raw material yields, maintaining safety stocks, managing lead time, and improving material requirements planning. Yield factor refers to raw material inputs necessary to meet WIP output. Variations on production lead times and changes in product and process designs require more slack in raw materials management. As a response to realize greater returns from WIP efficiency, RM inventory has to be less efficient (more flexible), as operations must hedge against potential variations in demand from the production process.

Lower RM inventory efficiency enhances the effect of increasing WIP efficiency on performance. As lower RM inventory efficiency increases the slack of raw materials, greater variations in manufacturing systems are rapidly met through availability of additional raw material. Variations in yield ratios and use ratios are better absorbed when raw materials are available from safety stocks and with shorter lead times. Higher raw material efficiency could lead to lower availability of raw materials, hinder experimentation, lead to higher overall costs, and lower the efficacy of WIP inventory efficiency on firm performance. Overall, we propose:

Hypothesis 1: *Under increasing work-in-process inventory efficiency, higher levels of raw material inventory efficiency will be negatively associated with firm financial performance.*

Next, we hypothesize that under increasing finished goods inventory efficiency, higher levels of WIP efficiency leads to lower performance. Higher FG inventory efficiency implies that firm varies its FG inventory according to variations in external demand. As finished goods inventory has a higher per unit cost than that of WIP, greater FG efficiency leads to lower costs and higher performance.

WIP efficiency has fate control on the FG inventory efficiency and performance relationship. WIP inventory efficiency emphasizes efficient planning and utilization of manufacturing resources. Increased focus on WIP efficiency renders the firm weak in meeting variations in demand. Higher WIP efficiency means focusing on lower variety and greater efficiency (or, lower flexibility) in equipment and processes to control costs, maximize capacity utilization by controlling setup and switching costs, and relying on more structured and centralized planning processes to enhance efficiency.

When demand exceeds FG inventory holdings, there is a greater 'pull' for products from manufacturing. If WIP inventory is highly efficient, increased demand may not be met, as the WIP system cannot adapt quickly to higher demand, weakening the effect of FG efficiency on performance. Increasingly efficient planning of WIP management resources weakens the effect of FG efficiency on performance. Overall, we propose:

Hypothesis 2*: Under increasing finished good inventory efficiency, higher levels of work-in-process inventory efficiency will be negatively associated with firm financial performance.*

As discussed in H1 and H2, when inventory efficiency is considered in dyads, fate control from efficiency in the previous inventory type leads to lower performance. However, when considered as a triad, behavioral control among the three types of efficiencies could increase performance. Behavioral control refers to "requirements for joint action as dictated by the technological, environmental, organizational [sic] determinants of work flow specified by the division and assignment of labor" Victor and Blackburn (1987, page 488).

Drawing on behavioral control under interdependence, and extending lean practices literature, we posit that only when efficiencies for each inventory type are greater, higher performance is realized. This argument, although implicit in the lean practices literature, remains underdeveloped and untested at the inventory efficiency level. Although past work has focused on antecedents of RM, WIP, or FG inventory efficiency Lieberman et al. (1999), considered their effects separately on performance (Bernard and Noel 1991; Capkun et al. 2009), or studied the nature of change in three inventory types Chen et al. (2005), the joint effect among the three inventory types is not explored.

Based on behavioral control, when all three types of inventory efficiencies are present, operations activities orchestrate joint actions to realize higher gains from the three inventory efficiencies. Both RM and WIP inventory efficiency complement FG inventory efficiency. If RM and FG inventory efficiency is greater, but WIP efficiency is lower, then there will be significant holding costs and the firm would decreasingly be able to meet demand variations or increase product variety. FG inefficiency and high RM and WIP efficiency could lower overall operational cost, but could reduce the firm's ability to meet or absorb demand variations. Joint efficiencies also improve supply chain performance Koutsoukis et al. (2000). Overall, we posit that interdependence among the three types of inventory efficiencies leads to higher performance only when all three efficiencies are increasing.

Hypothesis 3*: With increasing finished good inventory efficiency, the positive association between higher levels of work-in-process inventory efficiency and firm financial performance is further strengthened at higher levels of raw material efficiency.*

4. RESEARCH METHODOLOGY

Based on past studies exploring the inventory-performance relationship (e.g., Eroglu and Hofger 2011a), all of our data was retrieved from Standard and Poor's COMPUSTAT North America database. COMPUSTAT North America is a database of financial information (from quarterly and annual Income Statements, Balance Sheets, Statement of Cash Flows, and supplemental data items) for U.S. and Canadian publicly held companies. To more efficaciously assess firm-level inventory dynamics, we rely on quarterly inventory information of all manufacturing firms (SIC 20 to 39) in the database from 2000 to 2013. For model stability in panel data settings, we include only the firms that had a minimum of 20 consecutive quarters of data. This approach is in line with prior research studying the inventory-performance relationship (Chen et al. 2005; Gaur et al. 2005;Kesavan and Mani 2013). We dropped firms with missing inventory data (raw materials, work-in-process, or finished goods). Based on the above criteria, the final sample consisted of 1,286 firms representing 41,067 firm-quarter observations from 2000 to 2013 (no manufacturing firms had 20 consecutive quarters of complete data prior to 2000).

The current sampling strategy is comparable to prior studies. Although the three components of inventory were analyzed by Capkun et al. Capkun et al. (2009) for manufacturing firm data from 1980 through 2005, their study included companies that had as few as two consecutive quarters of data. Including firms with at least 20 consecutive quarters allows us to draw more reliable inferences in panel data setting. Shorter windows (e.g., two consecutive quarters) confound firm and period fixed effects and unobserved firm effects related to operational strategy. Table 1 summarizes the key statistics by SIC code.

4.1 Variable Operationalization

A list of all the variables and their operationalization is in Table 2. Table 3 presents the descriptive statistics for the variables.

4.1.1 Dependent Measure: Firm Financial Performance

We use return on assets (ROA) as the outcome variable. Prior studies focusing on the inventory-performance relationship (Balakrishnan et al. 1996; Boyd et al. 2002;Fullerton et al. 2003) have also used ROA as an outcome variable.

4.1.2 Inventory Efficiency

In order to capture the inventory resource efficiency for each of the three inventory types, we extend operationalization on aggregate inventory efficiency in Modi and Mishra (2011). We draw on their operationalization to develop individual measures of raw materials, work-in-process, and finished goods inventory efficiency. Their "output-to-input" approach captures the efficiency with which firms manage their inventory to generate sales relative to their industry competitors. As defined in Modi and Mishra (2011), inventory efficiency is sales per inventory dollar adjusted for industry sales per inventory dollar (at the four-digit SIC):

$$IE_{it}^{RM} = \frac{\left(\frac{Sales_{it}}{Inventory_{it}^{RM}}\right) - \mu\left(\frac{Sales_t}{Inventory_t^{RM}}\right)}{\sigma\left(\frac{Sales_t}{Inventory_t^{RM}}\right)};\ IE_{it}^{WIP} = \frac{\left(\frac{Sales_{it}}{Inventory_{it}^{WIP}}\right) - \mu\left(\frac{Sales_t}{Inventory_t^{WIP}}\right)}{\sigma\left(\frac{Sales_t}{Inventory_t^{WIP}}\right)};$$

$$IE_{it}^{FG} = \frac{\left(\frac{Sales_{it}}{Inventory_{it}^{FG}}\right) - \mu\left(\frac{Sales_t}{Inventory_t^{FG}}\right)}{\sigma\left(\frac{Sales_t}{Inventory_t^{FG}}\right)} \qquad (1)$$

Where in equation (1), IE_{it}^{z}=inventory resource efficiency of firm *i* for quarter *t* for inventory of type z (*z*=RM, WIP, or FG), $Sales_{it}$=sales of firm *i* in quarter *t*, *and*$Inventory_{it}^{z}$=the reported quarterly inventory of type *z* for firm *i* in quarter *t*. The mean (μ) and standard deviation (σ) are based on all firms in the same four-digit SIC code during quarter *t*. To control for industry heterogeneity and adjust for a firm's inventory resource efficiency relative to its industry peers, the above approach normalizes each firm's sales to inventory ratio in a given quarter, with the mean and standard deviation for this ratio across all firms in the same four-digit SIC code for quarter *t*. A higher (lower) IE_{it}^{z} indicates greater efficiency (slack) relative to industry peers.

4.1.3 Control Variables

In addition to the three inventory efficiency measures, based on prior studies, we also controlled for a number of firm-level and industry-level controls. As older firms may benefits from having more experience in developing supply chain networks to meet customer demands Jayanthi et al. 2009, we control for *Firm age (FIRMAGE)*. Firms with a larger market share enjoy positional advantages relative to their competitors. *Market share (MKTSHARE)* is calculated as sales in a quarter divided by the total sales in the industry during the same quarter. If sales realized by a firm are higher than forecasted, sales surprise could increase or lower performance. *Sales surprise (SS)* measure is based on Gaur et al. (2005), $(Sales_{it} - Forecast_{it})/Sales_{it}$. Sales surprise is the percent of unexpected demand out of the total sales demand realized.

Because larger firms have higher growth prospects, have necessary resources to initiate competitive action, and are more likely to have a higher performance, we control for *firm size (FIRMSIZE)* proxied by total assets Hendricks and Singhal (2003).

Table 1 Descriptive Statistics

SIC	Industry Name	Number of Observations	Return on Assets	Industry Growth	Firm Age	Market Share	Sales Surprise	Firm Size	IE_RM	IE_WIP	IE_FG
Other Manufacturing Industries											
2000– 2092	Food and Kindred Products	2130	-0.0002	1.0269	31.9066	28.8873	0.9980	4.2002	0.0000	0.0000	0.0000
2111	Tobacco Products	140	0.0334	0.5122	29.4643	20.7886	1.0014	19.7790	0.0000	0.0000	0.0000
2200 – 2272	Textile Mills Products	395	-0.0031	0.7623	33.8532	47.5056	0.9989	1.3115	0.0000	0.0000	0.0000
2300 – 2330	Apparel and Other Finished Products Made from Fabrics	732	0.0103	0.9034	31.5096	13.3894	0.9979	1.2542	0.0010	0.0010	-0.0010
2400 – 2452	Lumber and Wood Products	456	-0.0053	0.3625	31.7566	34.7817	0.9986	0.7240	-0.0016	-0.0016	0.0016
2510 – 2540	Furniture and Fixtures	682	0.0061	0.8814	34.4971	30.5547	1.0004	2.5438	-0.0010	-0.0010	0.0010
2611– 2670	Paper and Allied Products	728	-0.0068	0.7241	31.2830	23.1627	0.9999	4.2131	0.0010	0.0010	-0.0010
2721 - 2790	Printing, Publishing and Allied Industries	610	0.0059	2.2043	33.1098	42.7826	0.9994	1.5126	0.0012	-0.0012	0.0012
2800 – 2891	Chemicals and Allied Products	7159	-0.0111	0.8250	32.1260	7.8506	0.9982	3.9111	-0.0001	0.0001	-0.0001
2911 – 2990	Petroleum Refining and Related Products	187	0.0105	1.5721	31.7273	31.9287	1.0022	1.7423	0.0038	0.0038	0.0038
3011 – 3089	Rubber and Miscellaneous Plastics Products	887	0.0024	1.4877	30.8072	29.4527	0.9986	1.7308	-0.0008	-0.0008	-0.0008
3140	Leather and Leather Products	91	0.0191	0.1878	30.9560	31.5066	0.9943	0.3477	0.0000	0.0000	0.0000
3220 – 3290	Stone, Clay, Glass and Concrete Products	458	0.0080	0.6523	31.6135	51.6297	1.0009	1.8035	0.0000	0.0000	0.0000
3310 – 3390	Primary Metal Industries	1512	0.0104	0.7588	32.4729	21.5898	1.0019	2.5155	0.0000	0.0000	0.0000
3411 – 3490	Fabricated Metal Products, Except Machinery and Transportation Equip.	1247	0.0138	3.0147	33.5870	31.8656	1.0009	1.4820	0.0000	0.0000	0.0000
3711 – 3790	Transportation Equipment	2360	-0.0030	1.4252	33.2343	17.0293	1.0016	5.3888	0.0000	0.0000	0.0006
High-tech Manufacturing Industries											
3510 – 3585	Industrial and Commercial Machinery and Computer Equipment	5599	0.0030	3.2320	33.6532	16.3091	1.0009	3.1222	0.0000	0.0000	0.0000
3600 – 3695	Electronic and Electrical Equipment and Components, Except Computer	8284	-0.0103	2.5078	33.1426	7.7472	1.0011	1.7684	0.0001	0.0001	-0.0001
3812 – 3873	Measuring, Analyzing and Controlling Instruments	7410	-0.0245	1.8159	33.5934	7.9572	1.0006	1.5650	-0.0001	-0.0001	-0.0001
2000 - 3873	All industries	41067	-0.0069	1.8090	32.9064	14.9634	1.0001	2.7278	0.0000	0.0000	0.0000

Table 2 Description of Variables

Variable	Description
Return on Assets (ROA)	Ratio of net income to total assets.
Industry Growth	Similar to Gruca and Rego (2005), the difference between the most recent four quarters of sales and the most distant four quarters of sales were used.
Firm Age	Quarters since founding.
Market Share	Firm's sales divided by the industry sales, with industry defined at the 4-digit SIC code.
Sales Surprise	Sales surprise is realized sales compared to forecasted sales, specifically, a forecast is made each quarter using the parameters in Gaur et al. Gaur et al. 2005, and sales surprise is (sales - forecast) / sales.
Firm Size	Total assets of the firm.
Inventory Resource Efficiency – Raw Materials (IE_RM), Work-in-process (IE_WIP), and Finished Goods (IE_FG)	Similar to Modi and Mishra (2011), this is the ratio of the firm's sales to average inventory (RM, WIP, or FG types), normalized by the industry mean and standard deviation, with industry defined at the 4-digit SIC code.

Source: All data sourced from COMPUSTAT

Table 3 Correlations and Descriptive Statistics

N = 41,067	Mean	StdDev	Return on Assets	Industry Growth	Firm Age	Market Share	Sales Surprise	Firm Size	IE_RM	IE_WIP	IE_FG	IE_RM x IE_WIP	IE_WIP x IE_FG	IE_RM x IE_FG	IE_RM x IE_WIP x IE_FG
Return on Assets	-0.0069	0.1457	1.0000												
Industry Growth	1.8090	2.5607	0.0148*	1.0000											
Firm Age	32.9064	5.0744	0.0660*	0.0329*	1.0000										
Market Share	14.9634	26.1313	0.0677*	-0.1177*	0.1322*	1.0000									
Sales Surprise	1.0001	0.0734	0.0279*	0.0124*	0.0114*	0.0005	1.0000								
Firm Size	2.7277	7.7005	0.0541*	-0.0394*	0.0667*	0.3745*	-0.0003	1.0000							
IE_RM	0.0000	0.9255	0.0726*	-0.0002	-0.0083	0.1167*	0.0347*	0.1323*	1.0000						
IE_WIP	0.0000	0.9256	0.0404*	-0.0001	-0.0234*	0.0298*	0.0165*	-0.0046	0.1372*	1.0000					
IE_FG	0.0000	0.9256	0.0354*	0.0001	-0.0297*	-0.0115*	0.0320*	-0.0314*	0.1458*	0.0690*	1.0000				
IE_RM x IE_WIP	0.1175	1.1487	-0.0050	0.0184*	-0.0211*	-0.0122*	-0.0030	-0.0238*	0.1849*	0.1564*	0.0464*	1.0000			
IE_WIP x IE_FG	0.0591	1.0855	-0.0070	-0.0265*	-0.0178*	-0.0015	-0.0014	-0.0133*	0.0491*	0.1216*	0.1139*	0.2804*	1.0000		
IE_RM x IE_FG	0.1249	1.1305	0.0050	-0.0068	-0.0167*	-0.0068	-0.0058	-0.0306*	0.1930*	0.0471*	0.1329*	0.2395*	0.2473*	1.0000	
IE_RM x IE_WIP x IE_FG	0.0493	2.5559	0.0104*	-0.0101*	-0.0128*	-0.0112*	0.0082	-0.0076	0.1377*	0.1507*	0.1314*	0.4803*	0.4505*	0.4492*	1.0000

4.2 Execution Process

We used a mixed model approach to evaluate our hypotheses. Mixed models allow us to control for shared errors among firms in an industry and between quarters. Our model is:

$$ROA_{ijt} = \pi_{0j} + \pi_{ijt} x_{ijt} + \beta_y c_{ijt} + \gamma_t + \theta_i + \varepsilon_{ijt} \qquad (2)$$

$$where, \pi_{0j} = \alpha_0 + \mu_{0j}$$

$$\pi_{xj} = \beta_x + \mu_{xj}$$

In equation (2), ROA_{ijt} is the dependent variable firm *i* in industry *j* for quarter *t*, x_{ijt} is the vector of time varying predictor variables of interest (i.e., inventory resource efficiency for raw materials, work-in-process, and finished goods), and c_{ijt} represents the observed time varying firm level and industry level control variables. π_{0j} is the intercept term capturing both overall fixed effects (α_0) and unobserved industry level random fixed effects (μ_{0j}). π_{xj} represents the effect of the inventory resource efficiency measures on the ROA metric after accounting for overall firm level fixed effects (β_x) and industry level unobserved random heterogeneity (μ_{xj}). γ_t represents the unobserved time specific fixed effects, θ_i are the unobserved firm specific fixed effects, and ε_{ijt} is the random error term.

Using this framework, we have the following estimation to test the proposed model:

$$ROA_{ijt} = \pi_{0j} + \pi_{IE_{ijt}^{RM}}\left(IE_{ijt}^{RM}\right) + \pi_{IE_{ijt}^{WIP}}\left(IE_{ijt}^{WIP}\right) + \pi_{IE_{ijt}^{FG}}\left(IE_{ijt}^{FG}\right) + \pi_{IE_{ijt}^{RM,WIP}}\left(IE_{ijt}^{RM}\right) \times \left(IE_{ijt}^{WIP}\right) + \pi_{IE_{ijt}^{RM,FG}}\left(IE_{ijt}^{RM}\right) \times \left(IE_{ijt}^{FG}\right) + \pi_{IE_{ijt}^{WIP,FG}}\left(IE_{ijt}^{WIP}\right) \times \left(IE_{ijt}^{FG}\right) + \pi_{IE_{ijt}^{RM,WIP,FG}}\left(IE_{ijt}^{RM}\right) \times \left(IE_{ijt}^{WIP}\right) \times \left(IE_{ijt}^{FG}\right) + \beta_{FIRMAGE} FIRMAGE_{ijt} + \beta_{MKTSHARE} MKTSHARE_{ijt} + \beta_{FIRMSIZE} FIRMSIZE_{ijt} + \beta_{SS} SS_{ijt} + \beta_{Earnings} Earnings_{ijt} + \gamma_t + \theta_i + \varepsilon_{ijt} \qquad (3)$$

Where in equation (3):

$$\pi_{0j} = \alpha_0 + \mu_{0j}$$

$$\pi_{IE_j^z} = \beta_{IE^z} + \mu_{INV_j^z}$$

for each of the three inventory types (*z*). The coefficient of the interaction terms related to $\pi_{IE_{ijt}^{RM,WIP}}$, $\pi_{IE_{ijt}^{RM,FG}}$, $\pi_{IE_{ijt}^{WIP,FG}}$, and $\pi_{IE_{ijt}^{RM,WIP,FG}}$ are the moderation effects.

Table 4 Inventory resource efficiency and return on assets

VARIABLES	Model 1 Null Model ROA	Model 2 Controls Model ROA	Model 3 Control + Direct ROA	Model 4 Moderator 1 ROA	Model 5 Moderator 2 ROA	Model 6 Moderator 3 ROA	Model 7 Full Model ROA	Model 8 Log-Linear Model ROA
INDGROWTH		0.00113***	0.00108***	0.00109***	0.00105***	0.00107***	0.00108***	0.00107***
		(0.000282)	(0.000281)	(0.000281)	(0.000281)	(0.000281)	(0.000281)	(0.000281)
FIRMAGE		0.00161***	0.00170***	0.00170***	0.00170***	0.00170***	0.00169***	0.00169***
		(0.000142)	(0.000142)	(0.000142)	(0.000142)	(0.000142)	(0.000142)	(0.000142)
MKTSHARE		0.000282***	0.000249***	0.000247***	0.000248***	0.000248***	0.000248***	0.000239***
		(2.99e-05)	(3.00e-05)	(3.00e-05)	(2.99e-05)	(3.00e-05)	(3.00e-05)	(3.00e-05)
SS		0.0536***	0.0470***	0.0466***	0.0468***	0.0468***	0.0461***	0.0452***
		(0.00975)	(0.00974)	(0.00974)	(0.00974)	(0.00974)	(0.00974)	(0.00973)
FIRMSIZE		0.000609***	0.000527***	0.000513***	0.000524***	0.000519***	0.000505***	0.000492***
		(0.000100)	(0.000101)	(0.000101)	(0.000101)	(0.000101)	(0.000101)	(0.000101)
IE_RM			0.00868***	0.00923***	0.00873***	0.00894***	0.00928***	
			(0.000796)	(0.000808)	(0.000796)	(0.000809)	(0.000818)	
IE_WIP			0.00484***	0.00526***	0.00510***	0.00486***	0.00525***	
			(0.000780)	(0.000787)	(0.000785)	(0.000780)	(0.000791)	
IE_FG			0.00435***	0.00439***	0.00459***	0.00450***	0.00449***	
			(0.000782)	(0.000782)	(0.000786)	(0.000786)	(0.000790)	
IE_RM × IE_WIP				-0.00256***			-0.00277***	-0.00253***
				(0.000639)			(0.000721)	(0.000718)
IE_WIP × IE_FG					-0.00201***		-0.00189**	-0.00183**
					(0.000666)		(0.000743)	(0.000742)
IE_RM × IE_FG						-0.00114*	-0.000970	-0.000783
						(0.000648)	(0.000719)	(0.000715)
IE_RM × IE_WIP × IE_FG							0.000866**	0.000860**
							(0.000368)	(0.000368)
ln(IE_RM)								0.0623***
								(0.00533)

Table 4 Inventory resource efficiency and return on assets (Con't)

ln(IE_WIP)								0.0376***
								(0.00539)
ln(IE_FG)								0.0338***
								(0.00529)
Constant	-0.00687***	-0.122***	-0.117***	-0.116***	-0.117***	-0.117***	-0.115***	-0.352***
	(0.000719)	(0.0108)	(0.0108)	(0.0108)	(0.0108)	(0.0108)	(0.0108)	(0.0180)
AIC	-41636.25	-42035.61	-42266.25	-42280.34	-42273.37	-42267.35	-42284.32	-42316.73
BIC	-41619.01	-41975.25	-42180.02	-42185.48	-42178.52	-42172.5	-42163.59	-42196.01
Log-likelihood	20820.127	21024.807	21143.127	21151.168	21147.686	21144.676	21156.158	21172.364
		409.36***	236.64***	16.08***	9.12***	3.10***	26.06***	
		Model 2 vs. Model 1	Model 3 vs. Model 2	Model 4 vs. Model 3	Model 5 vs. Model 3	Model 6 vs. Model 3	Model 7 vs. Model 3	

Notes:
1,286 firms representing 41,067 firm-quarter observations from 2000-2013
Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.10

Table 5 Effect size

Variable	Coefficient	Standard Error	p-value	95% confidence interval	Interpretation
IE_RM	0.0086831	0.0007962	0.000	0.0071226 , 0.0102437	An increase of 1 in the standardized (by industry) sales to raw material inventory is associated with an average increase in ROA of 0.86 percent
IE_WIP	0.0048389	0.0007799	0.000	0.0033103 , 0.0063676	An increase of 1 in the standardized (by industry) sales to work in process inventory is associated with an average increase in ROA of 0.48 percent
IE_FG	0.0043523	0.0007818	0.000	0.00282 , 0.0058846	An increase of 1 in the standardized (by industry) sales to finished goods inventory is associated with an average increase in ROA of 0.43 percent
IE_RM × IE_WIP	-0.0027697	0.0007213	0.000	-0.0041834 , -0.001356	An increase in both IE_RM and IE_WIP is associated with an average decrease of .27 percent ROA (H1)
IE_WIP × IE_FG	-0.0018881	0.0007432	0.011	-0.0033447 , -0.0004316	An increase in both IE_WIP and IE_FG is associated with an average decrease of .18 percent ROA (H2)
IE_RM × IE_WIP × IE_FG	0.0008662	0.0003683	0.019	0.0001444 , 0.001588	An increase in all of IE_RM, IE_WIP, and IE_FG is associated with an average increase of .08 percent ROA (H3)

Notes.
Control variables: Industry growth, firm age, market share, sales surprise and firm size

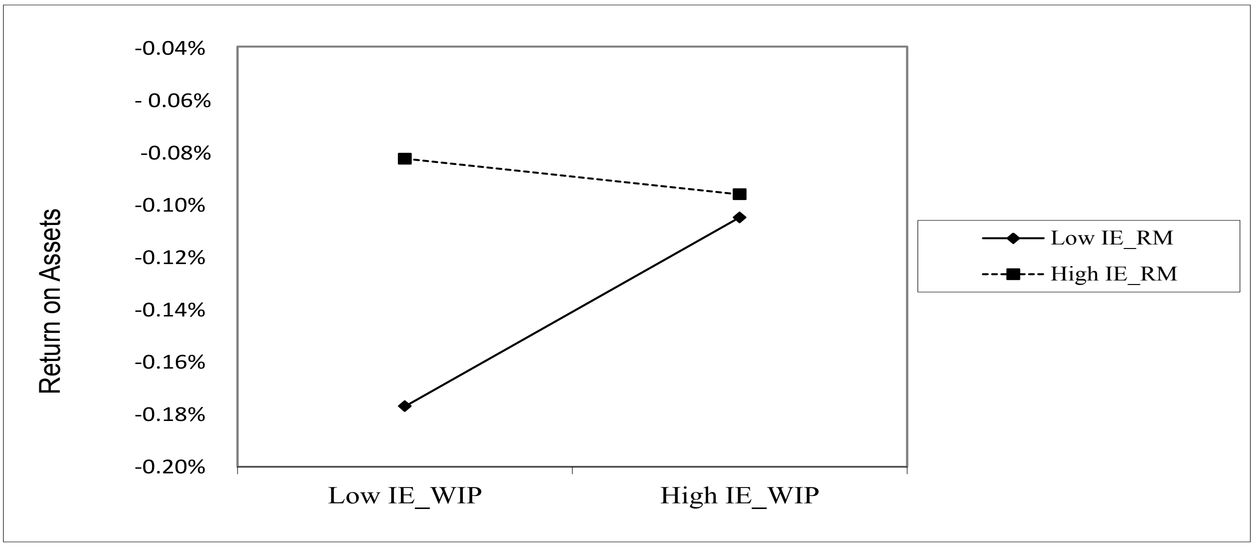

Figure 1(a) Moderation effect of raw material efficiency

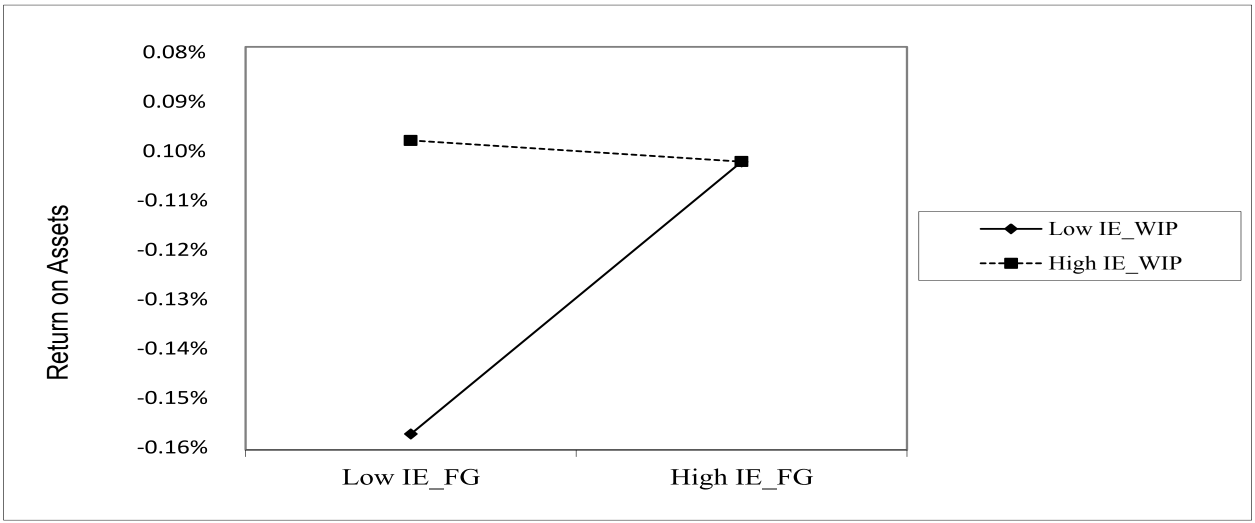

Figure 2(b) Moderation effect of WIP inventory efficiency

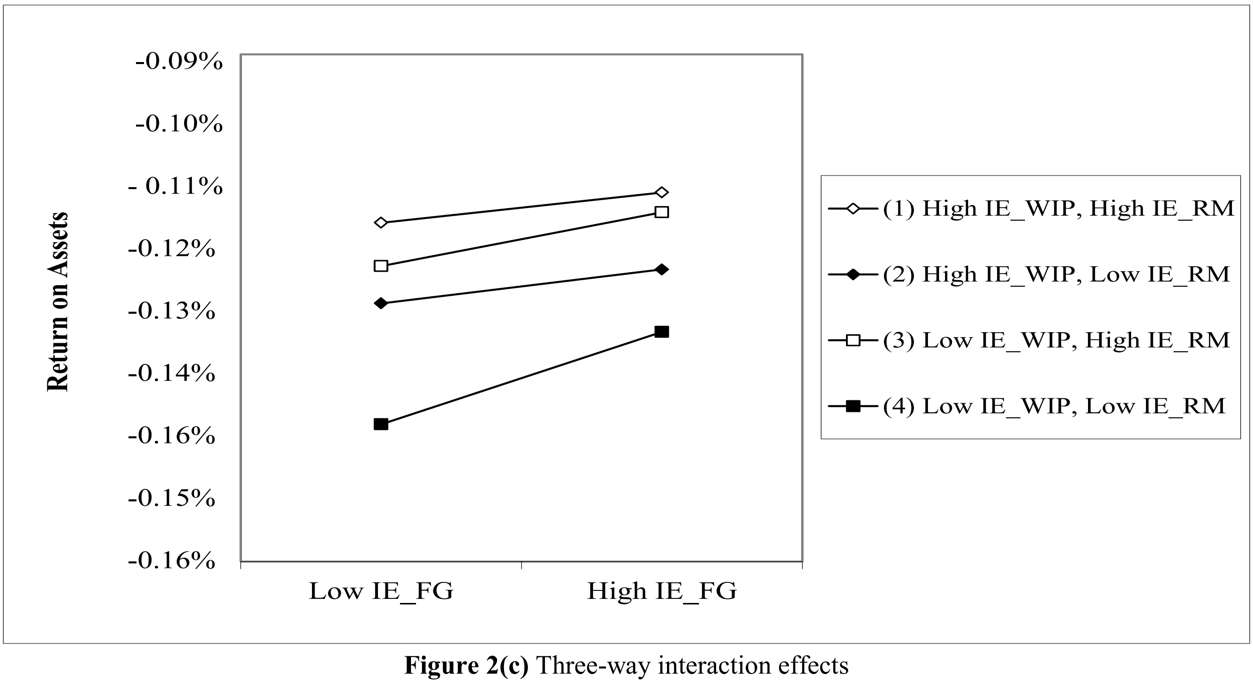

Figure 2(c) Three-way interaction effects

5. ANALYSIS AND RESULTS

Table 4 shows the results of the models that we examined. Model 1, the null model, contains only firm-specific and time-specific fixed effects. Model 2 includes control variables and firm-specific and time-specific fixed effects. Industry growth is positive related to ROA (Table 4, Model 2: β = 0.00113, p< 0.01). Older firms (Table 4, Model 2: β = 0.00161, p< 0.01) and larger firms (Table 4, Model 2: β = 0.000609, p< 0.01) have a higher ROA and those with higher market share have a higher ROA (Table 4, Model 2: β = 0.000282, p< 0.01). Firms with more sales surprises also had a higher ROA (Table 4, Model 2: β = 0.0536, p< 0.01). Model 3 includes the direct effects of the three inventory efficiency measures.

In line with prior research showing the positive benefits of lean total inventory on firm performance, our research demonstrates that inventory resource efficiency for any of the three inventory types is positively associated with performance. This supports the notion that excessive inventory is wasteful and total inventory should not be bloated.

Hypothesis 1 proposed that under increasing WIP efficiency, higher levels of raw material efficiency leads to lower performance (Table 4, Model 4: β = -0.00256, p< 0.01). Figure 2(a) shows that with increasing efficiency in work-in-process inventory, low raw material inventory increases performance. For Figure 2(a), the slope test shows that the effect of high raw material efficiency on performance was not significant (p = 0.311); however, the effect of low raw material inventory efficiency was positive and significant (p = 0.000). Hypothesis 2 proposed that under increasing FG inventory efficiency, higher levels of WIP inventory efficiency leads to lower performance (Table 4, Model 5: β = -0.00201, p< 0.01). Figure 2(b) supports the proposed hypothesis. The slope test shows that the effect of high WIP inventory efficiency on performance was negative and significant (p = 0.007); however, the effect of low WIP inventory efficiency was positive and significant (p = 0.000).

Although not hypothesized, but indirectly supporting the sequential interdependence framework among the three types of inventory, higher RM efficiency under increasing FG inventory efficiency had marginally significant effect on performance (Table 4, Model 6: β = -0.00114, p< 0.10). Compared to Eroglu and Hofer (2011b), who found that RM and FG inventory affect each other, the findings indicate a limited interaction in affecting firm performance.

Finally, a three-way interaction proposed in Hypothesis 3 also is supported (Table 4, Model 7: β = 0.000866, p<0.05). Figure 2(c) plotted at +/- 3 sd shows that highest performance is realized when under increasing finished goods inventory efficiency, both raw material and WIP inventory efficiencies are higher (line (1)). However, higher raw material inventory efficiency, but lower WIP inventory efficiency (line 3), leads to lower performance (p = 0.006). Additionally, higher WIP efficiency but low raw material efficiency, with increasing FG (line 2) results in higher performance than low WIP and low RM efficiency despite increasing FG efficiency (line 4) (p = 0.000) Overall, Hypotheses 1 and 2 are supported, and Hypothesis 3 is marginally supported.

Using natural log of inventory efficiency, the inferences in Model 8 are similar to the main inferences in Model 7.

The level of significance could be influenced by the large sample size. Therefore, based on recent work on this topic Lin et al. 2013, in Table 5, we present the effect size and 95% confidence interval for both direct effects and moderation effects. Specifically, one unit increase in RM, WIP, and FG inventory, ROA increases by 0.86, 0.48, and 0.43 percent, respectively. Representing a significant increase in ROA. Related to the hypotheses, for one unit increase in both RM and WIP (H1) and for one unit increase in WIP an FG (H2) ROA decreases by 0.27 and 0.18 percent respectively, representing a significant decline in ROA. Finally, for a joint increase in RM, WIP, and FG, ROA increases by 0.08 percent.

Despite higher sample size, the standard errors are significantly smaller indicating tighter spread of effect sizes. Additionally, we drew five random samples of 20% of the current sample and found similar effects.

5.1 Control for Firm Sales Pattern

Given the past sales data that would have been available to each firm at each point in time (quarter), and using commonly utilized exponential smoothing to forecast future sales, we created a new control variable, expected sales (EXPECTEDSALES). Using the linear exponential smoothing method proposed by Holt (2004), the sales forecast for firm i during quarter t is:

$$Sales\ Forecast_{it} = L_{i,t-1} + T_{i,t-1} \quad (4)$$

Where $L_{i,t-1}$ and $T_{i,t-1}$ are linear exponential smoothed series specified as:

$$L_{it} = \alpha S_{it} + (1-\alpha)(L_i + T_{i,\ t-1}) \quad (5)$$

$$T_{it} = \gamma(L_{it} - L_{i,t-1}) + (1-\gamma)T_{t,\ t-1} \quad (6)$$

Where $S_{it}$is the total sales for is firm i in quarter t; α and γ are weighting constants from zero to one. We used α=.05, γ=.05 as smoothing constants based on prior research showing that these minimized the Mean Absolute Percentage Error (MAPE) for similar, publically available, manufacturing firm data. The results of our analysis with EXPECTESALES as an additional control are shown in **Table 6**.

Table 6 Expected Sales Forecast as a Control

VARIABLES	Expected Sales Control ROA (MAPE)
INDGROWTH	0.00109***
	(0.000281)
FIRMAGE	0.00169***
	(0.000142)
MKTSHARE	0.000254***
	(3.04e-05)
SS	0.0461***
	(0.00974)
FIRMSIZE	0.000832***
	(0.000297)
EXPECTEDSALES	-1.87e-06
	(1.60e-06)
IE_RM	0.00929***
	(0.000818)
IE_WIP	0.00528***
	(0.000791)
IE_FG	0.00453***
	(0.000791)
IE_RM × IE_WIP	-0.00278***
	(0.000721)
IE_WIP × IE_FG	-0.00188**
	(0.000743)
IE_RM × IE_FG	-0.000954
	(0.000719)
IE_RM × IE_WIP × IE_FG	0.000859**
	(0.000368)
Constant	-0.115***
	(0.0108)
AIC	-42283.69
BIC	-42154.35
Log-likelihood	21156.84

Notes:

1,286 firms representing 41,067 firm-quarter observations from 2000-2013; Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.10

6. DISCUSSION

Inventory management practices undergird capabilities necessary for lean practices. While a significant body of work has focused on lean manufacturing practices, limited if any, work has focused on efficiency in types of inventory. On the other hand, without the lens of lean practices, inventory management would be relegated as a tactical activity aimed towards lowering costs. The key findings are as follows: (i) when WIP (FG) efficiency is increasing, low RM (FG) efficiency must be present to lower performance; (ii) systemic increase in RM, WIP, and FG efficiencies increase firm performance.

The notion of fate and behavior control from interdependence literature is a key contribution of the proposed framework, and the necessity of slack in the previous inventory type indicates that, when considering inventory efficiencies, presence of slack in the previous inventory type and efficiency of the inventory in the next stage are essential to improving performance.

These findings provide two key inferences. First, to realize piecemeal performance gains from a type of inventory efficiency, efficiency in the preceding inventory form should be lower --- e.g., focus on very efficient inventory in FG first, rather than trying to efficient in FG and WIP as while improving FG efficiency, any bumps, disruptions, or unexpected demands can be mitigated with the slack in the prior WIP stage. In Figure 2(a), to realize higher performance from higher WIP efficiency, RM efficiency must be lower. Similarly, Figure 2(b) shows that with increasing FG efficiency, lower WIP efficiency is necessary to improve performance. In other words, “slack” in the form of lower efficiency in the preceding stage (RM for WIP; WIP for FG) is important to realize higher performance gains in performance.

Second, efficient total inventory is important to realized financial performance gains.. The three-way interaction shows support for systemic nature of lean manufacturing, albeit with important caveats: (i) systemic efforts to improve efficiency in *all* inventory types is central to enhancing performance; and (ii) piecemeal efforts toward improving efficiency increases performance when the previous inventory type is not lean (less efficient). Firm financial performance is degraded by focusing on improving efficiency in next-stage inventory types simultaneously. Efficient total inventory (all three types) does associate with higher firm financial performance. However, having less efficient inventory (slack) in a stage followed by very efficiency (lean) inventory gives the best performance. Having some slack RM when WIP is very efficient, or slack WIP when FG is very efficient, allows overall inventory level efficiency but with an appropriately placed (RM or WIP) buffer against uncertainty and disruption. Although holding minimal inventory is increasingly the prescribed norm (Chen et al. 2005; Cooper and Maskell 2008; Eroglu and Hofger 2011a), these studies have focused on overall inventory in the system. We extend these works by assessing the relevance of two-way and three-way combinations of the three inventory types. Based on interdependence literature and mixed findings related to inventory efficiency, we focus on dynamics of the three types of inventory. The operational challenge faced by firms in these settings is: managing efficiency to lower costs, but also improving coordination among the three types of inventory to enhance performance. The tradeoff between the ability to meet demand variations by lowering efficiency for all three types of inventory efficiencies and the cost savings from increased efficiency call for the application of contingency theory Ketokivi (2006)to selectively focus on efficiency and slack between combinations of the three types of inventory.

A seminal work by Chen and colleagues Chen et al. (2005) shows that levels of all three inventory types have declined in recent years. Conversely, in recent years, there is increasing evidence of supply chain disruptions and natural disasters; therefore, lower inventories could increase disruptions. In an increasingly interconnected world, supply chain networks are increasingly fragile, and inventories could help firms absorb such shocks better Chopra and Sodhi (2004) and allow firms an upper hand over competitors who have relatively weaker inventory management capabilities. We find that inventory efficiency must be pursued for all types of inventory to realize higher performance, in case not all three types of inventory is efficient, the inventory in the previous stage should be more efficient.

Capkun et al. (2009) demonstrated a positive association between each of the three inventory types and financial performance. We draw on a fine grained sample based on more than 40,000 firm quarter observations spanning over a decade, we found support for past work that each of the three types of inventory directly improves firm performance. However, the three inventory types do not have pooled interdependence (as tested by independent effects), but rather have fate control interdependence (as tested by two-way moderation effects) or behavior control (as tested by three-way moderation effects). We propose the notion of interdependence related to behavior control among the three types of inventories. As the operations process follows the linear conversion process from raw materials to WIP to finished goods, inventory efficiency in the previous stage has a fate control over the subsequent inventory.

The framework also extends continuing work at the intersection of technology and engineering management. The tradeoff between implementation of ISO9000 certification and lean management has been assessed (Dreyfus et al., 2004). The findings in the current framework provide a more micro-dynamic view by highlighting the importance of managing interdependencies among three types of inventories. Moving from the systemic of leanness that subsumes all forms of inventory types, the current framework also shows that efficiency (leanness) in one type of inventory is less feasible if the inventory in the previous stage is highly efficient. The findings therefore explain the role of managing different types of inventory in implementation of operations management practices.

Elsewhere, the need to assess the level of synchronization with customer orders and managing internal capacity has been proposed Wikner et al. (2007). In the current findings, if a firm aims to meet customer demands and maintain high leanness in operations, then the focus must be on efficiency in finished goods inventory. Without buffers in previous inventory stages, leanness in finished goods inventory may not be feasible, unless the firm is able to realize higher inventory efficiency for each inventory type.

The proposed framework could be further extended in light of the need for process based cost modeling when working in a multi-product production setup as highlighted by Johnson and Kirchain (2010). While the current framework does not focus on challenges for three types of inventory management, it at least highlights cost tradeoffs between different inventory stages that could be taken into account when considering increasing costs of manufacturing different products.

6.1 Limitations and Directions for Future Research

The findings should be interpreted in light of their limitations. First, although relying on archival data of public firms allows future replication and ensures reliability in reporting of inventory data, our findings do not focus on micro-level inventory dynamics, as explored in industry level studies where such data are more readily observable. Second, the findings of the study are not generalizable to other non-manufacturing sectors, nor are they generalizable to smaller or younger manufacturing firms that are not publicly traded, or to non-U.S. publicly traded manufacturing firms. Future studies can draw on behavioral operations management to further assess decision making by operations managers.

Third, the results focus on the aggregate level of inventory dynamics, but the micro-level operational dynamics remain unexplored. We call on future research to collect process data and use qualitative methods, specifically temporal bracketing analysis approach Langley 1999, to understand how operations temporally manage inventory efficiency efforts. Inventory management decisions also are affected by complex behavioral factors. Future studies can draw on behavioral operations management to further assess decision making by operations managers.

Future research also could consider supply chain management issues in tandem with internal inventory efficiency efforts. It is plausible that supply chain partners could transmit, inculcate or imbibe inventory management practices into the firms. Complex, intra-firm and inter-firm interactions with supply chain participants could further add to our understanding of how firms could further increase inventory efficiency through supply chain collaboration. Raw material inventory efficiency could further be increased by suppliers, FG inventory efficiency by distributors and WIP inventory efficiency by the firm. Thus, future research could further explore contributions of external participants to different types of inventory efficiencies.

In closing, manufacturing firms today are aware of the significant financial burden of large inventories. Managers must not just focus on the efficiency of a specific inventory type, but also must understand the tradeoff in efficiency and slack between sequential inventory types. The results show that inventory efficiency for each type of inventory improved firm performance when there is slack in the previous inventory type, or when all three inventory types have higher efficiency.

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