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An Exploration of ‘Sticky’ Inventory Management in the Manufacturing Industry

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1. Introduction

Traditional models examining relationships between firm resources and revenues assume that the many expenses and asset holdings change in proportion to changes in demand (Noreen and Soderstrom 1994). For example, if revenues are reduced by fifty-percent, conventional wisdom holds that a cost or asset related to production should also be cut in half by management. However, an emerging body of behavioral accounting research has identified that some costs and assets that are assumed to vary proportionally with demand do not fit this paradigm. In actuality, research has found that for many costs and assets assumed to be proportionately variable, the magnitude of a change in a cost or asset in proportion to a change in revenue is smaller during periods when revenue decreases compared to the change in the cost or asset when revenue increases. Cost and assets which behave in this manner have been denoted as ‘sticky’ costs or assets (Anderson, Banker, and Janakiraman 2003; Guenther, Riehl, and Rößler 2014). In essence, as revenue increases by a certain amount, there is expected to be a corresponding proportional increase in a variable cost or asset. However, the concept of cost stickiness implies that when revenue decreases, the magnitude of the decrease in a variable cost or asset is less than it would be when revenue increases. Hence, cost or assets are sticky in that when revenues decline, the firm incurs an additional cost or retains a portion of an asset perhaps as a hedge for a future upswing in demand or as an artifact of manager inattention (Balakrishnan, Labro, and Soderstrom 2014; Guenther, Riehl, and Rößler 2014).

While the accounting literature has identified a number of sticky costs, to the best of this study’s authors’ knowledge, inventory levels within manufacturing firms have not been investigated previously to determine if they are managed in a sticky fashion. Interest in inventory stickiness is driven by prior research, particularly in the areas of lean and agile manufacturing, which advocate that excess inventory beyond the minimum needed to meet demand is a waste that should be eliminated and that firms should respond rapidly to changes in customer demand (Hines and Rich 1997; Vazques-Bustelo, Avella, and Fernandez 2007). Consequently, lean and agile philosophies advocate that manufacturers should directly adjust inventory levels proportionally and immediately in response to decreases in demand. In contrast, manufacturers with sticky inventory management policies will retain excess inventory holdings during periods when revenues decline.

Cost models which assume that particular inputs to production vary in direct proportion to firm activities fail to consider that changes in these inputs often require active managerial participation (Balakrishnan, Labro, and Soderstrom 2014; Guenther, Riehl, and Rößler 2014). In practice, the theorized relationship between inputs and activity levels does not hold true (i.e. inputs exhibit sticky behavior) when managers do not (or are unable to) decrease the level of a cost or asset immediately in response to decreases in demand (Anderson, Banker, and Janakiraman 2003). The literature has shown that advertising expenses, labor costs, employee levels, plant, property and equipment costs, research and development costs, and selling, general and administrative expenses all exhibit sticky behavior in a variety of industries and scenarios (Guenther, Riehl, and Rößler 2014). Conversely, as previously mentioned, prior literature has not specifically investigated if inventory levels exhibit sticky behavior when a firm’s revenue declines. Therefore, the first contribution of this study is to explore whether inventory is managed in a sticky fashion within the manufacturing industry.

Building on this, the second portion of this study investigates the impacts of inventory stickiness on manufacturing firm performance. Whether deliberate or inadvertent, inventory stickiness can be categorized as an outcome of a managerial response that sluggishly reduces inventory levels in reaction to decreases in demand. Supply chain research into agility, which considers a firm's ability to respond to market changes, and lean manufacturing, which examines a firm's ability to eliminate waste, explore a variety of potential causes and outcomes for inventory stickiness (Mason-Jones, Naylor and Towill 2000; Womack, Jones and Roos 1990). Whether stickiness is a product of a lack of agility or leanness (or a combination of the two), both agility and leanness have been linked to firm performance in prior studies (Fliedner and Vokurka 1997; Isaksson and Seifert 2014; Narasimhan, Swink and Kim 2006). Therefore, the second key contribution of this study is determining how inventory stickiness relates to firm performance.

The next section examines the relevant literature to build theoretical support for this study's examinations of inventory stickiness. The third section of the paper discusses the empirical methodology and the results are presented in the fourth section. The fifth and sixth sections respectively discuss the findings and conclusions of this effort.

2. Theoretical Development and Hypotheses

Guenther, Riehl, and Rößler (2014) describe decisions to manage costs in a sticky fashion as preventable happenings that are trade-offs between adjustment costs and holding costs. In the context of inventory, when firms' inventory levels are reduced in response to decreases in demand, adjustment costs (often in the form of inventory write-offs, scrap charges, or sell-offs at discounted prices) occur. However, a trade-off cost occurs if the firm acts in a sticky manner: By not proximately reducing inventory levels the firm will incur additional inventory holding costs. Though it is often assumed that managers will choose the approach which results in the lowest costs, additional factors may influence a manager to manage inventory in a sticky manner and accept additional holding costs.

2.1 Determinants of Inventory Stickiness

In manufacturing, a number of operational factors may steer managers to adopt sticky inventory policies. For example, sticky behavior is likely if the expected adjustment costs associated with an inventory reduction are substantially higher than the expected cost of retaining additional inventory. In this setting, managers will likely choose to keep a product as inventory, even when demand decreases, if the product's holding costs are low compared to its disposal costs. Similarly, managers may choose to retain inventory if they believe that a decline in revenue is only temporary and that demand will be increasing in the near future because the adjustment costs required to decrease inventory levels and then produce new goods outweigh the costs of holding excess inventory for a short period of time (Abel and Eberly 1994). Relatedly, when market demand is unstable, managers may retain additional inventory holdings as it has been shown to act as a protective buffer when demand is erratic (Kovach et al. 2015). These types of managerial decisions, often motivated by a preference to avoid risk, have been shown to lead to suboptimal inventory decisions that ultimately may contribute to the bullwhip effect (Hung and Ryo 2008).

A variety of behavioral factors may also induce inventory to be managed in a sticky manner. It has been suggested that managerial optimism about future growth may lead managers to refrain from reducing resources in a timely manner when demand decreases (Malik 2012). Additionally, cost stickiness has been found to be more prevalent in environments in which managers do not have substantial earnings targets or similar performance based incentives, the implication being that managers are more apt to rapidly reduce costs during periods of declining revenue when their incentives are tied to earnings targets (Kama and Weiss 2013). Another possible behavioral driver of sticky inventory management may simply be management inattention or indifference – during a period of declining revenues, a manager may be focused on other priorities and not have the ability to expend effort actively adjusting the firm's inventory levels. A lack of agility within a manufacturer may also drive inventory stickiness, i.e., firms with manufacturing systems that cannot quickly adapt to changing conditions may not be able to reduce inventory levels quickly even if the managers know that they should be shedding inventory (Swafford, Ghosh, and Murthy 2006).

Numerous studies have found when revenues decrease many of the costs required to support manufacturing operations are managed in a sticky manner. As discussed above, managers are motivated by a variety of reasons to act in this fashion. For a pure cost such as advertising expenses which has been found to be sticky (see, e.g., [Anderson and Lanen 2007]), reducing the expense in response to a revenue reduction might only require a managerial decision to simply reduce the firm's advertising effort. In contrast, because inventory is a physical asset, the decision to reduce it is more complicated. To reduce inventory levels, a firm cannot merely decide to spend less on inventory – to lower

inventory costs a firm likely needs to lower production levels while also disposing of excess goods or materials (often at discounted prices). The added complexity associated with inventory reductions mirrors the issues faced with reducing other costs that reflect tangible items, such as employee labor costs or plant, property, and equipment expenses, both of which have been found to be sticky when revenues decline (Anderson and Lanen 2007).

Due to the complexity associated with inventory reductions and the numerous factors motivating sticky inventory management, it is expected that manufacturing firms will typically manage inventory in a sticky manner. Specifically, the first hypothesis predicts that inventory stickiness exists for manufacturing firms:

Hypothesis 1 – When revenue declines, the magnitude of decreases in inventory levels (relative to sales) are smaller than the magnitude of inventory increases (relative to sales) in periods of growing revenues.

2.2 Implications of Inventory Stickiness

Although the existence of sticky costs has been widely explored, prior studies have not attempted to empirically connect stickiness with firm performance. To shed further light on the performance implications of inventory stickiness, this study leverages the bodies of literature examining lean production and agile manufacturing.

The elimination of excess inventory, which is considered a waste, is one of the principal tenets of lean management policies (Hines and Rich 1997). Excess inventory is wasteful as it generates additional holding costs, it necessitates the use of excess space for storage, it increases clutter which can increase lead times, and it also may conceal other issues in a manufacturing process (Womack, Jones and Roos 1990). Therefore, lean philosophy dictates that any excess inventory should be eliminated and only the minimum amount required for production should be retained. Lean inventory management has been empirically linked to improved business performance for manufacturers in a number of prior studies (Alan, Gao, and Gaur 2014; Capkun, Hameri, and Weiss 2009; Chen, Frank and Wu 2005; Koumanakos 2008).

In recent years, supply chain agility has become critical to the success of firms operating in today's competitive global environment (Lin, Chiu, and Chu 2006). A manufacturer's level of supply chain agility dictates its ability to quickly respond to the changing needs of its customers (Stratton and Warburton 2003; Swafford, Ghosh, and Murthy 2006). A responsive and agile firm can flexibly and rapidly produce the products demanded by customers (Holweg 2005; Sethi and Sethi 1990). This ability benefits a firm as it reduces the need to carry large stores of finished goods inventory as a buffer against demand uncertainty. Additional benefits of agility include improved customer satisfaction, shorter lead times, and faster times to market for new products. The benefits of agility have been shown to be crucial to manufacturing firms' success (Mason-Jones, Naylor and Towill 2000).

Firms that have implemented lean manufacturing policies produces goods with minimal waste and agile manufacturers efficiently respond to changing demand (Narasimhan, Swink and Kim 2006). However, lean and agile strategies do not necessarily represent divergent managerial policies – research has shown that firms' operations can be both lean and agile – an approach known as “leagile” management (Naylor, Naim, and Berry 1999). Leagile firms combine the positive aspects of both philosophies – they produce goods with a minimum of waste while also embedding capabilities that allow them to rapidly respond to fluctuating demand levels. In contrast, firms that manage inventory levels in a sticky fashion are not lean, as they are holding excess inventory, nor are they exhibiting agility as they are not responding rapidly to variations in demand. Therefore, since lean management and agility have both been found to be beneficial to firm performance, it is expected that a firm that manages inventory levels in a sticky manner will not enjoy these benefits.

Additionally, when firms hold excess inventory, cash invested in inventory is tied up and unavailable to be used to fund other business activities. Inventory reductions, such as those resultant from lean and agile management strategies, allow firms to reduce the duration of their cash flow cycles. Shorter cash flow cycles lead to improved firm liquidity, which has been linked to improvements in firm performance (Capkun, Hameri, and Weiss 2009; Chen, Frank and Wu 2005; Swamidass, 2007).

Considering these factors, this study proposes that inventory stickiness is negatively associated with firm performance such that a reduction in the level of stickiness will be associated with improved performance. The benefits of lower levels of inventory stickiness may impact firms both internally and externally. Internally, lower stickiness results in

less inventory, less waste and improved customer service, which should be reflected in improvements in internal performance. Externally, the benefits of lower stickiness should result in superior market performance for a firm's shareholders. Hence, it is hypothesized that:

Hypothesis 2a – Lower inventory stickiness is associated with improvements in a firm's internal performance.

Hypothesis 2b – Lower inventory stickiness is associated with improvements in a firm's external stock market performance.

In stable economic environments, the likelihood of sales diverting from an expected level is low, implying that lower inventory stickiness is preferred as noted in prior hypotheses. However, this relationship is less apparent during periods of high market instability. Some studies have found that high agility during turbulent economic periods leads to improved financial and market performance, which might imply that lower inventory stickiness that results from agile management principles is preferred when markets are unstable (Vazques-Bustelo, Avella, and Fernandez 2007). Yet, others have shown that excess inventory holdings can act as a buffer against demand uncertainty such that excess inventory strengthens firm performance, suggesting that higher levels of inventory stickiness may be favored when markets are turbulent (Kovach et al. 2015).

The realities of adopting agile strategies help to reconcile this apparent contradiction. Though manufacturers may desire to agilely match supply with demand, a policy that holds excess inventory during chaotic economic times may be more practical as supply chain agility is comparatively difficult to achieve in practice due to lead time and minimum economic batch size constraints which may make it infeasible to only produce goods in response to actual demand (Fisher 1997). Additionally, the holding costs of inventory are by definition less than the cost of goods sold and a potential near-term rebound in sales is possibly responded to more efficiently with inventory held over from a recent period of declining sales, rather than by discarding excess inventory immediately and then building new inventory to meet a future demand increase. Based on the relative ease of adopting a sticky inventory policy and the relatively low short term costs of holding inventory, excess inventory resulting from a sticky management policy may dampen the negative impact of higher inventory stickiness on performance during periods of high market instability. Thus, it is hypothesized that:

Hypothesis 3a – High market instability diminishes the negative impact of high inventory stickiness on improvements in a firm's internal performance.

Hypothesis 3b – High market instability diminishes the negative impact of high inventory stickiness on improvements in a firm's external stock market performance.

3. Research Methodology

3.1 Data Sample

This study utilizes firm financial data, acquired from the Standard and Poor's COMPUSTAT database, to empirically examine the relationship between inventory stickiness and firm performance for manufacturing firms. All of the measures included in the analysis are either directly retrieved or derived from the firm-level COMPUSTAT data. This approach follows practices established in the literature (Chen, Frank and Wu 2005; Modi and Mishra 2011) and uses a longitudinal dataset to investigate the relationships of interest over a 25 year time window (1991 through 2015) to ensure that any significant findings represent lasting relationships rather than short-term phenomena. Additionally, this methodology choice was motivated by Naim and Gosling's (2011) review of research inspired by Naylor, Naim, and Berry's (1999) seminal study of 'Leagility', in which they call for additional empirical, longitudinal studies of the matter.

The dataset includes publicly traded U.S. manufacturing firms (two-digit Standard Industry Classification [SIC] codes 20 to 39) operating between January 1, 1991 and December 31, 2015. The focus of the analysis is on manufacturers as they represent a broad sample of firms, well positioned in the middle of supply chains, capable of actively managing inventory levels in response to changes in firm revenues. As recommended by Hendricks and Singhal (2005), the top and bottom 1% of observations in each year of the study are winsorized to reduce the influence of outlier observations on the findings. This procedure yields a sample of 221,582 quarterly observations from 6,073 manufacturers.

3.2 Independent Variables

This study leverages and expands on prior investigations of stickiness and its impact on firms. Numerous investigations have explored and confirmed that stickiness exists across industries for a variety of costs and assets including Selling, General, and Administrative costs, Advertising expenses, Research and Development costs, Employee expenses, Inventory holdings, Costs of Goods Sold, and Plant, Property, and Equipment expenses (Bils and Klenow 2002; Guenther, Riehl, and Rößler 2014). However, in all of these prior studies, stickiness was examined across entire groups of firms rather than at the firm level. Specifically, as shown in Anderson, Banker, and Janakiraman (2003), the existence of stickiness has been measured across a cross-sectional sample of firms from a variety of industries but its impacts have not been investigated at the firm level.

In this study's initial analysis, the approach utilized in Anderson, Banker, and Janakiraman (2003) is replicated to examine if inventory stickiness exists within the sample of manufacturers. In their study, they utilize a regression model to predict changes in a cost (specifically Selling, General and Administrative expenses [SG&A]) in response to changes in revenue). Their model employs a binary interaction variable, *Decrease_Dummy*, which differentiates between quarters when revenue increases compared to the previous quarter (*Decrease_Dummy* = 0) and quarters when revenue decreases (*Decrease_Dummy* = 1). This paper adopts this same methodology, replacing the SG&A cost used in Anderson, Banker, and Janakiraman (2003) with the quarterly total inventory levels, to measure if inventory stickiness exists for manufacturers. We utilized total inventory levels as the component inventory levels (raw materials, work-in-process, and finished goods) were populated less than 30% of the time in the dataset. The regression model to test for inventory stickiness for firm *i* during quarter *t* is specified as:

$$\log \left[\frac{Inventory_{it}}{Inventory_{it-1}} \right] = \beta_0 + \beta_1 \log \left[\frac{Revenue_{it}}{Revenue_{it-1}} \right] + \beta_2 \times Decrease_Dummy_{it} \times \log \left[\frac{Revenue_{it}}{Revenue_{it-1}} \right] + \varepsilon_{it} \quad (1)$$

To interpret the results of this model, the coefficients β_1 and β_2 , are examined where β_1 measures the increase in inventory value in quarters when revenue increases and the sum of β_1 and β_2 measures the change in inventory value in quarters when revenue decreases. If stickiness exists, then it is expected that the inventory levels will respond less positively to changes in revenue during quarters in which revenue decreases. Hence, the empirical test for inventory stickiness is that $\beta_2 < 0$, contingent on $\beta_1 > 0$.

Building on this, this study then investigates the relationship between firm performance and the relative stickiness of firm inventory holdings in quarters of declining revenue. As described in Guenther, Riehl, and Rößler (2014), this study adopts the definition of 'stickiness' as a decline in a firm-level cost or asset during a period of decreasing revenue, that is relatively smaller in magnitude than the corresponding increase in the cost or asset during periods of improving revenue. To measure the relative 'stickiness' of firms, the Anderson, Banker, and Janakiraman (2003) model described above is transformed to create a firm-level measure of inventory stickiness. This firm level measure is calculated as the ratio of the current quarterly inventory level divided by the previous inventory level relative to the current revenue over the prior quarter's revenue (as this analysis focuses only on stickiness during quarters when revenue declines, this measure is only calculated for those quarters in which a firm's revenue is less than that in the previous quarter). Explicitly, inventory 'stickiness' for firm *i* in quarter *t* is measured as:

$$Inventory_Stickiness_{it} = \log \left[\frac{\frac{Inventory_Value_{it}}{Inventory_Value_{it-1}}}{\frac{Revenue_{it}}{Revenue_{it-1}}} \right] \quad (2)$$

For a firm, a quarterly value of 'inventory stickiness' greater than one represents an asymmetrically lower change in inventory relative to the decline in revenue, i.e. in that state, inventory is a 'sticky' cost. Essentially, inventory stickiness is the ratio of a firm's current versus prior inventory divided by the ratio of its current versus prior revenue. By comparing these two ratios, we are able to directly compare the stickiness levels across firms, compared to an approach that would require segmentation of the sample into portfolios. This firm-level measurement of stickiness

permits an investigation of the linkage between relative inventory stickiness and firm performance. Inventory stickiness was found to be non-linearly associated with performance across the sample, therefore the log of the ratio of inventory change to revenue change is used in the analysis.

To test the final hypothesis, the interaction between inventory stickiness and market instability is examined. Market instability, which measures the sales volatility within a two-digit SIC group of firms, is calculated quarterly for each group. Using quarterly sales data for the firms in a two-digit SIC group, the X-12-ARIMA Seasonal Adjustment Program is first employed to calculate the seasonally adjusted sales forecast for each group (Findley et al. 1998). Next, the quarterly instability is calculated as the standard error coefficient of the seasonally adjusted sales forecast divided by the mean sales within the two-digit SIC group (Keats and Hitt 1988; Wholey and Brittain 1989).

3.3 Firm Performance

To robustly assess the impact of inventory stickiness on a firm, two dependent measures of firm performance are tested: quarterly changes in return on assets serves as a measure of internal firm performance and changes in the unexplained stock responses measures external firm market performance. Both of these measures are dynamic measures of firm performance. While many past studies compare static firm performance metrics, a static approach only compares the relative levels of a measure between firms and it does not measure how the level of performance changes within the firm in relation to changes in a metric of interest. Since this analysis examines how inventory stickiness (which is a dynamic measure of inventory changes relative to revenue changes) relates to firm performance, the use of a dynamic approach that compares the change in performance was deemed more appropriate. This dynamic approach has been shown to be especially appropriate for longitudinal studies investigating relationships between managerial actions and performance changes (Hsiao 2007; Kroes and Manikas 2014; Nerlove 2005).

The first dependent measure, Return on Assets (*ROA*), is measured as a firm's quarterly net income divided by the firm's quarterly sales revenue. *ROA* was utilized as a measure of firm performance in a comparable study examining the relationship between inventory and performance in the retail industry (Shockley and Turner 2015). Since stickiness represents the changes in a firm's inventory holding practices in reaction to a decrease in the firm's sales revenue, *ROA* was a suitable internal measure of performance as it reflects a firm's ability to convert its assets into profits. *ROA* is calculated quarterly (*t*) at the firm level (*i*) as:

$$ROA_{it} = \frac{NIQ_{it}}{SALES_{it}} \quad (3)$$

To examine *ROA* from a dynamic perspective, the quarterly change in *ROA* is utilized as the dependent measure in the analyses:

$$\Delta ROA_{it} = ROA_{it} - ROA_{it-1} \quad (4)$$

The stock market's valuation of a firm gives a different view of firm performance from the internal *ROA* measure. Firms' quarterly Unexplained Stock Returns (*USR_{it}*) are used as the second dependent measure. The quarterly *USR* for a firm is the difference between a firm's actual stock quarterly return and the expected return predicted by the Fama-French three factor model. This approach has been used in prior studies (e.g. Alan, Gao, and Gaur 2014; Modi and Mishra 2011) to examine the external impacts of firm actions on performance, as shareholder valuation is a definitive measure of external firm performance. The *USR_{it}* is measured as the actual stock return for firm *i* in quarter *t* minus the return predicted using the Fama-French three factor model (which is calculated in an unbalanced panel regression model using that quarter's Fama-French factors (*SMB* [*Small minus Big*], *HML* [*High minus Low*], and *R_m* – *R_f* [*the excess return of the market*]) as predictors (French 2015).

To examine *USR_{it}* dynamically, the quarterly change in *USR_{it}* is evaluated as the second dependent measure in the analyses:

$$\Delta USR_{it} = USR_{it} - USR_{it-1} \quad (5)$$

3.4 Control Variables

Additional factors that may influence a firm's performance were identified through an examination of prior related studies. A firm's Total Assets, which has been positively connected to improved firm performance in existing studies, is used as a proxy for firm size (Brockman, Ma, and Ye 2015). In this analysis, the natural log of quarterly total assets is utilized, as the variable was observed to be non-linearly distributed within the sample. Leverage, which is measured as a firm's Long Term Debt divided by the firm's Total Assets, is included in the model as it has been negatively linked firm performance (Brockman, Ma, and Ye 2015). To control for possible industry concentration effects, we use the Herfindahl-Hirschman index (HHI) of market concentration by industry (SIC two-digit). A binary indicator variable is used to control for the potential effects of economic recessions on the analysis; the variable has a value of one during any quarter during which the U.S. economy was experiencing an economic recession and a value of zero otherwise. During the 1991 to 2015 timeframe of the sample, the U.S. economy experienced 3 distinct recessions impacting 12 calendar quarters.

In addition to inventory adjustments, firms attempting to improve their cash flow cycles may also manipulate their receivables and payables cycles (Ozbayraka and Akgun 2006). Additionally, a firm with a long receivables cycle may deliver goods (from inventory) during a quarter but have those sales reflected as revenue that quarter if payment is not received until a later quarter. Hence, firm-level measures of quarterly receivables and payables changes relative to revenue changes are included as controls in the model. These measures are calculated in the same fashion as the measure of inventory stickiness:

$$Receivables_Change_{it} = \log \left[\frac{\frac{Receivables_{it}}{Receivables_{it-1}}}{\frac{Revenue_{it}}{Revenue_{it-1}}} \right] \quad (6)$$

$$Payables_Change_{it} = \log \left[\frac{\frac{Payables_{it}}{Payables_{it-1}}}{\frac{Revenue_{it}}{Revenue_{it-1}}} \right] \quad (7)$$

3.5 Sample Firm Characteristics

Table 1 presents a summary of the data used in the study, segmented by two-digit SIC code. The data shows that for the levels of inventory stickiness are relatively consistent across the industries, ranging from a low of 1.16 for Paper and Allied Product Manufacturers to a high of 1.49 for Miscellaneous Manufacturers. Of the specific industries, the Fabric Apparel and Leather Products industries exhibit some of the highest levels of stickiness, which may be the result of a combination of factors including flexible raw materials that can be used for a variety of products and non-perishability of products. Similar to stickiness, the mean values of the two dependent variables are relatively consistent across industries. Though the differences between industries do not appear to be substantial, to adjust for industry differences when conducting our analyses, the variables of interest are centered and standardized within each two-digit SIC group, as recommended by Aiken, West, and Reno (1991).

Table 1 (a). Descriptive statistics by Two-Digit SIC Code.

2-digit SIC	Industry Title	# of Firms	# of Obs.	ROA	Δ ROA	USR	Δ USR	Total Inventory (\$MM)	Inventory Stickiness
				Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
20	Food and Kindred Products	333	12662	0.00 (0.15)	0.00 (0.06)	0.00 (0.22)	0.00 (1.36)	348.43 (977.33)	1.27 (0.56)
21	Tobacco Products	13	476	0.04 (0.06)	0.00 (0.07)	0.02 (0.20)	0.02 (1.25)	2126.31 (3404.39)	1.18 (0.32)
22	Textile Mill Products	71	2424	0.00 (0.06)	0.00 (0.06)	-0.02 (0.24)	0.00 (1.37)	147.18 (247.40)	1.22 (0.46)
23	Apparel, Finished Products from Fabrics and Similar Materials	137	4716	0.00 (0.07)	0.00 (0.07)	-0.01 (0.25)	-0.02 (1.37)	147.07 (217.23)	1.40 (0.65)
24	Lumber and Wood Products, except Furniture	82	3349	0.00 (0.05)	0.00 (0.05)	0.00 (0.22)	0.01 (1.38)	213.58 (672.41)	1.25 (0.46)
25	Furniture and Fixtures	73	3256	0.01 (0.04)	0.00 (0.04)	0.00 (0.21)	-0.01 (1.42)	139.52 (295.63)	1.17 (0.39)
26	Paper and Allied Products	135	5629	0.00 (0.04)	0.00 (0.04)	-0.01 (0.21)	0.00 (1.39)	339.16 (594.60)	1.16 (0.39)
27	Printing, Publishing and Allied Industries	156	5502	0.00 (0.06)	0.00 (0.07)	-0.01 (0.22)	-0.01 (1.40)	55.85 (99.59)	1.27 (0.55)
28	Chemicals and Allied Products	1026	32860	-0.04 (0.15)	0.00 (0.09)	0.00 (0.26)	-0.01 (1.40)	268.35 (937.49)	1.37 (0.70)
29	Petroleum Refining and Related Industries	96	3454	0.01 (0.07)	0.00 (0.04)	0.00 (0.20)	0.00 (1.39)	2541.16 (5690.01)	1.22 (0.49)
30	Rubber and Miscellaneous Plastic Products	152	5475	0.00 (0.07)	0.00 (0.06)	0.00 (0.25)	-0.01 (1.40)	144.73 (444.57)	1.22 (0.41)
31	Leather and Leather Products	31	1674	0.01 (0.05)	0.00 (0.05)	0.01 (0.24)	0.00 (1.38)	94.55 (128.00)	1.42 (0.63)
32	Stone, Clay, Glass, and Concrete Products	88	3218	0.00 (0.05)	0.00 (0.06)	0.00 (0.23)	0.00 (1.36)	133.36 (316.10)	1.31 (0.49)
33	Primary Metal Industries	209	7933	0.00 (0.08)	0.00 (0.06)	0.00 (0.24)	-0.01 (1.37)	439.88 (1526.28)	1.17 (0.35)
34	Fabricated Metal Products, except Machinery and Transportation Equipment	175	7163	0.00 (0.05)	0.00 (0.05)	0.00 (0.23)	-0.01 (1.39)	129.26 (253.87)	1.23 (0.43)
35	Industrial and Commercial Machinery and Computer Equipment	853	30362	-0.01 (0.10)	0.00 (0.07)	0.00 (0.26)	0.00 (1.39)	219.95 (926.28)	1.29 (0.55)
36	Electronic and other Electrical Equipment and Components, except Computer Equipment	1104	42344	-0.02 (0.11)	0.00 (0.08)	0.00 (0.27)	0.00 (1.40)	179.78 (742.30)	1.28 (0.53)
37	Transportation Equipment	291	11866	0.00 (0.10)	0.00 (0.06)	0.00 (0.23)	0.00 (1.40)	1048.15 (3571.09)	1.24 (0.44)
38	Measuring, Analyzing, and Controlling Instruments; Photographic, Medical, Optical Goods; Watches and Clocks	877	32130	-0.03 (0.12)	0.00 (0.08)	0.00 (0.26)	0.00 (1.41)	93.74 (380.58)	1.30 (0.55)
39	Miscellaneous Manufacturing Industries	171	5089	-0.01 (0.09)	0.00 (0.08)	-0.02 (0.26)	-0.01 (1.36)	74.29 (178.00)	1.49 (0.70)
	Total	6073	221582	-0.01 (0.11)	0.00 (0.07)	0.00 (0.25)	0.00 (1.39)	284.98 (1369.13)	1.29 (0.55)

Table 1 (b). Descriptive statistics by Two-Digit SIC Code.

2-digit SIC	Industry Title	Quarterly Revenue (\$MM)					
		Instability Mean (SD)	Mean (SD)	Total Assets (\$MM) Mean (SD)	Leverage Mean (SD)	Payables Mean (SD)	Receivables Mean (SD)
20	Food and Kindred Products	0.64 (0.09)	791.47 (1962.85)	3097.79 (8454.68)	0.57 (2.15)	289.76 (933.57)	310.96 (834.95)
21	Tobacco Products	0.36 (0.09)	3061.32 (4836.59)	16766.62 (25603.52)	0.92 (0.70)	520.95 (967.72)	961.20 (1813.18)
22	Textile Mill Products	0.16 (0.01)	185.23 (288.48)	656.45 (1126.80)	0.59 (0.31)	48.89 (83.70)	106.92 (152.36)
23	Apparel, Finished Products from Fabrics and Similar Materials	0.77 (0.01)	213.56 (348.93)	695.40 (1262.74)	0.51 (0.40)	54.73 (90.40)	114.40 (198.26)
24	Lumber and Wood Products, except Furniture	0.36 (0.05)	309.17 (785.41)	1556.98 (4568.07)	0.54 (0.39)	90.44 (196.14)	131.55 (307.36)
25	Furniture and Fixtures	0.12 (0.00)	426.98 (1204.18)	1174.89 (3276.76)	0.52 (0.31)	194.74 (688.47)	261.78 (790.60)
26	Paper and Allied Products	0.20 (0.05)	717.33 (1256.22)	3492.42 (6020.36)	0.61 (0.25)	328.20 (903.76)	451.06 (1080.01)
27	Printing, Publishing and Allied Industries	0.60 (0.00)	223.88 (369.32)	1017.88 (2084.70)	0.57 (0.30)	71.47 (155.98)	133.69 (243.97)
28	Chemicals and Allied Products	0.48 (0.11)	527.65 (1870.67)	2891.41 (11703.07)	0.60 (1.58)	191.72 (729.02)	350.47 (1259.55)
29	Petroleum Refining and Related Industries	0.43 (0.23)	10270.09 (20769.46)	37320.22 (75688.26)	0.57 (0.34)	4655.21 (10886.32)	4447.36 (10058.37)
30	Rubber and Miscellaneous Plastic Products	0.14 (0.01)	254.08 (743.70)	838.69 (2328.85)	0.57 (0.31)	87.07 (290.98)	156.28 (454.50)
31	Leather and Leather Products	0.30 (0.01)	139.50 (203.89)	389.88 (757.18)	0.40 (0.23)	36.74 (63.68)	61.43 (75.54)
32	Stone, Clay, Glass, and Concrete Products	0.85 (0.02)	275.54 (695.05)	1732.51 (6169.39)	0.54 (0.35)	117.56 (336.85)	163.26 (473.09)
33	Primary Metal Industries	0.50 (0.06)	645.88 (1897.72)	3035.68 (10024.17)	0.60 (0.49)	254.14 (924.14)	327.78 (903.28)
34	Fabricated Metal Products, except Machinery and Transportation Equipment	0.29 (0.03)	218.09 (468.44)	826.67 (1907.16)	0.55 (0.43)	81.07 (227.41)	141.81 (307.59)
35	Industrial and Commercial Machinery and Computer Equipment	0.28 (0.14)	424.19 (1853.56)	1807.19 (7987.02)	0.50 (0.52)	185.30 (935.80)	387.46 (1955.29)
36	Electronic and other Electrical Equipment and Components, except Computer Equipment	0.32 (0.16)	373.82 (1747.18)	1746.68 (8255.62)	0.47 (0.86)	182.19 (1064.17)	253.40 (1180.33)
37	Transportation Equipment	0.40 (0.19)	2253.05 (7572.22)	11314.96 (45002.11)	0.64 (0.97)	1035.66 (3570.70)	3089.86 (15103.37)
38	Measuring, Analyzing, and Controlling Instruments; Photographic, Medical, Optical Goods; Watches and Clocks	0.29 (0.20)	167.37 (692.85)	855.61 (3515.00)	0.44 (0.71)	55.87 (293.75)	121.62 (520.59)
39	Miscellaneous Manufacturing Industries	0.72 (0.01)	132.21 (390.02)	532.82 (1672.81)	0.53 (0.46)	45.20 (210.64)	92.51 (243.89)
	Total	0.39 (0.21)	647.58 (3678.34)	2895.39 (16607.22)	0.53 (0.99)	274.10 (1843.53)	473.33 (3946.23)

3.6 Model Specification

To investigate if inventory costs are sticky when revenue declines, in line with previous studies of the phenomenon, the regression model specified above in Equation 1 is utilized (Anderson, Banker, and Janakiraman 2003; Guenther, Riehl, and Rößler 2014). The use of log specified measures in the model that compute the changes in inventory relative to the changes in revenue facilitates the ready comparison of firms of varying sizes while also reducing the potential for heteroskedasticity. A Breusch-Pagan / Cook Weisberg test was conducted and heteroskedasticity was not found to be an issue within the sample.

Given the longitudinal nature of the dataset, for the second and third set of hypotheses, a panel study is conducted to analyze the long-term effects of sticky inventory management strategies on performance. All of the analyses were performed using STATA v.13.1 due to STATA's ability to analyze unbalanced panel datasets. The analysis consists of a control model, followed by a model testing the main effects of inventory stickiness, and a final model that tests the interaction between stickiness and instability. Each of these three models will be evaluated twice, respectively for the two dependent measures of firm performance (ΔROA and ΔUSR). The general form of the main effects panel model, where i represents the firm index and t represents the data year, is expressed as:

$$\begin{aligned} \Delta Firm_Performance_{it} = & \beta_0 + \beta_1 Inventory_Stickiness_{it} + \beta_2 Market_Instability_{it} \\ & + \beta_3 Leverage_{it} + \beta_4 Receivables_Change_{it} + \beta_5 Payables_Change_{it} \\ & + \beta_6 Recession_{it} + \beta_7 Firmsize_{it} + \varepsilon_{it} \end{aligned} \quad (8)$$

The interaction model is expressed as:

$$\begin{aligned} \Delta Firm_Performance_{it} = & \beta_0 + \beta_1 Inventory_Stickiness_{it} + \beta_2 Market_Instability_{it} \\ & + \beta_3 (Inventory_Stickiness_{it} \times Market_Instability_{it}) + \beta_4 Leverage_{it} \\ & + \beta_5 Receivables_Change_{it} + \beta_6 Payables_Change_{it} + \beta_7 Recession_{it} \\ & + \beta_8 Firmsize_{it} + \varepsilon_{it} \end{aligned} \quad (9)$$

To determine the appropriateness of a fixed effects versus a random effects approach in the analyses, Hausman tests were performed on each model (Greene 2008). The Hausman test was rejected ($p < 0.001$) for all specifications which indicates that fixed-effects are present in all six models; therefore, a fixed-effects methodology was adopted for the analyses.

4. Results

The results of the test for the existence of inventory stickiness within the sample are reported in Table 2. The analysis shows that in quarters when revenue increases, inventory also increases (i.e. $\beta_1 > 0$, $p < 0.05$), but in quarters in which revenue decreases, inventory levels do not decrease at the same rate ($\beta_2 < 0$, $p < 0.01$). These results indicate that inventory levels are sticky for manufacturers, supporting Hypothesis 1. Further, an examination of results shows that the sum of the coefficients ($\beta_1 + \beta_2$) is negative (i.e. $\beta_2 > \beta_1$) indicating that changes in inventory levels are negatively related to changes in revenue during periods of declining revenue. Therefore, for the average firm, inventory levels in periods of declining revenue do not merely decrease at a rate lagging behind the level of revenue change, but in fact the inventory levels increase during these periods.

Table 2. Test for existence of Inventory Stickiness – dependent variable: $\log[Inventory_{i,t}/Inventory_{i,t-1}]$.

	Test for Inventory Stickiness
$\log(Revenue_{i,t}/Revenue_{i,t-1})$ [H1]	0.00584** (0.0024)
$Decrease_Dummy_{i,t} * \log(Revenue_{i,t}/Revenue_{i,t-1})$ [H1]	-0.0204*** (0.0036)
Intercept	0.0141*** (0.0005)
Observations	221,582
Adjusted R^2	0.0002
F test:	23.39***

Standard errors in parentheses
 *** p<0.01, ** p<0.05, * p<0.10

The results of the investigation of the relationship between inventory stickiness and ΔROA and ΔUSR are presented in Tables 3 and 4, respectively. The sample sizes in these two investigations are reduced compared to the first analysis as these models only examine quarters during which firms' revenues decrease. The sample sizes used in the ΔROA and ΔUSR models vary slightly (90,918 versus 84,850 observations) due to the incomplete reporting of data by some firms in the sample. The estimates for control models (Column 1 in Tables 3 and 4) show that two of the control variables are significantly related to both performance measures and the remaining three are significantly associated with ΔROA .

Table 3. Inventory Stickiness and Firm Performance in quarters with declining revenue – dependent variable: ΔROA_{it} .

	Control Variables	Inventory Stickiness	Inventory Stickiness and Instability Interaction	Inventory Stickiness (Next Quarter Revenue Increase)
Inventory Stickiness [H2a]		-0.167*** (0.0116)	-0.228*** (0.0248)	-0.223*** (0.0151)
Inventory Stickiness x Market Instability [H3a]			0.153*** (0.0549)	
Market Instability	0.0844*** (0.0317)	0.0983*** (0.0316)	0.0709** (0.0331)	0.0985*** (0.0371)
Leverage	-0.0252*** (0.00481)	-0.0262*** (0.00481)	-0.0261*** (0.00481)	-0.0232*** (0.00613)
Herfindahl-Hirschman Index	0.0974 (0.111)	0.0867 (0.111)	0.0940 (0.111)	-0.0314 (0.135)
Receivables Change	0.00146*** (0.000502)	0.00166*** (0.000501)	0.00166*** (0.000501)	0.00183*** (0.000564)
Payables Change	-0.00653*** (0.00126)	-0.00389*** (0.00127)	-0.00393*** (0.00127)	-0.0243*** (0.00370)
Recession	0.0223** (0.00894)	0.0230*** (0.00893)	0.0235*** (0.00893)	0.0368*** (0.0112)
Firm Size	0.0673*** (0.00533)	0.0661*** (0.00532)	0.0660*** (0.00532)	0.0654*** (0.00621)
Intercept	-0.505*** (0.0347)	-0.474*** (0.0347)	-0.464*** (0.0349)	-0.423*** (0.0416)
Observations	90,918	90,918	90,918	55,716
Number of Firms	6,073	6,073	6,073	5,811
F test:	39.16***	60.30***	54.46***	68.63***

Standard errors in parentheses

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

Table 4. Inventory Stickiness and Firm Performance in quarters with declining revenue – dependent variable: ΔUSR_{it} .

	Control Variables	Inventory Stickiness	Inventory Stickiness and Instability Interaction	Inventory Stickiness (Next Quarter Revenue Increase)
Inventory Stickiness [H2b]		-0.0805*** (0.0200)	-0.141*** (0.0426)	-0.127*** (0.0269)
Inventory Stickiness x Market Instability [H3b]			0.152 (0.0941)	
Market Instability	0.156*** (0.0530)	0.162*** (0.0531)	0.135** (0.0556)	0.182*** (0.0652)
Herfindahl-Hirschman Index	0.000254 (0.0108)	-0.000225 (0.0108)	-1.34e-05 (0.0108)	-0.00184 (0.0117)
Leverage	-0.174 (0.184)	-0.177 (0.184)	-0.170 (0.184)	-0.555** (0.236)
Receivables	-0.000239 (0.000820)	-0.000158 (0.000820)	-0.000157 (0.000820)	0.00127 (0.000980)
Payables	-0.00403** (0.00205)	-0.00290 (0.00206)	-0.00293 (0.00206)	0.00488 (0.00658)
Recession	0.0113 (0.0150)	0.0117 (0.0150)	0.0121 (0.0150)	0.00843 (0.0198)
Firm Size	-0.0223** (0.00908)	-0.0229** (0.00908)	-0.0231** (0.00908)	-0.0213* (0.0110)
Intercept	0.0498 (0.0602)	0.0647 (0.0603)	0.0750 (0.0606)	0.101 (0.0742)
Observations	84,850	84,850	84,850	54,085
Number of Firms	5,897	5,897	5,897	5,754
F test:	4.226***	5.732***	5.385***	5.567***

Standard errors in parentheses

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

The tests of the relationship between inventory stickiness and firm performance (Column 2 in Tables 3 and 4) indicate that inventory stickiness is negatively related to changes in both internal and external firm stock market performance. This finding suggests that firms with sticky inventory policies (i.e. firms which reduce inventory levels in periods of decreasing revenue at proportions [relative to sales] lower than subsequent inventory increases occurring during periods of increasing revenue) experience more sizable declines across two distinct measures of firm performance. These results strongly support both H2a and H2b.

The next model evaluates the moderating effect of market instability on the relationship between inventory stickiness and firm performance (Column 3 in Tables 3 and 4). The results find that higher instability does significantly dampen the negative relationship between inventory stickiness and ΔROA which supports H3a. However, H3b is not supported as the interaction effect between instability and stickiness does not significantly associate with ΔUSR .

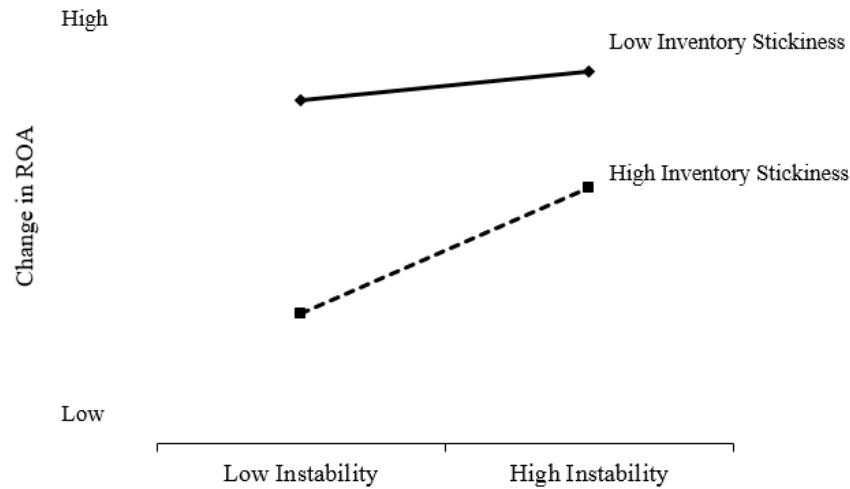
5. Discussion and Managerial Implications

The extant literature has shown that stickiness exists for many cost measures. Building on this, our study confirms that across a broad sample of manufacturing firms, inventory levels vary disproportionately when revenue declines compared to when it increases, and consequently, that inventory stickiness exists. The existence of inventory stickiness within the manufacturing industry should not be viewed as a surprise; despite the abundance of managerial literature touting lean and agile strategies (which would lead to lower levels of inventory stickiness), these strategies are difficult to successfully execute in practice (Voss 1995). Additionally, writing off inventory (which would also lead to lower levels of inventory stickiness) is a difficult management decision that has been shown to negatively affect the value of a firm's stock as it is commonly viewed a symptom of underlying financial difficulties (Francis, Hanna, and Vincent 1996). These factors combined with additional issues such as frozen production schedules, supplier commitments, and in-transit inbound shipments, may explain the finding that inventory is not merely sticky, but that it typically increases for firms during periods of declining revenue.

Prior research into the stickiness phenomena did not explicitly test if stickiness was good, bad, or neutral for firms. Leveraging literature exploring lean and agile management, it was posited that firms with lower inventory stickiness (i.e. 'lower' meaning that they had larger inventory reductions that were more proportionately correlated to reductions in revenue) should perform better because they produce goods with less inventory waste and better match supply to demand. The results of the analysis lend strong support to this contention across two distinct measures of firm performance. Coupled with prior findings that discourage inventory reductions through write-offs, a primary implication of this study is that to maximize performance, firms should adopt lean and agile (i.e. "leagile") management strategies that reduce inventory stickiness.

The quantitative results indicate that in an environment of unstable demand, being slower to reduce inventory in the face of a drop in revenue (i.e. being stickier) results in a statistically significant lower penalty on internal performance (ΔROA). However, a more in depth exploration of this finding may challenge the practical applications of this finding. As shown in Figure 1, despite this finding, a policy of lower inventory stickiness is still superior to one of higher stickiness even in times of high market instability (where 'Low Instability' and 'High Instability' respectively represent levels 1.5 standard deviations below and above the mean level of instability). Post hoc, the point of equivalence for the expected change in ROA for low and high inventory stickiness was calculated and found to occur when market instability is 5.1 standard deviations above the mean. By comparison, across the 25 year sample, the highest level of market instability is only 2.3 standard deviations above the mean level. This implies that, despite the statistical significance, the market conditions required to change the relationship between inventory stickiness and performance to a point where higher stickiness is preferred are extremely unlikely to occur. Additionally, as market instability was not found to mitigate the positive impact of lower inventory stickiness on external firm stock market performance, the results suggest that managers should strive to reduce inventory stickiness under most realistic market conditions.

Figure 1. The interaction effect of Market Instability on the relationship between Inventory Stickiness and Firm Performance (ΔROA).



An additional argument in support of a sticky inventory policy is that a decline in sales may be temporary and that excess inventory may be used as soon as the market conditions improve. To investigate this contention, an additional post-hoc analysis was conducted to test if the findings hold in situations when a quarterly decline in sales is followed by a quarter during which sales improve. The results of these tests, shown in the fourth columns of Tables 3 and 4, indicate that even when sales improve the following quarter, lower levels of inventory stickiness are associated with improvements in both internal and external firm performance. This result further supports the contention that manufacturers should make every effort to reduce their inventory stickiness, regardless of market conditions.

Relatedly, managers may question whether the negative performance impacts of inventory stickiness are ephemeral or if they persist and influence future performance. A second post-hoc analysis, investigating the lagged effects of inventory stickiness on performance, was conducted to explore this question. The results (which are not presented for parsimony) indicate that inventory stickiness only impacts external market performance (ΔUSR) in the next quarter; however, the inventory stickiness has a significant negative impact on internal performance (ΔROA) that endures for three successive quarters. The difference in findings between internal and external performance might be the result of market efficiency, i.e. although inventory stickiness will continue to impact a firm for several quarters, investors understand the longer term impacts of inventory stickiness, hence the initial negative market reaction reflects the lasting impact on the firm (Fama 1998). Regardless, the lasting negative impact on internal performance further strengthens the case against policies that result in high levels of inventory stickiness.

Explicitly, for managers, our examination of both an internal (ΔROA) and an external (ΔUSR) measure of firm performance show that sticky inventory policies are not likely to benefit firms – as stickiness does not improve the bottom line nor does it improve shareholder wealth. Instead, managers should attempt to match inventory supplies with the changing demands in the market, even when demand is expected to rebound in the near term. Future research into behavioral operations management should try to ascertain why managers are using sticky strategies with inventory; for example, is inventory stickiness a result of strategic hedging based on some insight or gut feeling, or managerial inaction, or is it merely a form of anchoring (Sterman, 1989).

Some limitations of this study are that the dataset only includes publically traded firms. Additionally, because actual demand data is not captured in the financial database, we use revenue as a proxy of demand. Clearly, this approach does not capture fully scenarios such as those where demand exceeds total inventory, but revenue is commonly used as a proxy for demand in the literature as it is the most closely related publicly reported indicator of demand (c.f., Manikas and Patel, 2016). Further, where manufacturers hold inventory in their supply chain (raw materials, work-in-process, finished goods) would be a useful extension of this

research. However, only 30% of the firms in our sample report this information which led us to instead assess the widely reported total inventory measure. Finally, the manufacturing firm’s location in the supply chain may be a driver of inventory stickiness; as shown in a bullwhip environment (Wang and Disney, 2016), manufacturers with incomplete information are likely to make imperfect inventory decisions. A final limitation is that there is likely variance in the positioning between this study’s firms and the final consumer as the COMPUSTAT data does not indicate if a firm is an OEM, Tier 1 Supplier, Tier 2 Supplier, etc. Future studies that have identified manufacturers’ tier locations could produce a more nuanced future study.

6. Conclusions

Taken together, this study’s findings highlight that inventory stickiness conclusively exists amongst manufacturers and that it has important implications for a firm’s performance (see Table 5 for a summary of the analytical results). Although managers may view holding onto inventory in the face of declining revenues as strategic hedges, this study’s findings do not agree. Sterman (1989) noted that often incorrect inventory policies come from managers using anchoring, or from misperceptions of time lags associated with the placing and receiving of items (perhaps in the manufacturing context, scheduling of work and finished good product). Internally, firms’ returns on their assets stand to benefit from lean and agile management strategies which minimize inventory stickiness. Similarly, external investors seem to penalize mismatches between changes in revenue and inventory – which may indicate that sticky policies that result in excess inventory holdings are viewed as a signal of management inaction or even incompetence.

Table 5. Summary of empirical test results.

Hypothesis		
1	Supported	
2	(a) ΔROA_{it}	(b) ΔUSR_{it}
	Supported	Supported
3	(a) ΔROA_{it}	(b) ΔUSR_{it}
	Supported	Not Supported

Managers within manufacturing firms that operate with high levels of inventory stickiness should not necessarily consider inventory write-offs as a path to lower stickiness. Instead, they should strive to implement changes that improve the leanness and agility of their production processes. Such improvements, which will decrease inventory stickiness, will also reduce waste in the firm and improve the ability of firms to meet their customers’ demand and ultimately improve firm performance.

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