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# Lean, leaner, too lean? The inventory-performance link revisited

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ABSTRACT

While firms increasingly adopt lean inventory practices, there is limited evidence that inventory leanness leads to improved firm performance. This study reexamines this relationship in an attempt to overcome some shortcomings of previous research. To that end, a theory-based measure of inventory leanness, which takes into account industry-specific inventory management characteristics, is proposed. The analysis of a large panel data set of U.S. manufacturing companies reveals that the significance and shape of the inventory–performance relationship varies substantially across industries. This relationship is significant in two-thirds of the 54 industries studied. In most of these instances, the relationship is concave, suggesting that there is an optimum level of inventory leanness beyond which firm performance deteriorates. A post-hoc analysis is conducted to identify industry-level characteristics that may determine the nature the inventory–performance relationship. Managerial implications are discussed and several opportunities for future research are outlined.



## 1. Introduction

The lean production philosophy considers inventory a form of waste that should be minimized (Womack et al., 1990). In recent decades, as lean production has gained widespread adoption (IndustryWeek, 2008), lean inventory management has become synonymous with good inventory management (Hall, 1983; Zipkin, 1991; Chen et al., 2005; Cooper and Maskell, 2008). As a result, inventories have been decreasing in many industries (Chen et al., 2005, 2007). Yet evidence of improved firm performance is mixed (Rumyantsev and Netessine, 2007). The purpose of this research is to investigate the effect of inventory leanness on firm performance by analyzing empirical data from the U.S. manufacturing industry.

Specifically, this study aims to contribute to existing research on three accounts: first, the effect of inventory leanness on firm performance is explored on an industry-by-industry basis. The advantage of this approach is that it controls for industry-specific characteristics that may lead to different types of relationships between inventory leanness and firm performance in various industries. When data from multiple industries are pooled, as is the case in most previous studies, the dissimilar functional forms present in these industries may mask each other and yield insignificant estimation results. Hence, the analysis of data by narrowly defined industries creates a more comprehensive understanding of the relationship between inventory leanness and firm performance.

Second, the functional form of this relationship is explored. While previous empirical studies have assumed a linear relationship only, the use of a more flexible functional form affords a richer perspective on the inventory–performance relationship. For example, there may be industries in which inventory leanness increases firm performance up to a certain point beyond which the incremental effect becomes negative.

Third, an alternative measure of inventory leanness, the Empirical Leanness Indicator (ELI), is proposed. The distinguishing feature of the ELI, as compared to previously used measures, is that it takes into account the nonlinear relationship between firm size and inventory holdings. Prior research has often relied on metrics such as inventory turnover (Schonberger, 2007; Gaur et al., 2005) and average inventory levels (King and Lenox, 2001) to gauge inventory leanness. These measures ignore the effect of firm size on inventory holdings, i.e. economies of scale in inventory management, and can lead to bias in estimation results. Drawing on inventory theory, the ELI estimates a firm's inventory leanness relative to industry-specific norms and takes into account economies of scale. Subsequently, the ELI and conventional inventory leanness measures are compared in terms of their explanatory power in describing the relationship between inventory leanness and firm performance.

The analyses of data from a large set of publicly traded U.S. manufacturing firms presented here provide detailed insights into the linkages between inventory leanness and firm performance, thereby contributing to both inventory theory and the theory of lean production. From a practical perspective, managers can use the methodology presented here as a new technique to benchmark their operational performance.

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**Table 1**
Overview of survey-based studies on lean production and firm performance.

| Study | Sample or data source | Dependent variable | Independent variable | Methodology | Results |
|---|---|---|---|---|---|
| Inman and Mehra (1992) | U.S. manufacturing firms adopting JIT ($N = 114$) | ROI, service, total cost | Lean production factors | Regression analysis | Lean production implementation benefits firm performance |
| White (1993) | Manufacturing and service firms ($N = 1035$) | Net benefit | Lean production adoption | Percentage breakdown | Most respondents consider lean production a net benefit to organization |
| Norris et al. (1994) | Plant managers operating under JIT ($N = 48$) | Plant performance | Lean production adoption | Percentage breakdown | Respondents report positive views on plant performance, e.g. plant efficiency, value added, etc |
| Callen et al. (2000) | Canadian manufacturing plants ($N = 100$) | Profitability, total costs | Lean production adoption | Regression analysis | Plants using lean production are more profitable and have lower total costs |
| Fullerton and McWatters (2001) | U.S. manufacturers adopting JIT ($N = 95$) | Profitability improvement | Lean production practice scales | ANOVA | Firms scoring higher on lean production-quality factor experience greater profitability improvement |
| Cua et al. (2001) | Manufacturers adopting JIT ($N = 163$) | JIT practices | Plant performance | Discriminant analysis | Categorizing plants as high or low performers, differences in lean production practice adoption is tested |
| Shah and Ward (2003) | Manufacturing plants ($N = 1575$) | Plant performance | Lean production practice bundles | Regression analysis | Lean production practice bundles have a positive effect on plant performance |
| Fullerton et al. (2003) | Manufacturing firms ($N = 253$) | Profitability, ROA, cash flow margin | Lean production practice bundles | Regression analysis | Three lean production practice factors have a positive effect on firm performance |
| Jayaram et al. (2008) | Auto parts manufacturers ($N = 57$) | Profitability, ROA | Lean production | SEM | No significant effect of lean production on firm performance |

The remainder of this paper is organized as follows: In Section 2, the relevant literature is reviewed. Research hypotheses are presented in Section 3. The definition and measurement of inventory leanness, a central concept in this study, are discussed in Section 4. Other variables of interest and data collection procedures are outlined in Section 5. The results of the empirical analysis are presented in Section 6, and a discussion of various post-hoc analyses is provided in Section 7. The paper concludes with a summary of the study's results, and a discussion of limitations and future research prospects in Section 8.

## 2. Literature review

Lean production can be described as a strategy or philosophy that relies on a set of practices (e.g. Kanban, total quality management, etc.) to minimize waste (e.g. excess inventories, scrap, rework, etc.) in order to improve firm performance (Womack et al., 1990). In other words, the implementation of lean production practices is expected to result in improved operational outcomes such as inventory leanness, which, in turn, should enhance firm performance. There is, thus, a natural linkage between the broader concept of lean production and inventory leanness. While the latter is the focus of this research, this literature review also includes prior research on the linkage between lean production and firm performance outcomes.

The effects of lean production on firm performance have been studied since the 1980s when U.S. manufacturers first started adopting lean practices (Young and Selto, 1991). However, early evidence was mostly anecdotal in nature with limited generalizability (Inman and Mehra, 1992; Huson and Nanda, 1995). Starting in the 1990s, researchers have explored this relationship in more rigorous ways and three research streams have emerged. The first stream consists of survey-based studies exploring the relationship between lean production practices and firm performance. In the second stream, researchers conceptualize lean production implementation as a dichotomous variable and explore its effects on firm performance. The third stream focuses on the analysis of the relationship between inventory leanness, a presumed outcome of the implementation of lean practices, and firm performance. Each of these streams is discussed in more detail below.

### 2.1. Stream 1: studies on lean practices and firm performance

The first stream of research uses survey data to explore the effects of lean production practices on firm performance (Table 1). Lean production is typically conceptualized as a multi-dimensional construct composed of multiple lean practices such as total quality control, total productive maintenance, and just-in-time (White, 1993; Fullerton and McWatters, 2001; Cua et al., 2001; Shah and Ward, 2003). Prior studies not only indicate that these practices are widely implemented (White, 1993), but also present evidence that their implementation results in improved operational performance in terms inventory management, process control, information flows, human factors, delivery, flexibility and quality (Norris et al., 1994; Fullerton and McWatters, 2001; Cua et al., 2001). Moreover, multiple studies find that financial performance is positively affected by the implementation of lean production practices (Inman and Mehra, 1992; White, 1993; Callen et al., 2000; Fullerton and McWatters, 2001; Fullerton et al., 2003). Jayaram et al. (2008), however, find no significant effects of lean production on firm performance (profitability and ROA).

While most of the survey-based studies on lean production present at least some evidence of a positive impact of lean production practices on firm performance, there are several common weaknesses among these studies. First, nearly all of them rely on subjective assessments of firm performance in addition to subjective evaluations of lean production. This approach may introduce systematic measurement error resulting in biased estimation results (Podsakoff et al., 2003). Second, none of these studies take into account the endogeneity in their data sets (Huson and

**Table 2**
Overview of studies on lean production adoption and firm performance.

| Study | Sample or data source | Dependent variable | Independent variable | Methodology | Results |
|---|---|---|---|---|---|
| Huson and Nanda (1995) | Literature search ($N=55$) | Inventory turnover, labor, unit cost, gross margin, earnings per share | | Simultaneous equations | After lean production adoption, unit costs, inventory turnover, earnings per share increase while labor needs and gross margins decrease |
| Balakrishnan et al. (1996) | Literature search ($N=46\times 2$) | Return on assets<br>Inventory turnover | Lean production adoption | t-test | Firms that use lean production have higher inventory turnover than firms that do not. No significant difference in ROA |
| Biggart (1997) | Literature search ($N=106$) | Return on assets | Lean production adoption | Regression analysis | No significant improvement in ROA after lean production adoption |
| Kinney and Wempe (2002) | Literature search ($N=201\times 2$) | Profitability<br>Return on assets | Lean production adoption | Regression analysis | Lean production adoption improves profitability and return on assets |

Nanda, 1995). In other words, the respondents who implement and benefit from lean production may be more likely to respond to the surveys, thus introducing potential self-selection (endogeneity) bias. Third, none of the survey-based studies control for industry-specific factors. It is conceivable that certain industries may be more amenable to lean inventory systems than others due to inherent characteristics of manufacturing technologies, markets, and other environmental factors. The lack of control for inter-industry heterogeneity may distort the results of these studies.

### 2.2. Stream 2: studies on lean production adoption and firm performance

The second stream of research relies on secondary financial data and uses econometric methods to identify the performance effects of the adoption of lean production (Table 2). Huson and Nanda (1995) identify a set of firms that adopted lean production between 1980 and 1990, and analyze changes in firm performance measures over time. Their results suggest that, in the periods following lean production adoption, labor requirements decrease, inventory turnover increases, and earnings per share increase, whereas unit manufacturing costs increase and operating margin decreases. In explaining these seemingly contradictory results, the authors point to the trade-off between expected cost savings from lean production and costs that may increase as a result of lean production implementation. In a similar study, Biggart (1997) finds no improvement in ROA subsequent to lean production implementation.

Balakrishnan et al. (1996) and Kinney and Wempe (2002) compare the financial performance of a group of firms that had adopted lean production and an equal number of similar firms that had not. While Balakrishnan et al. (1996) observe a significant increase in inventory turnover in the treatment group as compared to the control group, they find no significant differences in ROA between these two groups. Kinney and Wempe (2002), in contrast, detect an improvement in profitability for firms that adopt lean production relative to those that do not. Both studies note that small firms do not benefit from lean production adoption as much as large firms.

**Table 3**
Overview of econometric studies on inventory management and firm performance.

| Study | Sample or data source | Dependent variable | Independent variable | Methodology | Results |
|---|---|---|---|---|---|
| Chen et al. (2005) | 7433 U.S. manufacturers 1981–2000 | Inventory/Assets, Inventory days, Tobin's q, Market-to-book ratio, Stock returns | Abnormal inventory, Time | Linear mixed models, fixed effects, random effects models | Raw-material and WIP inventories have decreased, inventory management performance is reflected in stock market returns |
| Chen et al. (2007) | 1662 retailer, wholesalers 1981–2004 | Inventory levels, Stock returns | Abnormal inventory, Time | Linear mixed models, fixed effects, random effects models | Retail and wholesale inventories decrease. Inventory management is reflected in stock market performance in the long term |
| Swamidass (2007) | 14,400 firm-years | Inventory-to-sales ratio | Z-score (firm performance) Time | Regression analysis | Top performers have lower inventory-to-sales ratios than low performers |
| Cannon (2008) | 244 firms 1991–2000 | ROA, ROI, Tobin's q, market value added | Inventory turnover, Capital intensity | Hierarchical linear model | Inventory management has minimal impact on firm performance |
| Koumanakos (2008) | 1358 Greek firms 2000–2002 | Gross margin, Net operating margin | Inventory days | Regression analysis | Varying results for food, textile and chemical industries |
| Capkun et al. (2009) | 52,254 firm-years 1980–2005 | EBIT, gross profit | Inventory scaled by sales | Regression analysis | Inventory management positively affects firm performance |

The main feature of this stream of research is that it relies on objective measures of firm performance. Yet, the evidence of a positive impact of lean production on firm performance is mixed. One reason for this may be that lean production implementation is measured using a dichotomous variable, thereby ignoring the nature, extent, and effectiveness of the implementation. A second reason for these mixed results may be that these cross-sectional studies largely ignore industry and firm-specific factors that may shape the leanness–performance relationship. Many papers in this stream refer to a cost trade-off in justifying a lean production strategy (e.g. Huson and Nanda, 1995; Balakrishnan et al., 1996). It is conceivable that lean production may not make sense for a given firm using a particular technology or operating in a certain industry. Hence, such factors may potentially explain the mixed results that have emerged in this stream of research.

### 2.3. Stream 3: studies on inventory management and firm performance

The third stream of research analyses the link between inventory management and firm performance without categorizing firms as lean manufacturers or traditional manufacturers (Table 3). Instead, this stream uses continuous measures of inventory leanness. Chen et al. (2005) analyze inventory data from U.S. manufacturing firms between 1981 and 2000. Assuming that lean production and inventory management principles gained widespread acceptance over this period, they observe a significant decrease in raw material and work-in-process inventories as expected, but no change in finished goods inventories. Testing whether this decline in inventory investment is reflected in stock market prices of firms, they document better performance for stock portfolios of firms with lower inventory levels relative to their industry peers over time. They note that stock market returns seem to be best for firms with inventories that are slightly below industry average.

Chen et al. (2007) replicate their 2005 study in retail and wholesale industries between the years of 1981 and 2004. During this period, the wholesale inventories have decreased at a rate comparable to that of manufacturing inventories. However, the decrease in retail inventories begins in the latter part of the 1990s. While the authors find no significant difference in stock price performance of firms with high versus low inventories in the retail and wholesale sectors cross-sectionally, differences are detected in longitudinal analyses, indicating that high inventory levels seem to negatively affect stock price performance. Swamidass (2007) investigates the effects of lean production adoption on inventory-performance of U.S. manufacturing firms. After grouping firms by performance, he finds that better performing firms have improved their inventory management performance, as measured by total inventory-to-sales ratio, while the opposite is true for poor performers. Koumanakos (2008) examines the relationship between inventory management and firm performance for Greek manufacturing firms in textile, food, and chemical industries over a period between 2000 and 2002. No conclusive results are obtained, as industry-specific results vary. Cannon (2008) uses a hierarchical linear model to explore the effects of changes in inventory turnover on firm performance measured by ROA, ROI, market value added, and Tobin's Q. He concludes that improvements in inventory management do not lead to improved firm performance. Capkun et al. (2009) analyze firm-level data on U.S. manufacturing firms from 1980 to 2005 to estimate the effect of inventory management on firm performance. Their results indicate that total inventory levels, as well as raw materials, work-in-process inventory, and finished goods, have a positive effect on firm performance.

While this stream of research relies on large data sets and uses objective measures of inventory leanness (e.g. inventory turns), it ignores the role of economies of scale in inventory management.[1] Therefore, the use of measures such as inventory turns introduces potential measurement errors that may bias and weaken econometric results (see Section 4 for further discussion of this issue). A second drawback in this stream of research is that the firms are grouped into rather broadly defined industry sectors which may mask industry or market specific factors that could affect the relationship between inventory leanness and firm performance.

Thus, two major directions for future research emerge from this literature review: first, inter-industry heterogeneity should be taken into account when assessing inventory leanness and its effect of firm performance. Second, economies of scale in inventory management should be accounted for. To this end, a measure of inventory leanness which benchmarks a firm's inventory levels against those of firms of similar size within the same industry is developed in this study. Using this measure, the relationship between inventory leanness and firm performance is explored in further detail. Hypotheses about the nature of this relationship are developed below.

## 3. Hypothesis development

As discussed in the literature review, the results regarding the effect of lean production and inventory leanness on firm performance are mixed. Clearly, the decision to implement lean production affects every aspect of an organization and trade-offs exist among various cost components (Womack et al., 1990). Thus, a lean strategy may not be appropriate for all firms (Zipkin, 1991). Furthermore, the feasibility and desirability of lean strategies may also depend on industry-specific production, supply and demand conditions (de Haan and Yamamoto, 1999). It is expected that inventory leanness and its resulting benefits vary across industries (Schonberger, 2007; Koumanakos, 2008). However, many prior studies pool observations from a broad cross-section of industries (e.g. Swamidass, 2007; King and Lenox, 2001; Huson and Nanda, 1995). As a result, statistical findings are weakened by unobserved inter-industry heterogeneity.

Some studies conclude that the effect of inventory leanness on performance is not significant (e.g. Cannon, 2008), while others present evidence that greater inventory leanness can result in improved profitability (e.g. Huson and Nanda, 1995; Koumanakos, 2008). As noted previously, the variability in these results may, at least in part, be due to sampling and measurement issues (Podsakoff et al., 2003; Huson and Nanda, 1995) as a result of not controlling for industry-specific effects. It is expected that addressing these concerns will result in more robust statistical results. Specifically, and in line with the central tenet of the theory of lean production, a positive effect of inventory leanness on firm performance should be observed.

**Hypothesis 1.** Inventory leanness will have a positive effect on firm performance.

Prior literature estimates the effects of inventory leanness on firm performance using linear models. There seems to be an implicit assumption that greater inventory leanness always leads to better firm performance. However, inventory control theory suggests that there is an optimal level of inventory leanness (e.g. Nahmias, 2005). Similarly, Zipkin (1991) distinguishes between "romantic JIT" and "pragmatic JIT" views. The romantic JIT view suggests that inventories should ideally be eliminated altogether as they are "inherently evil". In contrast, the pragmatic JIT view holds that there is an

[1] The interested reader is referred to Evers (1995) for a discussion of the square-root law of cycle stocks and safety stocks which explains the rationales for scale economies in inventory management.

optimal level of inventory that depends on trade-offs among multiple factors such as inventory carrying costs, shortage costs, and production technology. In fact, there is some empirical evidence supporting the pragmatic JIT view. Chen et al. (2005) document that firms that carry inventory slightly below industry average perform best in terms of stock market returns. However, no evidence exists to show if the same is true in terms of performance measures like profitability and ROA. In line with the pragmatic JIT view, Hypothesis 2 is proposed as follows:

**Hypothesis 2.** The relationship between inventory leanness and firm performance will be concave.

In Section 4, the measurement of inventory leanness is discussed and in Section 5, the proposed hypotheses are tested using the ELI and traditional measures of inventory leanness.

## 4. The empirical leanness indicator

In this section, a critique of inventory leanness measures used in prior research is presented and a measure for inventory leanness, the Empirical Leanness Indicator (ELI), is introduced.

### 4.1. Critique of existing inventory leanness measures

Econometric studies rely on various measures as proxy for inventory leanness. These measures can be classified into three groups: (1) absolute measures, including average inventory levels and maximum inventory levels (King and Lenox, 2001); (2) standardized measures, such as inventory turnover (Schonberger, 2007; Gaur et al., 2005), inventory-to-sales ratios (Swamidass, 2007) and days of supply (Koumanakos, 2008); and (3) complex measures, such as those based on fuzzy set theory (e.g. Bayou and de Korvin, 2008) and data envelopment analysis (e.g. Wan and Chen, 2008).

The first group of inventory leanness measures are absolute in nature. Yet, it is important to measure inventory leanness with respect to some anchor (e.g. a size-adjusted industry average) because absolute measures of inventory management effectiveness can be misleading. The economic benefit of increased inventory leanness depends on a firm's status quo and industry-specific inventory management characteristics. To illustrate this point, consider the following examples: while the department store chain Dillard's saw its profits triple after cutting inventories by 18% (Manthey, 2009), technology firm EMC Corp.'s stock dropped nearly 7% when investors learned that the company did not maintain enough inventory to satisfy customer demand (Stape, 2006).

The second group of inventory leanness measures is based on inventory turnover and its variants. These are the most widely used measures of a firm's inventory leanness (e.g. Chen et al., 2005; Gaur et al., 2005). However, such measures ignore economies of scale in inventory management. That is, prior research has shown that if a firm's sales double, its inventories generally less than double due to economies of scale (e.g. Pratten, 1971; Buzacott et al., 1982). Ignoring these economies of scale results in biased estimates of a firm's inventory leanness, which, in turn, yields biased estimates of the marginal effect of inventory leanness on firm performance.

To illustrate this point, consider firm A in Fig. 1, where line $l_1$ represents the mean of inventory turns across firms in the same industry and line $l_2$ represents the industry average of inventory turns adjusted for sales. In other words, firms with lower sales are expected to have lower inventory turns while firms with higher sales should have higher inventory turns, all else equal. At first glance, inventory turns for firm A appears to be above the unadjusted industry average (line $l_1$), but they are actually below the industry average when economies of scale are considered (line $l_2$). A similar measurement error is present for other firms in the industry as well.

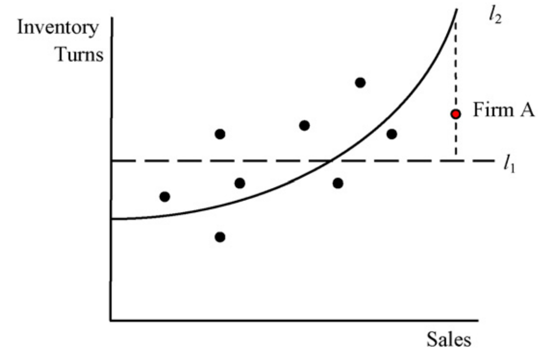


**Fig. 1.** The relationship between sales and inventory turns.

This measurement error leads to attenuation bias where the estimate for inventory turns will be diluted. Specifically, the failure to consider economies of scale in inventory management and ensuing measurement errors result in coefficient estimates that are biased towards zero (Spearman, 1987). When additional explanatory variables are included in the same model the measurement error is likely to bias them as well (Greene, 2008, p. 327).

The third group of inventory leanness measures rely on complex analytical models (e.g. Bayou and de Korvin, 2008; Wan and Chen, 2008) and require expertise in solving such models and interpreting the results. As such, these measures are not well suited for widespread use by managers.

The review of existing measures of inventory leanness calls for a new measure of inventory leanness that takes into account economies of scale in inventory management, is anchored with respect to industry-specific inventory management practices, and is easy to calculate and communicate.

### 4.2. Development of the empirical leanness indicator

An alternative measure of inventory leanness, namely, the Empirical Leanness Indicator (ELI) is proposed. This measure's distinctive feature is that it evaluates a firm's inventory leanness relative to firms of comparable size within a narrowly defined industry. It is, in part, based on the work of Ballou (1981, 2000, 2005). Ballou estimates turnover curves that describe the specific nature of the relationship between sales and inventories in multiple stocking locations of a firm, thereby identifying economies of scale in inventory holding (Fig. 2).

In his empirical work, Ballou (1981, 2000, 2005) uses a flexible functional form, $I = \beta\lambda^{\alpha}$, to estimate a turnover curve. An estimate of shape parameter $\alpha < 1$ indicates economies of scale (increasing inventory turnover), $\alpha > 1$ diseconomies of scale (decreasing inventory turnover), and $\alpha = 1$ a constant inventory turnover. Ballou's studies show that the coefficient estimates of $\alpha$ are typically around 0.7 (Ballou, 2000).

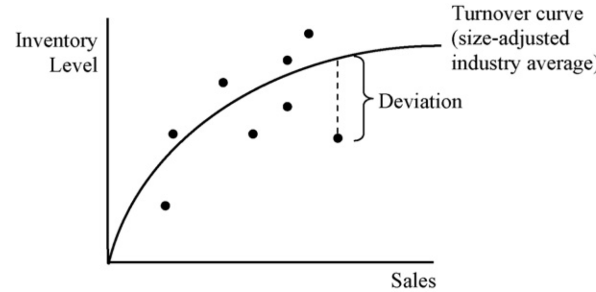


**Fig. 2.** The relationship between sales and inventory levels.

The concept of Ballou's turnover curve is adopted for within-industry benchmarking purposes. It is argued that it is a suitable tool to control for size differences between otherwise largely homogeneous firms within narrowly defined industries and identify prevalent industry-specific inventory practices. As such, turnover curves are estimated for each narrowly defined industry. This curve represents the size-adjusted industry average inventory turnover. Deviations of firms from this curve are the basis for the assessment of a firm's inventory leanness: firms that are below this curve are considered to be "lean" as they hold less inventory than firms of similar size. The ELI is then calculated as the studentized residual estimated during the fitting of the turnover curve for a given industry (Fig. 2).

In summary, the ELI is a measure of inventory leanness that is rooted in inventory theory and, unlike inventory turnover, accounts for economies of scale in inventory management. Moreover, the ELI inherently controls for industry-specific inventory management characteristics which make it particularly suitable for use in cross-sectional studies such as this one.

## 5. Data collection and measurement

To test the proposed hypotheses, data on U.S. manufacturing firms are collected from Standard & Poor's COMPUSTAT database. The query covered the 2003–2008 time period and U.S. domestic manufacturing firms that were active, reported at the six-digit NAICS level and had positive sales and inventory figures. Furthermore, firms in industries with less than 10 firm-level observations were eliminated from the data set. In an additional screening step, observations with obviously flawed data (such as observations with gross profit margins greater than 100%) were excluded. The resulting data set contains 7804 firm-year observations from 1600 firms in 54 industries corresponding to an average of 4.88 years per firm. The breakdown of the sample by six-digit NAICS industries is presented in Table 10 in the Appendix.

In calculating the ELI, firms are grouped into six-digit NAICS industries (which is the most detailed level of classification) in order to account for industry-specific factors such as production technology as well as supply and sales market conditions. As a result, between-firm differences in the inventory–sales relationship primarily arise from differences in inventory management strategies among firms in the same industry. This is consistent with previous research (Huson and Nanda, 1995). To calculate the ELI, total inventories are regressed on sales for each industry $i$ and year $t$.

$$\ln(Inva_{ift}) = \alpha_{it} + \beta_{it}\ln(Sale_{ift}) + u_{ift},\ \forall i = 1, 2, \ldots, 54; \forall t = 2003, \ldots, 2008 \tag{1}$$

where $\ln(Inva_{ift})$ is the natural logarithm of the firm's average total inventory (measured in U.S. dollars) in year $t$ (the average of total inventories reported at the end of years $t-1$ and $t$). $\ln(Sale_{ift})$ is the natural logarithm of the net annual sales volume (measured in U.S. dollars) of firm $f$ in industry $i$ and year $t$. It should be noted that each firm $f$ is associated with a unique six-digit NAICS industry $i$. Although redundant, both subscripts are used to emphasize the industry-specific nature of the estimation procedure. Fitting this equation by year also has the advantage that the effects of time-specific factors on the estimation results are minimized. It is interesting to note that Equation (1) includes only one explanatory variable even though numerous variables such as capital, warehousing, and stockout costs are known to influence inventory policies. The initial estimation results with a single explanatory variable yielded very high levels of $R^2$, ranging from 0.7103 to 0.9982 with a mean value of 0.9211 (Table 8). Out of 324 regressions (54 industries × 6 years), 315 (97%) had an $R^2$ greater than 0.80. Consequently, it was deemed unnecessary to include additional control variables.

**Table 4**
Descriptive statistics ($N = 7804$).

| | Median | Mean | Std. Dev. |
|---|---|---|---|
| Total assets* | 145.98 | 4415.00 | 19,651.70 |
| Net sales* | 113.04 | 4111.00 | 20,889.60 |
| Total inventory* | 15.66 | 377.00 | 1616.70 |
| Growth rate | 0.12 | 0.14 | 0.32 |
| ROS | 0.01 | 0.02 | 0.29 |
| ROA | 0.01 | 0.01 | 0.12 |
| Inventory turns | 7.52 | 12.45 | 47.86 |
| ELI | 0.07 | 0.00 | 1.01 |

* Reported in million dollars.

The model shown in Equation (1) was estimated using an OLS procedure. The shape parameter, i.e. the coefficient of the *Sale* variable, ranged from 0.6295 to 1.3323 with a mean coefficient estimate of 0.9077. These results are broadly consistent with those presented by Ballou (2000) and confirm the contention that economies of scale are reflected in the relationship between sales and inventory.

The disturbance term $u_{ift}$ is the basis of the ELI. These residuals are studentized and subsequently multiplied by $(-1)$ so that negative deviations (below expected inventory levels) produce positive ELI measures and positive deviations (above expected inventory levels) produce negative ELI measures. The advantage of using studentized residuals (99% of studentized residuals range from $-3$ to 3) to calculate the ELI is that it makes it comparable across firms, industries, and years, and also facilitates the interpretation of parameter estimates in subsequent analyses.

The serial correlation of a firm's ELI measures is calculated over the 2003–2008 time period to ascertain that the ELI measures systematic inventory management practices rather than only noise and random variability in inventory leanness levels. The median within-firm serial correlation coefficient of the ELI is 0.25, which is statistically significant at the $p < 0.01$ level, thus confirming that the ELI measures *systematic* inventory leanness to at least some extent. The fact that the correlation coefficient is not larger in magnitude is not surprising since a firm's inventory management practices are expected to change over the six-year time period studied here. In addition, it is important to keep in mind that the ELI estimates will also be impacted by changes in competitors' inventory and operations practices. Moreover, inventory turnover and the ELI are positively correlated across all 54 industries, with a mean Pearson product-moment correlation coefficient of .76 and a median of .78. This finding also lends support to the contention that the ELI is a systematic measure of inventory leanness.

In terms of firm financial performance, two commonly used metrics are employed: return on sales (ROS) and return on assets (ROA) (Kinney and Wempe, 2002; Cannon, 2008; Koumanakos, 2008). ROS can be considered as a measure of profitability and is calculated as net income divided by net sales, whereas ROA can be viewed as a measure of efficiency and is calculated as net income divided by total assets averaged over years $t$ and $(t-1)$. The two alternative measures of firm performance, ROS and ROA, are positively correlated for all 54 industries, with a mean of .67 and median of .74. This is expected because both measures reflect firm performance from slightly different angles. These two distinct, albeit correlated, performance measures are used to assess the robustness of the empirical results.

While industry-specific subsamples are analyzed, only the medians, averages, and standard deviations of the entire data sample are reported in Table 4 below due to space constraints. It is apparent from the data presented in Table 4 that the distributions of assets, sales, and inventory data are positively skewed. These data are, therefore, logged prior to the empirical estimation.

## 6. Empirical results and discussion

In order to test the proposed hypotheses regarding inventory leanness and firm performance, the following regression model is estimated for each industry:

$$Performance_{ift} = \alpha + \beta_1 \ln(Assets_{ift}) + \beta_2 Growth_{ift} + \beta_3 Leanness_{ift} + \beta_4 (Leanness_{ift})^2 + \sum \beta_f F_f + \sum \beta_t F_t + \nu_{ift}, \quad i = 1, 2, \ldots, 54 \tag{2}$$

where $Performance_{ift}$ represents the performance of firm $f$, in industry $i$, during year $t$ as measured by ROS or ROA. The value of total assets ($Assets_{ift}$), a measure of firm size, and the year-over-year percentage change in sales (*Growth*) were added as control variables following prior research (Rumyantsev and Netessine, 2007). $F_f$ and $F_t$ denote firm and time fixed effects, respectively. $Leanness_{ift}$ refers to inventory leanness as measured by the ELI.

It should also be noted that *Leanness* enters the regression equation in the first- and second-degree polynomial form, which allows for a flexible functional relationship between inventory leanness and firm performance. If the parameter estimate of the quadratic term is not significant, the regression reduces to a linear model. Otherwise, various parabolic forms are possible with interesting managerial and theoretical implications. For example, if the second-degree term has a negative parameter estimate, it means that there is an "optimal" level of leanness (Fig. 3). In other words, a firm could have too much as well as too little inventory. An advantage of using the ELI to measure inventory leanness is that it allows managers to determine the degree of leanness that, on average, tends to yield superior performance within the respective industries.

The regression model (Equation (2)) is estimated for each of 54 six-digit NAICS industries separately to control for inter-industry heterogeneity. The samples sizes range between 34 and 872 firm-year observations. Out of 54 industries, 27 (50%) industries have more than 87 observations, 40 (74%) industries more than 60 observations and 49 (91%) industries more than 50 observations. In other words, only five industries have between 34 and 50 observations and no industry has fewer than 30 observations. The average sample size is 144 observations. No evidence of within-panel autocorrelation (Drukker, 2003; Wooldridge, 2002) was found prior to estimation.

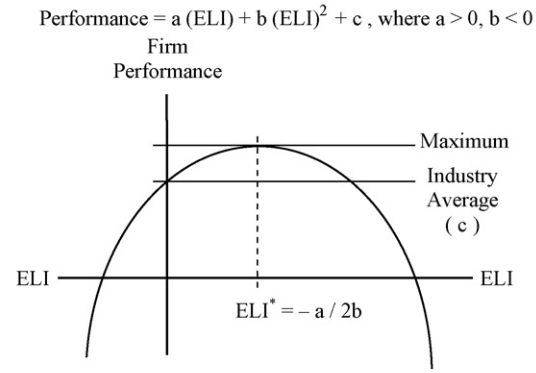


**Fig. 3.** An illustration of inventory leanness–performance relationships.

All nine possible functional forms of the relationship between the ELI and firm performance are shown in Fig. 4. Each functional form is identified by the sign and significance levels of the coefficient estimates for ELI and ELI$^2$. The vertical axis shows the signs of the coefficient of the ELI, and the horizontal axis shows the possible signs of the coefficient of ELI$^2$. The estimation results in Table 5 are categorized according to the nine possible combinations of coefficient estimates for ELI and ELI$^2$.

Table 5 summarizes the estimation results for ROS as a measure of firm performance with ELI as the explanatory variable. The top portion of the table lists the various functional forms of the ELI–performance relationship as outlined in Fig. 4. The $R^2$ values

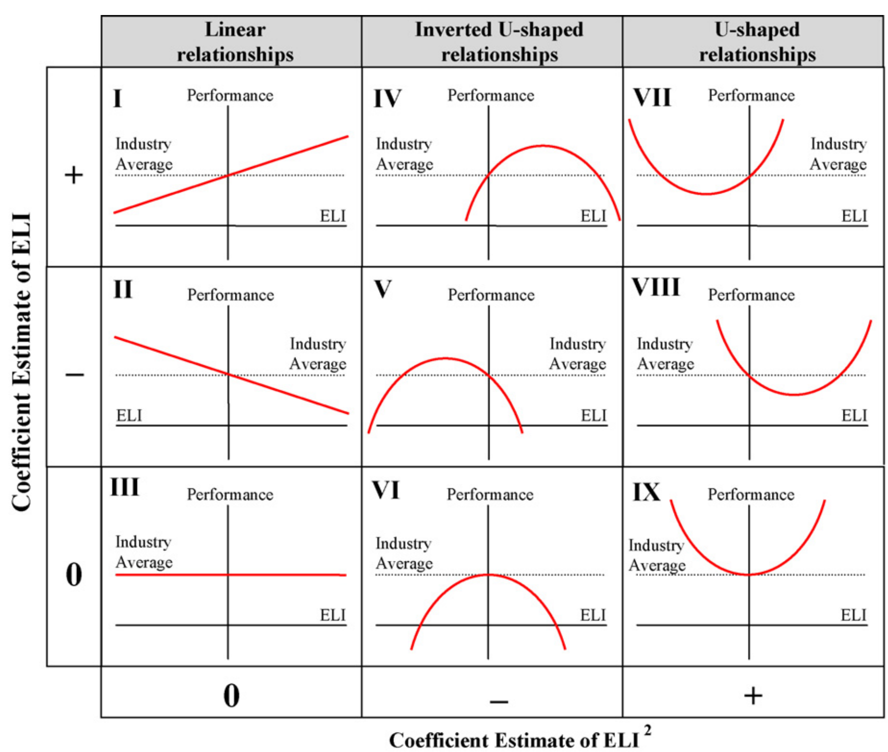


**Fig. 4.** Functional forms of the inventory leanness and firm performance relationship. Note: the "+" sign indicates that the coefficient estimate is positive and statistically significant at $p < 10\%$, the "–" sign indicates that it is negative and significant at $p < 10\%$, and "0" indicates that it is not significant.

**Table 5**
Summary of estimation results (dependent variable: ROS).

| | Linear | | | U-shaped | | | Inverted U-shaped | | |
|---|---|---|---|---|---|---|---|---|---|
| Functional form | I | II | III | IV | V | VI | VII | VIII | IX |
| $\hat{\beta}_{ELI}$ | + | – | 0 | + | – | 0 | + | – | 0 |
| $\hat{\beta}_{ELI^2}$ | 0 | 0 | 0 | – | – | – | + | + | + |
| Number of industries | 6 | 0 | 18 | 17 | 1 | 8 | 1 | 1 | 2 |
| Average $R^2$ | 0.75 | | 0.77 | 0.69 | 0.94 | 0.83 | 0.79 | 0.93 | 0.94 |
| Average $\hat{\beta}_{ELI}$ | 3.52 | | 0.30 | 21.70 | −1.09 | 0.13 | 0.09 | −1.38 | −0.07 |
| Average $\hat{\beta}_{ELI^2}$ | −0.38 | | 0.13 | −11.14 | −0.31 | −0.70 | 0.05 | 0.59 | 0.08 |

Note: The "+" sign indicates that the coefficient estimate is positive and statistically significant at $p < 10\%$, the "–" sign indicates that it is negative and significant at $p < 10\%$, and "0" indicates that it is not significant.

across all categories indicate a very good model fit. Also, the models' F statistics are significant at the less than 5% level in all industries. While not shown here due to space constraints, it is noted that the *Assets* and *Growth* variables have the expected positive and significant coefficient estimates in most industries.

The full estimation results for ROS and ROA as dependent variables and ELI and inventory turns as measures of inventory leanness are shown in Table 9 in the Appendix. Industry-specific estimation results are shown in Table 10 (Appendix). While not all results are discussed in detail, a few observations are highlighted: the results vary depending on the dependent variable used (ROS and ROA), but are broadly similar. The finding that the statistical results are generally more robust for ROS than for ROA as the dependent variable mirrors Kinney and Wempe's (2002) conclusion that leanness affects profit margins to a greater extent than asset turnover. All subsequent discussions will, therefore, focus on ROS as the dependent variable only.

As an explanatory variable, the ELI generally yields more significant results than inventory turnover. Thirty-six industries (36/54 = 67%) exhibit significant leanness–performance relationships with the ELI as a measure of inventory leanness. When the latter is measured using inventory turns, a significant effect of leanness on ROS is found in only 27 (27/54 = 50%) industries. This finding is consistent with the attenuation bias discussed in Section 4.1. Otherwise, the results remain similar across ELI and inventory turns with respect to the frequency of functional forms detected in the industries studied. For simplicity, the discussions below are focused on ELI as the measure of inventory leanness.

First, it is noted that evidence of significant positive or negative returns to leanness of various functional forms is found in 36 of the 54 industries studied here. This finding provides some evidence in support of Hypothesis 1. The corresponding null hypothesis of no effect of inventory leanness on firm performance, however, cannot be rejected for 18 of 54 industries (category III). This finding is consistent with the contention that the use of lean inventory practices may not be justified in all contexts. Some industries, by virtue of their particular product, manufacturing, demand, or supply conditions, may not support lean (inventory) operations. As a result, inventory leanness is not a source of superior performance in such instances. This finding, thus, highlights the importance of analyzing inventory leanness within an industry-specific context and explains why some prior cross-sectional research found only limited evidence of a positive effect of inventory leanness on financial performance (e.g. Cannon, 2008).

Inverted U-shaped relationships (categories IV, V, VI) between inventory leanness and firm performance are observed in 26 (26/54 = 48%) industries. This result is particularly interesting because it suggests that there is an optimal degree of leanness. Firms that are leaner than the industry average generally see positive returns to leanness, although at a decreasing rate. At some point, the benefits of lean inventory strategies are exhausted, and the incremental effect of leanness on firm performance becomes negative. The analysis of data from the Electromedical and Electrotherapeutical Apparatus Manufacturing industry (NAICS 334510, $N = 448$), for example, yields ELI coefficient estimates of $\beta_{ELI} = 8.58$ and $\beta_{ELI^2} = -6.94$. The profit-maximizing degree of leanness can thus be computed as $ELI^* = -\beta_{ELI}/2\beta_{ELI^2} = 0.62$. With the ELI being a studentized residual, this means that firms at the 73rd percentile in terms of inventory leanness (among all the firms in this industry) will have the highest ROS, all else equal. Firms that hold comparatively more or less inventory will have lower financial performance. From an inventory theory perspective, this finding is expected. While firms tend to benefit from the efficiencies of lean inventories, excessively low inventories likely come at the expense of high transportation and stockout costs, thus negating the cost savings commonly associated with lean inventory systems. Therefore, Hypothesis 2 is supported by the empirical results.

A number of checks were carried out to assess the robustness of the results reported in Table 5. First, the number of employees and net sales were used as alternate measures of firm size (instead of total assets). In both cases, the results were consistent. Second, ending inventory in year $t$ was used instead of the average of ending inventories in years $t$ and $t-1$ to estimate inventory leanness. Again, the results remained similar. Third, observations of firms with sales of less than one million dollars and less than five million dollars a year, respectively, were eliminated. In both cases, similar results were obtained. Finally, observations from 2008, a year marked by severe economic distress, were removed from the data set and the analysis was replicated with the remaining data. The results remained largely consistent.

As Table 10 indicates, some industries include a small number of firms and a small number of firm-year observations. A limited sample size makes existing relationships between variables more difficult to detect. Thus, finding significant relationships even in smaller samples actually strengthens the results. Table 10 indicates that the various functional forms tend to have industries with both large and small numbers of firms. The relative frequency with which the various functional forms of the inventory leanness–performance relationship are observed does not change significantly when industries with comparatively few firm-level observations are excluded.

## 7. Post-hoc analysis

Reviewing the empirical results shown in Table 5, a clear pattern emerges: in 18 of the 54 industries studied (category III), no statistically significant effect of inventory leanness on firm performance was observed. The other prominent group includes those 23 industries (categories I and IV) that exhibit a linear or curvilinear positive effect of leanness on performance. What makes lean inventory strategies appropriate for one industry but not for another? Are there systematic differences between those industries that experience positive returns to inventory leanness and those that do

**Table 6**
Split-sample industry statistics.

| Variable | Group 1: positive effect ($N=23$) | | Group 2: no effect ($N=18$) | |
|---|---|---|---|---|
| | *M* | *SD* | *M* | *SD* |
| Growth rate | 5.88% | 5.44% | 7.67% | 6.49% |
| Employees | 66,348 | 27,654 | 46,835 | 40,532 |
| Gross margin | 36.63% | 13.66% | 29.76% | 10.32% |
| CR-4 | 37.01% | 17.86% | 39.91% | 16.71% |

Note: Group 1 includes industries with a positive effect of inventory leanness on firm performance while Group 2 includes industries with no significant effect of inventory leanness on firm performance.

not? These questions are further explored in the post-hoc analysis below. This analysis is limited to those industries that fall within categories I/IV and III (see Fig. 4), respectively, since the total number of industries in the data set (54 six-digit NAICS industries) is too small to allow for more comprehensive discriminant function analyses including all nine categories identified in Table 5.

Porter (1981) suggests that industries are most appropriately characterized by their economical and technical opportunities and threats. Teece (1984) argues that such industry structural characteristics not only help explain firm conduct, but also impact to what extent a firm's conduct affects its financial performance. Thus, this analysis is rooted in the structure-conduct-performance paradigm (Bain, 1968). Prior research has proposed numerous measures of industry structural characteristics including, most notably, variables such as industry concentration (e.g. Henley, 1987), industry size (e.g. Gupta, 1979), industry profitability (e.g. Wernerfelt and Montgomery, 1986), and industry growth (e.g. Hause and Du Rietz, 1984). While there are many other metrics that can be used to characterize industries, the exploratory analyses presented here rely on these four measures in order to preserve a sufficient number of degrees of freedom.

Industry-level data were collected from the Annual Survey of Manufacturing Firms and the 2007 Economic Census,[2] both published by the U.S. Bureau of Economic Analysis, for the year 2007. For each of the 41 industries included in this analysis, four data points were collected: *Growth Rate* refers to the average annual growth of total industry sales calculated over the 2002–2007 time period. Industry size is measured by the total number of *Employees* in the respective industries (this variable was logged prior to analysis due to its non-normal distribution). Industry profitability is estimated by the industry average *Gross Margin*, i.e. the ratio of gross industry profits and total industry sales. Industry concentration, finally, is measured by the four-firm concentration ratio (*CR-4*) which is the sum of the market shares of the respective industries' four largest firms. The descriptive statistics are shown in Table 6.

Hotelling's $T^2$ test was performed to assess the statistical significance of the differences in the vectors of means between the two groups of industries. The resulting test statistic of $T^2=9.21$ corresponds to an $F$ statistic of 2.13 which is marginally significant ($p=0.098$). Likewise Wilk's $\Lambda$ (a generalization of Hotelling's $T^2$ test) is 0.79 and statistically significant at $p=0.07$. The rather weak significance levels may, of course, be attributed at least in part to the small sample size. There is nonetheless empirical evidence of multivariate differences between these two groups. To further explore the nature of these differences, a logistic regression analysis was performed with industry group membership as the binary criterion variable ("1" for a positive ELI-performance effect and "0" for no ELI-performance effect) and the four industry structural variables defined above as explanatory variables. The model yields a $\chi^2$ statistic of 9.45 which is statistically significant at the 5% level.

The results shown in Table 7 indicate that industry size (as measured by the total number of *Employees*) and industry profitability (*Gross Margin*) are statistically significant discriminant factors. A series of univariate two-sample t-tests confirm that the groups of industries show statistically significant differences in terms of employees and gross margins, but not in terms of growth rates and industry concentration levels. In summary, the preceding analyses indicate that inventory leanness tends to have a positive effect on firm performance in larger industries (as measured by the total number of individuals employed in the industry). Moreover, firms appear to realize positive returns to inventory leanness in industries that have higher gross margins. Caution must be exercised, however, when interpreting these results since causality is not implied. Therefore, a further theoretical and empirical exploration of industry and firm-level characteristics that favor a positive effect of inventory leanness on financial performance is an important endeavor suggested for future research.

## 8. Summary and concluding remarks

This research investigates the effect of inventory leanness on firm performance. The analysis of a large sample of U.S. manufacturing firms over a 6-year time period indicates that the significance and shape of this relationship varies greatly from one industry to another. One-third of the 54 industries studied here exhibit no significant effect of inventory leanness on firm performance. In other words, while lean inventory strategies may be economically viable in some industries, other industries may not be amenable to such approaches due to their particular product, production technology, supply or demand characteristics. The findings of this study, thus, replicate and reconcile the contradictory results of Cannon (2008) and Capkun et al. (2009). Pooling data from industries with dissimilar inventory–performance relationships can yield diluted estimation results. Hence, researchers should take this finding into account when designing future studies.

Another finding of this study is that the effect of inventory leanness on firm performance is mostly positive and generally nonlinear. In most instances, the effect of inventory leanness is concave implying – in line with inventory control theory – that there is an optimal degree of inventory leanness beyond which the marginal effect of leanness on financial performance becomes negative. This provides empirical support for the "pragmatic JIT" view of Zipkin (1991) which suggests that leaner is not always better.

**Table 7**
Industry-level logistic regression results ($N=41$).

| Variable | Coefficient estimate | $p$-value |
|---|---|---|
| Intercept | −12.73 | 0.07 |
| Growth rate | −7.78 | 0.25 |
| ln(Employees) | 1.09 | 0.08 |
| Gross margin | 7.75 | 0.04 |
| CR-4 | −0.02 | 0.40 |

[2] 2007 industry concentration data were not yet available at the time of writing. Data from the 2002 Economic Census were used to approximate industry concentration levels.

Post-hoc analyses reveal statistically significant differences in structural industry characteristics between industries with significant and non-significant performance effects of inventory leanness. Thus, it is inferred that observed differences in inventory–performance relationships are likely due to systematic inter-industry heterogeneity, rather than random chance.

Moreover, this study adds to prior lean production and inventory research by theoretically and empirically controlling for the effect of firm size on inventory leanness and presenting a size-adjusted inventory leanness measure (ELI). It is argued that this metric presents a more accurate assessment of a firm's true degree of leanness, which makes it useful and relevant both in academic research as well as in managerial practice.

As with any study, this research has a number of limitations. First, certain firm-level variables and the trade-offs among them that determine the appropriateness of lean inventory strategies are not observed. In an attempt to address this concern, the data are grouped in six-digit NAICS clusters to provide some control for unobserved heterogeneity among firms in the data set. Moreover, the results rely predominantly on data from industries with a moderate to high number of publicly traded firms.[3] As such, the generalizability to smaller industries or industries with relatively large numbers of privately held companies cannot be ascertained. Another limitation of this study is that it relies on U.S. data only. Many countries have expanding manufacturing industries in which industry-specific conditions may be different and differentially affect the inventory leanness–performance relationship. Thus, the results may not be generalizable beyond the U.S. From a managerial perspective, finally, the need for a comparatively large data set and basic statistical skills likely limits the usability of the ELI for at least some managers.

The empirical results suggest that industry-specific characteristics may drive the nature of the relationship between inventory leanness and firm performance. In the post-hoc analysis, an initial exploration of variables that may explain differences in the shape and magnitude of the inventory leanness–performance link was presented. Further research is needed, however, to define the firm-level and industry-level factors that make lean strategies appropriate for some firms and industries but not for others. Furthermore, what might be the factors that determine the functional form (linear versus inverted U-shape) of the relationship between inventory leanness and firm performance? Also, examining aspects of leanness other than inventory leanness might be interesting. For example, asset leanness can be differentiated from employee leanness. It may be interesting to gain an understanding of how different leanness measures and their interactions affect firm performance. In short, while this research addresses some interesting questions regarding lean production and inventories, many questions worthy of further investigation still remain.

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## Appendix A.

Tables 8–10.

[3] It is assumed that the secondary financial data (Compustat) data used here accurately represent a firm's financial characteristics. We thank an anonymous referee for pointing out that the manipulation or misrepresentation of balance sheet and income statement data may potentially be a concern associated with the use of such data.

**Table 8**
Summary of estimation results for Equation (1).

| | 2003 | | 2004 | | 2005 | | 2006 | | 2007 | | 2008 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NAICS | *N* | $R^2$ | *N* | $R^2$ | *N* | $R^2$ | *N* | $R^2$ | *N* | $R^2$ | *N* | $R^2$ |
| 334413 | 122 | 0.8951 | 132 | 0.8933 | 143 | 0.8702 | 156 | 0.8689 | 163 | 0.8841 | 156 | 0.8237 |
| 325412 | 109 | 0.9109 | 116 | 0.8982 | 123 | 0.8947 | 130 | 0.9277 | 137 | 0.9140 | 126 | 0.8919 |
| 334220 | 68 | 0.8898 | 71 | 0.8969 | 72 | 0.8650 | 78 | 0.9132 | 75 | 0.9074 | 70 | 0.9063 |
| 334510 | 68 | 0.8272 | 71 | 0.8228 | 74 | 0.8254 | 81 | 0.8496 | 82 | 0.8616 | 72 | 0.8611 |
| 334119 | 65 | 0.8119 | 67 | 0.8390 | 67 | 0.8553 | 72 | 0.7994 | 71 | 0.8434 | 66 | 0.8327 |
| 339113 | 38 | 0.9198 | 37 | 0.9426 | 39 | 0.9471 | 38 | 0.9597 | 35 | 0.9424 | 34 | 0.9351 |
| 325414 | 33 | 0.8238 | 40 | 0.7902 | 46 | 0.8054 | 51 | 0.8152 | 50 | 0.8366 | 46 | 0.8240 |
| 334210 | 33 | 0.8912 | 33 | 0.9125 | 30 | 0.9070 | 30 | 0.9050 | 30 | 0.8711 | 26 | 0.9023 |
| 339112 | 32 | 0.8833 | 35 | 0.8799 | 40 | 0.8339 | 40 | 0.8152 | 40 | 0.8274 | 39 | 0.8708 |
| 324110 | 30 | 0.9401 | 33 | 0.9322 | 33 | 0.9506 | 35 | 0.9276 | 36 | 0.9241 | 33 | 0.9206 |
| 334516 | 28 | 0.9501 | 29 | 0.9272 | 27 | 0.9467 | 26 | 0.9517 | 28 | 0.9270 | 24 | 0.8730 |
| 325413 | 27 | 0.8197 | 30 | 0.8574 | 31 | 0.8607 | 34 | 0.8964 | 35 | 0.8158 | 29 | 0.8497 |
| 333295 | 27 | 0.8802 | 28 | 0.9006 | 28 | 0.7781 | 28 | 0.9247 | 28 | 0.9049 | 22 | 0.8484 |
| 334515 | 26 | 0.8791 | 26 | 0.9260 | 26 | 0.9094 | 26 | 0.9209 | 27 | 0.9283 | 22 | 0.9561 |
| 326199 | 23 | 0.8875 | 22 | 0.9133 | 20 | 0.9250 | 19 | 0.9678 | 21 | 0.9389 | 17 | 0.9558 |
| 334290 | 23 | 0.7743 | 23 | 0.8634 | 26 | 0.8669 | 26 | 0.8850 | 26 | 0.9259 | 21 | 0.9116 |
| 334419 | 23 | 0.9164 | 23 | 0.8767 | 23 | 0.8531 | 22 | 0.8326 | 22 | 0.8806 | 20 | 0.9151 |
| 336399 | 23 | 0.9565 | 23 | 0.9378 | 20 | 0.9477 | 20 | 0.9443 | 19 | 0.9591 | 18 | 0.9281 |
| 325620 | 20 | 0.9584 | 19 | 0.9511 | 20 | 0.9814 | 19 | 0.9703 | 18 | 0.9563 | 17 | 0.9489 |
| 331111 | 20 | 0.9585 | 20 | 0.9488 | 20 | 0.9491 | 22 | 0.9537 | 22 | 0.9496 | 22 | 0.9496 |
| 334519 | 19 | 0.8376 | 20 | 0.8077 | 20 | 0.8629 | 20 | 0.8929 | 20 | 0.9333 | 19 | 0.8550 |
| 334112 | 18 | 0.8451 | 18 | 0.8868 | 19 | 0.9242 | 18 | 0.8586 | 17 | 0.8246 | 16 | 0.7103 |
| 334412 | 18 | 0.9700 | 18 | 0.9630 | 19 | 0.9550 | 18 | 0.9728 | 18 | 0.9691 | 15 | 0.9854 |
| 334513 | 18 | 0.9373 | 17 | 0.9287 | 16 | 0.9049 | 16 | 0.9450 | 16 | 0.9442 | 16 | 0.9670 |
| 334511 | 17 | 0.9033 | 17 | 0.8276 | 18 | 0.7923 | 18 | 0.8839 | 17 | 0.8872 | 17 | 0.8950 |
| 325998 | 16 | 0.8863 | 16 | 0.8263 | 16 | 0.8945 | 16 | 0.9744 | 15 | 0.9782 | 13 | 0.9683 |
| 334310 | 15 | 0.9661 | 16 | 0.9693 | 15 | 0.9421 | 12 | 0.9532 | 15 | 0.9395 | 13 | 0.9791 |
| 333132 | 14 | 0.8929 | 14 | 0.9183 | 14 | 0.9523 | 14 | 0.9424 | 16 | 0.9206 | 16 | 0.9221 |
| 325211 | 13 | 0.9876 | 13 | 0.9875 | 11 | 0.9693 | 11 | 0.9591 | 11 | 0.9578 | 11 | 0.9674 |
| 333314 | 13 | 0.9585 | 13 | 0.9668 | 13 | 0.9310 | 13 | 0.9491 | 14 | 0.9464 | 13 | 0.9297 |
| 334111 | 13 | 0.9358 | 13 | 0.9046 | 12 | 0.9143 | 12 | 0.9193 | 10 | 0.9299 | 10 | 0.9362 |
| 335312 | 13 | 0.9300 | 13 | 0.9609 | 13 | 0.9761 | 13 | 0.8705 | 13 | 0.8936 | 12 | 0.9742 |
| 336413 | 13 | 0.9688 | 13 | 0.9659 | 13 | 0.9731 | 13 | 0.9529 | 14 | 0.9619 | 11 | 0.9247 |
| 312111 | 12 | 0.9800 | 13 | 0.9852 | 13 | 0.9725 | 14 | 0.9849 | 15 | 0.9654 | 13 | 0.9771 |
| 322121 | 12 | 0.9793 | 12 | 0.9771 | 11 | 0.9869 | 11 | 0.9869 | 12 | 0.9790 | 12 | 0.9847 |
| 325188 | 12 | 0.9190 | 12 | 0.9314 | 13 | 0.9363 | 13 | 0.9514 | 13 | 0.9527 | 12 | 0.9198 |
| 333315 | 12 | 0.9731 | 12 | 0.9863 | 11 | 0.9799 | 11 | 0.9639 | 11 | 0.9610 | 9 | 0.9300 |
| 335999 | 12 | 0.7611 | 12 | 0.8373 | 13 | 0.8198 | 13 | 0.8887 | 15 | 0.8953 | 15 | 0.8383 |
| 333298 | 11 | 0.9086 | 9 | 0.9522 | 9 | 0.9618 | 9 | 0.9877 | 12 | 0.9428 | 12 | 0.7793 |
| 339920 | 11 | 0.9721 | 10 | 0.9651 | 10 | 0.9661 | 10 | 0.9173 | 10 | 0.9123 | 9 | 0.9330 |
| 333111 | 10 | 0.9806 | 10 | 0.9773 | 9 | 0.9702 | 9 | 0.9709 | 8 | 0.9800 | 8 | 0.9641 |
| 339932 | 10 | 0.9428 | 10 | 0.9784 | 10 | 0.8741 | 9 | 0.9556 | 8 | 0.9646 | 9 | 0.9531 |
| 325199 | 9 | 0.9389 | 9 | 0.9246 | 10 | 0.9255 | 8 | 0.8744 | 8 | 0.8902 | 8 | 0.8707 |
| 333319 | 9 | 0.9448 | 9 | 0.9336 | 11 | 0.8931 | 9 | 0.8859 | 9 | 0.9430 | 8 | 0.9534 |
| 334418 | 9 | 0.7744 | 10 | 0.8915 | 10 | 0.8969 | 10 | 0.8593 | 10 | 0.8964 | 9 | 0.9409 |
| 336322 | 9 | 0.9624 | 9 | 0.9586 | 9 | 0.9359 | 8 | 0.9559 | 8 | 0.9302 | 8 | 0.9212 |
| 339999 | 9 | 0.9723 | 10 | 0.9258 | 10 | 0.9267 | 13 | 0.9693 | 13 | 0.9475 | 14 | 0.9142 |
| 322130 | 8 | 0.9666 | 8 | 0.9796 | 8 | 0.9775 | 8 | 0.9881 | 8 | 0.9849 | 9 | 0.9868 |
| 325411 | 8 | 0.8539 | 8 | 0.9312 | 8 | 0.9688 | 7 | 0.9078 | 7 | 0.9456 | 7 | 0.9584 |
| 336111 | 8 | 0.9806 | 9 | 0.9825 | 9 | 0.9916 | 9 | 0.9945 | 9 | 0.9933 | 4 | 0.9982 |
| 339115 | 8 | 0.9944 | 8 | 0.9848 | 8 | 0.9734 | 10 | 0.9286 | 9 | 0.9694 | 9 | 0.9703 |
| 325612 | 7 | 0.9811 | 6 | 0.9792 | 7 | 0.9876 | 8 | 0.9801 | 8 | 0.9581 | 7 | 0.9700 |
| 335911 | 6 | 0.9962 | 6 | 0.9916 | 8 | 0.9910 | 9 | 0.9497 | 12 | 0.9004 | 10 | 0.8932 |
| 334517 | 5 | 0.9145 | 6 | 0.9372 | 6 | 0.9633 | 5 | 0.9738 | 6 | 0.9724 | 6 | 0.9348 |

**Table 9**
Summary of estimation results for Equation (2).

| Panel A | Explanatory variable: empirical leanness indicator (*ELI*) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Functional form | Linear | | | U-shaped | | | Inverted U-shaped | | |
| | I | II | III | IV | V | VI | VII | VIII | IX |
| $\hat{\beta}_{ELI}$ | + | – | 0 | + | – | 0 | + | – | 0 |
| $\hat{\beta}_{ELI^2}$ | 0 | 0 | 0 | – | – | – | + | + | + |
| Dep Var: ROS | | | | | | | | | |
| Number of industries | 6 | 0 | 18 | 17 | 1 | 8 | 1 | 1 | 2 |
| Average $R^2$ | 0.75 | | 0.77 | 0.69 | 0.94 | 0.83 | 0.79 | 0.93 | 0.94 |
| Average $\hat{\beta}_{ELI}$ | 3.52 | | 0.30 | 21.70 | −1.09 | 0.13 | 0.09 | −1.38 | −0.07 |
| Average $\hat{\beta}_{ELI^2}$ | −0.38 | | 0.13 | −11.14 | −0.31 | −0.70 | 0.05 | 0.59 | 0.08 |
| Dep Var: ROA | | | | | | | | | |
| Number of industries | 11 | 2 | 24 | 2 | 0 | 6 | 2 | 2 | 5 |
| Average $R^2$ | 0.80 | 0.71 | 0.76 | 0.84 | | 0.85 | 0.79 | 0.93 | 0.78 |
| Average $\hat{\beta}_{ELI}$ | 0.13 | −0.47 | 0.02 | 0.18 | | 0.03 | 0.12 | −0.56 | −0.04 |
| Average $\hat{\beta}_{ELI^2}$ | 0.00 | 0.11 | 0.05 | −0.10 | | −0.09 | 0.04 | 0.35 | 0.15 |
| **Panel B** | **Explanatory variable: inventory turns (*InvTurn*)** | | | | | | | | |
| Functional form | Linear | | | U-shaped | | | Inverted U-shaped | | |
| | I | II | III | IV | V | VI | VII | VIII | IX |
| $\hat{\beta}_{InvTurn}$ | + | – | 0 | + | – | 0 | + | – | 0 |
| $\hat{\beta}_{InvTurn^2}$ | 0 | 0 | 0 | – | – | – | + | + | + |
| Dep Var: ROS | | | | | | | | | |
| Number of industries | 4 | 0 | 27 | 20 | 0 | 0 | 0 | 2 | 1 |
| Average $R^2$ | 0.80 | | 0.72 | 0.75 | | | | 0.91 | 0.72 |
| Average $\hat{\beta}_{InvTurn}$ | 1.90 | | 0.48 | 1.00 | | | | −0.29 | −0.29 |
| Average $\hat{\beta}_{InvTurn^2}$ | −0.11 | | −0.01 | −0.02 | | | | 0.01 | 0.01 |
| Dep Var: ROA | | | | | | | | | |
| Number of industries | 7 | 0 | 30 | 9 | 0 | 0 | 0 | 5 | 3 |
| Average $R^2$ | 0.77 | | 0.82 | 0.82 | | | | 0.77 | 0.77 |
| Average $\hat{\beta}_{InvTurn}$ | 0.03 | | 0.00 | 0.19 | | | | −0.49 | −0.03 |
| Average $\hat{\beta}_{InvTurn^2}$ | 0.00 | | 0.00 | −0.01 | | | | 0.03 | 0.001 |

Note: The "+" sign indicates that the coefficient estimate is positive and statistically significant at $p < 10\%$, the "–" sign indicates that it is negative and significant at $p < 10\%$, and "0" indicates that it is not significant.

**Table 10**
Industry-level sample and model fit statistics by functional form.

| Shape | NAICS | FY | F | $R^2$ | Industry |
|---|---|---|---|---|---|
| I | 325620 | 113 | 22 | 0.72 | Toilet preparation manufacturing |
| I | 333132 | 88 | 16 | 0.69 | Oil and gas field machinery and equipment manufacturing |
| I | 322121 | 70 | 14 | 0.80 | Paper (except newsprint) mills |
| I | 334111 | 70 | 15 | 0.74 | Electronic computer manufacturing |
| I | 325199 | 52 | 11 | 0.63 | All other basic organic Chemical manufacturing |
| I | 325612 | 43 | 10 | 0.92 | Polish and other sanitation good manufacturing |
| III | 324110 | 200 | 39 | 0.55 | Petroleum refineries |
| III | 334515 | 153 | 27 | 0.75 | Instrument manufacturing for measuring and testing electricity and electrical signals |
| III | 331111 | 126 | 24 | 0.73 | Iron and steel mills |
| III | 334412 | 106 | 19 | 0.57 | Bare printed circuit board manufacturing |
| III | 334513 | 99 | 19 | >0.99 | Instruments and related products Mfg. for measuring, displaying, and controlling Ind. process variables |
| III | 325998 | 92 | 19 | 0.76 | All other miscellaneous chemical product and preparation manufacturing |
| III | 333314 | 79 | 14 | 0.67 | Optical instrument and lens manufacturing |
| III | 336413 | 77 | 16 | 0.87 | Other aircraft parts and auxiliary equipment manufacturing |
| III | 325188 | 75 | 13 | 0.88 | All other basic inorganic chemical manufacturing |
| III | 333315 | 66 | 12 | 0.90 | Photographic and photocopying equipment manufacturing |
| III | 339920 | 60 | 14 | 0.91 | Sporting and athletic goods manufacturing |
| III | 333319 | 55 | 13 | 0.75 | Other commercial and service industry machinery manufacturing |
| III | 333111 | 54 | 10 | 0.72 | Farm machinery and equipment manufacturing |
| III | 335911 | 51 | 13 | 0.99 | Storage battery manufacturing |
| III | 336322 | 51 | 10 | 0.75 | Other motor vehicle electrical and electronic equipment manufacturing |
| III | 322130 | 49 | 10 | 0.53 | Paperboard mills |
| III | 336111 | 48 | 10 | 0.66 | Automobile manufacturing |
| III | 334517 | 34 | 8 | 0.94 | Irradiation apparatus manufacturing |
| IV | 334413 | 872 | 173 | 0.43 | Semiconductor and related device manufacturing |
| IV | 325412 | 741 | 167 | 0.46 | Pharmaceutical preparation manufacturing |
| IV | 334510 | 448 | 96 | 0.82 | Electromedical and electrotherapeutic apparatus manufacturing |
| IV | 334220 | 434 | 85 | 0.77 | Radio and television broadcasting and wireless communications equipment manufacturing |
| IV | 325414 | 266 | 71 | 0.52 | Biological product (except diagnostic) manufacturing |
| IV | 339112 | 226 | 46 | 0.69 | Surgical and medical instrument manufacturing |
| IV | 325413 | 186 | 39 | 0.45 | In-vitro diagnostic substance manufacturing |
| IV | 333295 | 161 | 29 | 0.73 | Semiconductor machinery manufacturing |
| IV | 334290 | 145 | 28 | 0.72 | Other communications equipment manufacturing |
| IV | 334419 | 133 | 24 | 0.71 | Other electronic component manufacturing |
| IV | 336399 | 123 | 23 | 0.94 | All other motor vehicle parts manufacturing |
| IV | 335999 | 80 | 17 | 0.56 | All other miscellaneous electrical equipment and component manufacturing |
| IV | 335312 | 77 | 14 | 0.93 | Motor and generator manufacturing |
| IV | 325211 | 70 | 14 | 0.88 | Plastics material and resin manufacturing |
| IV | 339999 | 69 | 19 | 0.98 | All other miscellaneous manufacturing |
| IV | 333298 | 62 | 14 | 0.45 | All other industrial machinery manufacturing |
| IV | 334418 | 58 | 10 | 0.67 | Printed circuit assembly (electronic assembly) manufacturing |
| V | 339113 | 221 | 45 | 0.94 | Surgical appliance and supplies manufacturing |
| VI | 334119 | 408 | 79 | 0.97 | Other computer peripheral equipment manufacturing |
| VI | 334210 | 182 | 35 | 0.48 | Telephone apparatus manufacturing |
| VI | 326199 | 122 | 27 | 0.87 | All other plastics product manufacturing |
| VI | 334112 | 106 | 24 | 0.87 | Computer storage device manufacturing |
| VI | 334310 | 86 | 22 | 0.88 | Audio and video equipment manufacturing |
| VI | 312111 | 80 | 17 | 0.74 | Soft drink manufacturing |
| VI | 339932 | 56 | 12 | >0.99 | Game, toy, and children's vehicle manufacturing |
| VI | 325411 | 45 | 9 | 0.84 | Medicinal and botanical manufacturing |
| VII | 334519 | 118 | 20 | 0.79 | Other measuring and controlling device manufacturing |
| VIII | 334511 | 104 | 20 | 0.93 | Search, detection, navigation, guidance, aeronautical, and nautical system and instrument Mfg |
| IX | 334516 | 162 | 33 | 0.99 | Analytical laboratory instrument manufacturing |
| IX | 339115 | 52 | 10 | 0.89 | Ophthalmic goods manufacturing |

Note: F stands for number of firms, FY for number of firm-years.

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