Exploring Inventory Leanness on Firm Performance with a Non-linear Empirical Leanness Indicator using Kernel Regularized Least Squares (KRLS) Regression

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Abstract

The extant literature assumes linearity between inventories and sales We relax this assumption, suggesting the relationship may indeed be non-linear. We develop a measure of leanness termed non-linear empirical leanness indicator (NELI) using kernel regularized least squares (KRLS), which is an efficient and interpretable machine learning method allowing us to accurately capture the true functional form in the data without losing any explanatory power offered by traditional regression models. Next, we benchmark and demonstrate its potential as a better explanatory variable than the traditional measures in explaining both accounting-based performance measures (ROA) as well as market based measures (Market Capitalization). Prior literature tends to bunch industries together potentially missing industry specific characteristics. To avoid this, we analyze this relationship accounting for firm-specific fixed effects which encapsulates any industry specific effects. We examine this relationship in an emerging economy - Indian manufacturing firms. The dataset we use has been used in publications such as *Econometrica, Journal of Finance* and *Strategic Management Journal* amongst others, alluding towards its reliability. Our results suggest that overall leanness has a positive impact on firm performance. We also find that this effect is more pronounced in firms operating in a relatively stable environment. Overall, our results contribute to the literature by: a) documenting a positive impact of leanness on performance; b) showing that the effect can be dependent on the underlying business industry dynamics; and, c) showing that this effect is documented in samples outside the western world where management theories and practices are evolving.

Keywords: Inventory, Leanness, Kernal Regularized Least Squares (KRLS) Regression, Non-linear Empirical Leanness Indicator

1. Introduction – lean manufacturing and firm performance

Adoption of lean production practices is a well evidenced in the operations management literature (Novias *et al.,* 2020; Jain *et al.,* 2013; Koumanakos 2008;). Specifically, the role of advanced production techniques in reducing inventory inefficiency has been a point of focal interest (Ivanov 2021). The fundamental philosophy underlying most inventory management innovations in recent times is reduction of waste (e.g., Darby *et al.,* 2019; Womack, *et al.,* 1990a). In this backdrop lean inventory management has been viewed favorably as a technique which helps reduce wastage and improves operational efficiency (See Garcia-Buendia *et al.,* 2021; Chen *et al.,* 2005; Cooper and Maskell, 2008). Initially, efficient inventory management systems led to a reduction in overall inventory levels held by firms primarily in the United States (Chen *et al.,* 2005). However, the linkage between inventory performance and improvement in firm performance (as measured by accounting/market-based performance metrics) is mixed (Capkun *et al.,* 2009; Rumayantsev and Nettisine, 2007). The current mixed state of the literature exhibits an opportunity for further inquiry.

First, there is a debate in the extant literature on over what is the ideal measure of inventory efficiency (Eroglu and Hofer 2011; Hofer *et al.,* 2012). Existing research typically uses different measures of inventory such as average inventory levels, inventory turnover or similar measures using absolute or relative inventory levels (Capkun *et al.,* 2009; Gaur *et al.,* 2005) and examine its impact on either accounting measures of performance or market-based measures. However as noted by Eroglu and Hofer (2011), these measures suffer from a significant bias -- it does not take into account the relative size of the firm. Thus, economies of scale which can significantly impact the performance of the firm is potentially an omitted variable when using absolute inventory measures, which in turn could explain the lack of robust results. Eroglu and Hofer (2011) suggest an alternative measure of leanness based on an industry-year regressions of sales on inventory levels. Their measure is more robust to some of the common criticisms such as the scale effects which is well documented as causing measurement error in inventory models. While their measure offers an advantage over existing techniques, it is still restrictive in the sense that there is a strong assumption that the relationship between sales and inventories is strictly linear. What if the linearity assumption between inventories and sales does not hold? In this paper we seek to relax this and suggest that based on analytical models in inventory management, the relationship between sales and inventories may indeed be non-linear. To accommodate for this factor, we propose to develop a new measure of leanness termed non-linear empirical leanness indicator (NELI) using kernel regularized least squares (KRLS). KRLS is an efficient and interpretable machine learning method which allows us to more accurately capture the true functional form in the data without losing out on the explanatory power offered by traditional regression models.

Second, using our new measure we seek to benchmark and demonstrate its potential as a better explanatory variable as compared to the traditional measures in explaining both accounting based performance measures (ROA) as well as market based measures (Market Capitalization). Prior literature typically tends to bunch industries together when undertaking this analysis and thus may miss out on industry specific characteristics which can potentially shape the relationship between leanness and firm performance. To avoid this, we analyze this relationship by accounting for firm-specific fixed effects which encapsulates any industry specific effects.

Third, while a bulk of the existing literature on operations efficiency focuses on North America, we believe that it is especially relevant and timely given that manufacturing activities are outsourced to a large extent, to examine operational efficiency and its impact on firm performance in developing nations. Keeping this in mind, we examine the relationship between inventory efficiency and firm performance on Indian manufacturing firms. The dataset that we use has been used in publications such as *Econometrica, Journal of Finance and Strategic Management Journal* amongst others, alluding towards its reliability.

The results from our analysis show that overall leanness has a positive impact on both accounting-based performance as well as market-based performance. We also find that the effect is pronounced in firms which tend to be operating in a more stable setting as compared to firms that are operating in a relatively risky environment. Overall, our results contribute to the literature by: a) documenting a positive impact of leanness on performance; b) showing that the effect can be dependent on the underlying business dynamics of the industry; and, c) showing that this effect is documented in samples outside the western world where management theories and practices have not evolved as much.

2. Literature support and hypotheses development

The common belief elucidated in operational management research is that inventory leanness has a positive relationship with financial performance (see Hofer *et al.,* 2012) for a thorough review of empirical studies on the lean production-financial performance relationship). This belief has recently been reinforced with Logisitcs 4.0, an evolutionary view of logistics featuring vertical integration, horizontal integration, and end-to-end engineering integration (Bag *et al.,* 2020). In theory, the better a firm is at keeping inventories low, which frees up space and capital for other investments in the company, the better the firm's financial performance will be. The literature on this theory is mixed although a majority of research does provide evidence of a significant positive relationship between inventory leanness and financial performance (Srinivasan and Iyer 2020). The common theme in previous research papers is that there is some form of inventory measure that is studied to examine the effect on some indicator of financial performance, usually an account measure like ROA or EBIT. Salawati *et al.,* (2012), while noting that performance measurement remains a surprisingly unsettled area, lend credence to the work done by Chen *et al.,* (2005) in using Tobin's q as a measurement for firm performance and number of days in inventory as a measurement of inventory management.

Inventory production can also be broken down into internal and external lean practices with each having an independent effect on financial performance (Hofer *et al.,* 2012) - Return on Sales, while also having a larger significant effect when taken simultaneously. Capkun *et al.,* (2009) also contribute to the literature by delving deeper into the actual components of inventory leanness and their relationship to financial performance. They found that various components of inventory such as Raw Materials, Work-in-Process and Finished Goods each had a significant positive correlation with Earnings Before Tax and Gross Profit.

Kolias *et al.,* (2011) found that, based on an econometricanalysis of Greek retail firms over a period from 2000-2005 Inventory Turnover Ratio as a measure of inventory management, is negatively correlated with Gross Margin. They found a negative correlation between Gross Margin and Inventory Turnover, implying a tradeoff between gross margin and inventory turns in the retail sector. Hofer *et al.,* (2012) empirically investigated the relationship between lean production and financial performance, and elucidated the mediating role of inventory leanness in driving the financial performance benefits commonly associated with lean production. Llerton *et al.,* (2014) found a clear link in performance improvement as firms take a holistic lean approach combined with management accounting practices, termed MAP. Kim and Na (2021) found that firms with overconfident CEOs and COOs, other circumstances being equal, increase (decrease) inventory leanness as the market becomes more competitive.

While most of the aforementioned studies use inventory-turnover based metrics as a measure to capture changes in inventory leanness, these variables do not consider economies of scale and often are unreliable when measuring true changes in inventory leanness. Cannon (2008) used percentage increase in inventory turnover and found no significant evidence that increases in inventory turnover improved the firms' Market Value or Tobin's Q, as well as a negative relationship between inventory leanness and financial performance - ROA and ROI. Recent research has adopted a new metric to measure inventory leanness called the Empirical Leanness

Indicatory (ELI) developed by Eroglu and Hofer (2011). Eroglu and Hofer (2011), studying US manufacturers over a five-year period, argue that ELI was the best measure of inventory management given that many firms use JIT inventory and lean manufacturing principles which treats inventory as a potential waste. The ELI does a better job of capturing the relationship between inventory and sales. According to Eroglu and Hofer (2011) the ELI does a better job compared to accounting measures of inventory leanness because it is easy to interpret, takes economies of scale into consideration, and addresses concerns of potential attenuation bias. Recent empirical examinations of ELI and operational efficiency include the study of the moderating roles of firm size and demand uncertainty (Chuang, Oliva, & Heim 2019); the mediating effect on production efficiency (Sahare and Chandra 2021); and, stock price sensitivity (Chakrabarty and Wang 2021).

As indicated by this select literature review, the results regarding the impact of lean production on firm performance is clearly mixed. Some studies find that there is a positive effect of leanness on performance. It is important to note that adoption of leaner operations has a systemic impact on all operations at the firm level which in turn has an impact on the overall performance of the firm. Lean production, it has been argued is not necessarily ideally suited for all firms (Zipkin, 1991) and is also susceptible to the vagaries of the industry (Haan and Yamamoto, 1999). We should expect a firm's financial performance to increase as they adopt inventory leanness measures as it will free up a firm's resources. Having large amounts of inventory and poor inventory efficiency will shore up a company's capital by increasing the amount of capital tied up due to high inventory levels. This leads us to our first hypothesis:

H1: Financial Performance is positively affected by an increase in a firm's inventory leanness.

Figure 1. Hypotheses one

Market value is a measurement that allows us to determine the real net worth of a firm and gives us insight into the value of the firm. Our hypothesis predicts that as a company becomes leaner with regards to inventory they should see an increase in their market value. Firms that do not hold onto a lot of inventory will be able to grow faster which will increase their market value as they increase their profits and expansion opportunities, for instance. This leads us to our second hypothesis:

H2: Market value is positively affected by an increase in a firm's inventory leanness.

Figure 2. Hypotheses two

3. Data and empirical methods

For our analysis, we use the ProwessDx database from the Centre for Monitoring the Indian Economy (CMIE). The Prowess database contains information on firm characteristics for all publicly traded companies. This dataset has long been used extensively in the literature when studying Indian firms (e.g., Khanna and Palepu 2001; Goldman and Viswanath 2017; Komera and Tiwari 2021; Alrashidi and Baboukardos 2021; and, Mal and Gupta 2020). We use yearly data that spans the time frame between 2008 through 2017 and covers all firms listed on either the Bombay Stock Exchange (BSE) or the National Stock Exchange (NSE). The descriptive statistics and correlations are provided in Tables I and II respectively.

Table 1. Descriptive statistics

	Mean	SD	Min	Max
Log ROA	-2.193	0.725	-8.030	1.412
Log Market Cap	2.847	2.165	-2.962	10.429
ELI	-0.006	1.046	-9.597	5.662
ELI * ELI	1.093	2.296	0.000	92.097
ELI * Total Assets	-0.261	4.673	-48.841	33.910
ELI * Sales Growth	0.583	72.830	-3258.979	4553.125
Log Total Assets	3.770	1.716	-1.746	10.216
Sales Growth	1.230	51.378	-0.992	3102.348

Table 2: Correlation matrix

	I	II	III	IV	V	VI	VII	VIII
Log ROA	1.00							
Log Market Cap	0.27	1.00						
ELI	0.17	-0.07	1.00					
ELI * ELI	-0.03	0.08	-0.13	1.00				
ELI * Total Assets	0.14	-0.14	0.92	-0.16	1.00			
ELI * Sales Growth	0.02	-0.01	0.03	0.01	0.02	1.00		
Log Total Assets	0.11	0.85	-0.13	0.09	-0.22	-0.01	1.00	
Sales Growth	-0.02	-0.01	0.01	0.01	0.01	0.32	-0.01	1.00

3.1 Measure of firm performance

Following prior literature we use two measures of firm performance. Our first measure is an accounting-based return measure (Return on Assets). Our second measure is a market-based measure (Market Capitalization).

3.2 Measures of Operational Excellence

There is a debate in the literature on what is the ideal measure of inventory efficiency. Existing research typically uses different measures of inventory such as average inventory levels, inventory turnover or other measures using absolute inventory level (Capkun *et al.,* 2009; Gaur *et al.,* 2005) and examine its impact on either accounting measures of performance or market-based measures. However as noted by Eroglu and Hofer (2011), these measures suffer from a significant bias in the sense that it does not take into account the relative size of the firm. Thus, economies of scale which can significantly impact the performance of the firm is potentially an omitted variable when using absolute inventory measures, which in turn could explain the lack of robust results. Eroglu and Hofer (2011) suggest an alternative measure of leanness based on a industry-year regressions of sales on inventory levels. The residuals from this regression are used as a measure of inventory leanness. However, their model assumes that a linear regression is sufficient to capture this relationship. We use a different approach which allows for a non-linear functional form to determine the relationship between inventory and sales. To this end we compute the residuals from a regression model using Kernel Regularized Least Squares (KRLS) (Hainmueller, 2014) to use as our measure of leanness.

3.3 Measures of Risk

We also check if our results hold for various sub-samples. Specifically, we identify those firms which face higher sales volatility relative to their industry and class them as high-risk firms as compared to others who face lower volatility compared to their peers.

3.4 Control Variables

In order to ensure that the results from our analysis are not influenced by other omitted correlated variables, we control for other determinants of performance. Primarily we include proxies for the size of the firm, as measured by total assets, and sales growth.

4. Analysis and results

To test our hypotheses we use the following regression model:

$$ln(Performance) = \beta_0 + \beta_1 ELI_t + \sum \beta_k X_{kit} + \eta_{ij} + d_t + \varepsilon_{it} \qquad (1)$$

where our dependent variable is a measure of log performance (ROA or Market Cap). The set of control variables X_{kit}, include the log of total assets, sales growth, ELI^2 (to capture any non linearities) and interaction terms between ELI and Growth & ELI and Size. Following prior research, we also control for firm and year fixed effects to remove any unobserved heterogeneity within our data. All standard errors are also clustered at the firm level to remove any potential serial correlations (Petersen 2009).

Our main coefficient of interest is β_1 which captures the impact of how leanness impacts firm performance. The results from our analysis for the full sample is presented in Table III. Models m 1 through m 6 measure the impact of leanness as measured by our ELI indicator on firm accounting performance as measured by the ROA. As can be seen from Table III, ELI has a positive and strongly significant relationship to ROA in all models. Thus, we find strong support for hypothesis 1 in our sample. We do not find any non-linearity in the relationship between ELI and firm performance as the squared term which captures such non linearities are indeed insignificant across all models. We also do not find any moderating effects of firm size and/or firm growth on performance in our models.

Table 3: Inventory leanness and firm performance

	m1	**m2**	**m3**	**m4**	**m5**	**m6**
ELI	0.223***	0.223***	0.294***	0.225***	0.300***	0.300***
	(0.018)	(0.018)	(0.051)	(0.018)	(0.051)	(0.051)
Log Total Assets	-0.108***	-0.107***	-0.109***	-0.108***	-0.110***	-0.110***
	(0.038)	(0.038)	(0.038)	(0.038)	(0.038)	(0.038)
Sales Growth	0.011	0.011	0.011	0.013	0.013	0.013
	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)
ELI * ELI		-0.008	-0.010	-0.006	-0.009	-0.009
		(0.008)	(0.008)	(0.008)	(0.008)	(0.008)
ELI * Total Assets			-0.017		-0.018	-0.018
			(0.011)		(0.011)	(0.011)
ELI * Growth				-0.014	-0.015	-0.015
				(0.011)	(0.011)	(0.011)
Firm Fixed Effects	YES	YES	YES	YES	YES	YES

Year Fixed Effects	YES	YES	YES	YES	YES	YES
Clustered SE's	Firm	Firm	Firm	Firm	Firm	Firm
Number of observations	6,367	6,367	6,367	6,367	6,367	6,367
Adjusted R2	0.510	0.510	0.511	0.511	0.511	0.511

note: .01 - ***; .05 - **; .1 - *;

To test Hypothesis 2 we ran the same regressions with the only exception being that we now use market cap as our dependent variable. Results from this analysis is presented in Table 6. As can be seen from Table 6, the results are qualitatively very similar to those presented in Table 2. Substantively it implies that as leanness improves, market performance also improves. The effect is robust and significant across all models. We do not find any significant moderating effect or non-linearities in our regressions. Overall, we find support for Hypothesis 2 in our data.

Finally, we also conduct sub-sample analysis to check if firms facing differential risk environments react differently. For instance, firms with highly volatile sales might not be as inclined to focus on leanness as compared to firms with relatively stable sales. To check for these differences we run sub-sample analysis where the sample is divided into two groups, one which has sales volatility greater than its industry sales volatility and vice versa. The results from this analysis is presented in Tables IV and V respectively. As can be seen from Table IV, the impact of leanness on performance is not as robust as in the full sample. Two of the specifications show that this relationship is insignificant. Further Table V shows that for the low volatility sample, the impact of leanness on performance is fairly robust and substantively larger (higher effect sizes) as compared to the high volatility sample. Cumulatively, this suggests that leanness takes priority in firms which have relatively stable sales as compared to their respective industries.

Table 4: Inventory leanness and firm performance (high volatility firms)

	m1	**m2**	**m3**	**m4**	**m5**	**m6**
ELI	0.194**	0.170**	0.088	0.179**	0.197	0.197
	(0.079)	(0.068)	(0.286)	(0.069)	(0.327)	(0.327)
Log Total Assets	-0.158	-0.141	-0.141	-0.181	-0.181	-0.181
	(0.129)	(0.130)	(0.130)	(0.121)	(0.119)	(0.119)
Sales Growth	0.256	0.236	0.238	0.309*	0.309*	0.309*
	(0.161)	(0.144)	(0.145)	(0.160)	(0.161)	(0.161)
ELI * ELI		-0.039*	-0.038	-0.025*	-0.025	-0.025
		(0.023)	(0.024)	(0.015)	(0.015)	(0.015)
ELI * Total Assets			0.012		-0.003	-0.003
			(0.038)		(0.042)	(0.042)
ELI * Growth				-0.148	-0.149	-0.149
				(0.122)	(0.128)	(0.128)
Firm Fixed Effects	YES	YES	YES	YES	YES	YES
Year Fixed Effects	YES	YES	YES	YES	YES	YES
Clustered SE's	Firm	Firm	Firm	Firm	Firm	Firm
Number of observations	378	378	378	378	378	378
Adjusted R2	0.578	0.586	0.585	0.598	0.597	0.597

note: .01 - ***; .05 - **; .1 - *;

Table 5: Inventory leanness and firm performance (low volatility firms)

	m1	m2	m3	m4	m5	m6
ELI	0.225***	0.225***	0.309***	0.228***	0.315***	0.315***
	(0.018)	(0.018)	(0.055)	(0.018)	(0.055)	(0.055)
Log Total Assets	-0.104***	-0.103***	-0.105***	-0.105***	-0.107***	-0.107***
	(0.039)	(0.039)	(0.040)	(0.039)	(0.039)	(0.039)
Sales Growth	0.010	0.010	0.010	0.012	0.012	0.012
	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)
ELI * ELI		-0.004	-0.007	-0.003	-0.006	-0.006
		(0.008)	(0.008)	(0.008)	(0.008)	(0.008)
ELI * Total Assets			-0.021*		-0.022*	-0.022*
			(0.012)		(0.012)	(0.012)
ELI * Growth				-0.013	-0.014	-0.014
				(0.011)	(0.011)	(0.011)
Firm Fixed Effects	YES	YES	YES	YES	YES	YES
Year Fixed Effects	YES	YES	YES	YES	YES	YES
Clustered SE's	Firm	Firm	Firm	Firm	Firm	Firm
Number of observations	5,989	5,989	5,989	5,989	5,989	5,989
Adjusted R2	0.504	0.504	0.505	0.505	0.505	0.505

note: .01 - ***; .05 - **; .1 - *;

5. **Discussion and conclusion**

Lean production is one of the common initiatives that firms adopt to improve firm's competitiveness because it is supposed to reduce waste along the value chain (Abreu-Ledon, *et al.,* 2018; Womack *et al.,* 1990b; Holweg 2007). However, it is still unresolved, whether firms indeed improve firm performance using lean manufacturing. While a number of studies have found a positive relationship between lean manufacturing and financial performance (e.g. Kaynak 2003; Ahmad *et al.,* 2004; Nawanir *et al.,* 2014), there are a number of studies that do not find any such relationship (Balakrishnan *et al.,* 1996; Avittathur and Swamidass 2007; Jayaram *et al.,* 2008). Our research attempts to resolve the relationship between lean production and firm performance, with a unique design, that can answer this vexing question universally, and that is more generalizable. Using modified measures for accounting-based performance as well as market-based performance, we find that there is a positive relationship between leanness and firm performance. Further, we also show that the underlying business fundamentals play an important role in determining if leanness contributes to firm performance. It is more likely that lean manufacturing improves firm performance, in those firms that are operating in a relatively stable environment.

Our study is also unique because it has used data from an emerging economy. Using data from an emerging economy is advantageous, and more pertinent to answering our research question. As India is an emerging economy, use of lean manufacturing is not completely pervasive, unlike developed economies, where there is some level of lean manufacturing in most companies. That allows us to have a discriminant data between companies with well-developed lean manufacturing, and companies without much lean manufacturing. Additionally, it allows us

to test the relationship between lean production and firm performance in an emerging economy.

Table 6: Inventory Leanness and Market Performance

	m1	m2	m3	m4	m5	m6
ELI	0.171***	0.170***	0.130**	0.166***	0.121**	0.121**
	(0.023)	(0.023)	(0.058)	(0.023)	(0.058)	(0.058)
Log Total Assets	0.849***	0.850***	0.852***	0.850***	0.852***	0.852***
	(0.045)	(0.045)	(0.045)	(0.045)	(0.045)	(0.045)
Sales Growth	0.000	0.000	0.000	0.010	0.010	0.010
	(0.000)	(0.000)	(0.000)	(0.008)	(0.008)	(0.008)
ELI * ELI		-0.006	-0.005	-0.007	-0.006	-0.006
		(0.010)	(0.009)	(0.009)	(0.009)	(0.009)
ELI * Total Assets			0.010		0.011	0.011
			(0.014)		(0.014)	(0.014)
ELI * Growth				0.008	0.008	0.008
				(0.006)	(0.006)	(0.006)
Firm Fixed Effects	YES	YES	YES	YES	YES	YES
Year Fixed Effects	YES	YES	YES	YES	YES	YES
Clustered SE's	Firm	Firm	Firm	Firm	Firm	Firm
Number of observations	6,496	6,496	6,496	6,496	6,496	6,496
Adjusted R2	0.922	0.922	0.922	0.922	0.922	0.922

note: .01 - ***; .05 - **; .1 - *;

Our finding also contribute to the field in terms of improved measures used in such stream of research. Most studies that used inventory efficiency suffered from a significant measurement bias. They did not take into account the relative size of the firm when measuring inventory efficiency (Eroglu and Hofer (2011). While Eroglu and Hofer (2011) used an alternative measure of leanness based on an industry-year regressions of sales on inventory levels, their measure was criticized because there is a strong assumption that the relationship between sales and inventories is strictly linear. In our measurement, we have addressed both these weaknesses simultaneously.

Our findings suggest both normative and positive implications for practicing managers. Our results suggest that overall leanness has a positive impact on firm performance, validating the quest for firms to continue to embark on lean inventory management practices and develop industry-specific lean principles. We also find that this effect is more pronounced in firms operating in a relatively stable environment, implying that management needs to continually assess the stability and volatility in their respective industries while simultaneously embarking on lean inventory practices. Future research is needed to verify if these findings hold for other lean manufacturing practices and principles in the firm, as well as in more mature economies.

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