Paradoxical Association Between Lean Manufacturing, Sustainability Practices and Triple Bottom Line Performance

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***Abstract*— This study examines the associations between lean manufacturing (LM), sustainability practices, and corporate performance in the form of the triple bottom line (TBL). In particular, we examine how LM is associated with environmental practices (EPs) and social practices (SPs) for TBL performance. While the positive association between LM and EPs is widely discussed in literature, it remains unclear whether this association persists when firms aim to implement SPs together with EPs to improve TBL performance further, particularly from the Asian perspective. Using two conflicting views of corporate sustainability as a theoretical lens, we seek to address these gaps by developing a set of hypotheses about the direct and interactive associations among them. The data were collected via a survey of 177 manufacturing firms in India, one being regarded as a next global manufacturing hub. Based on the data, we conducted ordinary least squares (OLS) regression analysis. The results suggest that LM is positively associated with EPs, SPs and TBL performance. Nevertheless, when LM interacts with EPs, SPs or both, we find that it is detrimental for TBL performance. These results are further validated by additional analyses using Johnson–Neyman and bootstrapping techniques. This paper contributes to the sustainable operations management and lean manufacturing literature by untangling complex and paradoxical association between LM, sustainability practices and TBL performance. Also, our paper initiates a crucial discussion on ways of managing paradoxical tensions between LM and sustainability practices.**

***Index Terms*— Lean manufacturing, Paradoxical tension, Regression analysis, Sustainability practices, Triple bottom line performance**

I. Introduction

Lean manufacturing (LM) has been developed to reduce costs while maximizing resource utilization by eliminating production inefficiency (i.e., waste) as well as empowering workers [1], [2], [3]. Though extensively studied, inconsistencies remain regarding how LM is defined in the literature [4], [5]. This ambiguity might be because LM is an ever-evolving concept, which is becoming "everything that is good" [6]. A recent trend of LM being integrated with 'good' is being discussed regarding sustainability. Numerous scholars have improved our understanding of LM as an approach to enhancing both efficiency and sustainability in supply chains (e.g., [7-8]. Following this, we refer to LM as manufacturer's initiatives to eliminate inefficiency or waste, which can lead to corporate sustainability in the form of the triple bottom line (TBL) [9-10].

According to the TBL framework, corporate sustainability practices can be composed of environmental (EPs) and social practices (SPs) [9-10]. EPs are referred to as a firm's initiatives for waste reduction and preservation of natural resource in its own businesses. In manufacturing, EPs concern activities to produce eco-friendly products with low waste and by resource-efficient methods such as employing reusable packages [11], [12]. On the other hand, SPs refer to activities to advance labor conditions, gender equality, social security, human rights, minority development and workforce welfare [13], [14]. For example, a common form of SPs is labor policies and conventions within a manufacturing firm to maintain a high level of employee welfare by providing fair labor conditions, clear labor standards, and rigorous health and safety standards. While a firm's sustainability practices refer to a firm's set of strategies, programs and activities to promote the positive environmental and social effects of its products and operations [15-17], sustainability performance, on the other hand, measures the results of such initiatives [9-10]. For this reason, this paper investigates the practices and performance of corporate sustainability separately in order to provide deeper insights into the nature of their relationships with LM.

Associations between LM and EPs have been extensively discussed (e.g., [12], [18-22]). The consensus in the literature is that LM tends to share common characteristics (e.g., waste reduction) with EPs and is also positively associated with EP implementation. However, what is lacking is knowledge of whether this positive association remains the same when firms try to implement SPs alongside EPs to improve TBL performance. Although scholars have investigated how LM is associated with SP implementation (e.g., [7], [23-24]), it remains unclear how LM would interact with both SPs and EPs together. Indeed, improving TBL requires firms to implement various sustainability practices simultaneously [9-10]. However, the performance implication of such practices is not well understood and anecdotal evidence points towards paradoxical outcomes [25-27]

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Most prior studies on LM are based on the developed countries' view [28] using data from the United States or Europe, and LM studies from the Asian perspective remain relatively rare. The small but growing number of LM studies using data from Asia, however, mostly reflect Chinese companies. Thus, it is relatively unknown how these practices are executed in other Asian emerging economies such as India. Recently, Indian manufacturing exports have set a record high of $418 billion in 2022 and are expected to reach $1 trillion by 2028 [29]. The Indian government aims to increase the contribution of manufacturing to GDP 25% by 2025 [30]. In addition, the Indian government has launched various pro-manufacturing policies such as 'Make in India' and 'Production Linked Incentive Scheme' to achieve its ambitious target to be the next global manufacturing hub [31-32]. Despite such positive growth prospects in the manufacturing sector, India has been struggling to meet its sustainability goals. For example, India has been ranked as the third biggest CO_2 emitter after China and the United States, and its government has set a new 45% emissions reduction target by 2030 [33]. Such sustainability initiatives by the government, however, may collide with its ambition to become the next global manufacturing powerhouse.

Against this background, this study delves into LM in the context of sustainable operations management. In particular, we investigate the following research question using the data from Indian manufacturing industry: *How is LM paradoxically associated with sustainability practices (i.e., EPs and SPs) for TBL performance*? Using the two conflicting views of corporate sustainability [34-35] as a theoretical lens, we argue that when implemented separately, LM, EP and SP are positively associated with TBL performance (i.e., win-win). When implemented together, however, they can collide, thus potentially undermining TBL performance (i.e., win-lose). Our analysis of data collected from 177 manufacturing firms in India confirms our assumption. Indeed, our study provides empirical evidence of the paradoxical nature of the associations between LM, sustainability practices and TBL performance in manufacturing.

This study contributes to the intersection of LM and sustainable operations management literature. Our results suggest that manufacturing firms face inherent trade-offs when they aim to achieve TBL goals through EPs and SPs together with the implementation of LM. These tensions (trade-offs) among corporate sustainability initiatives have been extensively studied in management research [36-37], and our study advances this stream of research further by shedding light on the complex trade-off relationships among sustainability practices from the LM perspective [2], [23], [38]. Managers would also gain practical insights from our study. Our findings show a negative interaction of LM with sustainability practices for TBL performance. However, this negative result does not necessarily mean that managers should drop either LM or sustainability practices. Instead, as neither LM nor sustainability practices are unnecessary for businesses, managers are required to better perceive those inherent conflicts and seek workable responses [39]. Firms need to understand the inherent trade-offs in sustainable manufacturing to move toward win-win outcomes.

The present study is organized as follows. Section II provides the literature review on the TBL view of corporate sustainability. In particular, we present two conflicting views on the links between the pillars of TBL as our theoretical lens. This description is followed by the development of hypotheses. Section III describes the research methodology employed in this study. Section IV provides data analysis and results along with robustness checks. In Section V, we discuss theoretical and practical contributions of our paper alongside limitations and suggestions for future research.

II. THEORETICAL BACKGROUND AND HYPOTHESES

A. The TBL view of sustainability

The idea of sustainability has been around since the 17th century, with the encouragement of sustainable logging practices in Germany. In this sense, the term sustainability originated in ecology. The domain of sustainability has been often built on the concept of TBL (Elkington, 1997; 2018), namely the planet (environment), profit (economic), and people (social). The TBL view of sustainability argues that firms should maintain not only the economic aspect of their business, but also the interests of society and the environment. That is, corporate sustainability can only be achieved by balancing all three aspects of TBL together [40], often viewed as an integrative logic [39], [41].

The first pillar of TBL is environmental sustainability, which refers to firms' ability to sustain efficient use of natural resources, reduce emissions, and avoid environmental harm [42]. Reduction of CO2 emissions has long been a central goal in this pillar due to climate change [40], [43-44]. Waste reduction and energy utilization are other important aspects of environmental sustainability. For instance, Lee and Vachon [45] suggest employing eco-efficiency approach to guide firms in the fulfilment of better-quality goods and services with less energy usage and pollution. Also, legal requirements (e.g., EU's recycling and recovery laws) as well as market intervention (e.g., heave waste discharge fees), and customer demand on pollution prevention have placed increasing pressures on firms to adopt measures to reduce their waste load [46-47].

Economic sustainability is another pillar of TBL, which mainly concerns with a firm's ability to maintain its financial outcomes [42]. For example, firms pursuing sustainability initiatives can sometimes expect to achieve cost competitiveness at the same time through increased productivity and savings in input and waste-disposal expenses [48]. Cost benefits from improved production efficiency may comprise of manufacturing costs, material procurement, and energy consumption expenses. Furthermore, reduction in waste disposal costs (e.g., waste treatment, discharge expenses) is often one of the main motivations for manufacturing firms to adopt resource reduction initiatives [49].

The last pillar in the TBL framework is social sustainability. This involves firms' ability to care for labor/human rights and occupational health and safety, which are important for both internal (e.g., employees) and external communities [11]. Ensuring such social sustainability is recognized as a critical element in achieving international competitiveness [50]. Firms excelling in social sustainability would build employee goodwill and loyalty often resulting in achieving superior financial performance [51]. By motivating and providing support to employees in their community projects and activities, firms strengthen their relationship with local communities and improve their living standards.

The three pillars of TBL are interdependent and affect each other in numerous ways. In this view, some scholars argue that one pillar's sustainability, e.g., the planet, can be achieved only by way of the other two's sustainability pillars [52]. In a similar vein, some contend that society and economic activities cannot exist without the natural environment, and thus should be nested within the planetary component [53]. However, these views do not refute the goal of TBL that underlies the 17 Sustainable Development Goals [54]. Since Elkington's TBL [9], firms have prioritized economic interests ahead of the other two (i.e., instrumental logic). In 2018, 25 years later, Elkington highlighted his original intention of TBL that needs "breakthrough change" for true TBL goals [10]. To make it (i.e., right balance) happen, however, it is important to examine conflicts inherent among TBL pillars, which we discuss next from the context of LM.

B. Two conflicting views of TBL

In this study, we examine the paradoxical association between LM and sustainability practices, that is, EPs and SPs, for TBL performance. Our focal premise is that LM, EPs and SPs, when implemented separately, would enhance TBL performance, but collide with each other creating negative performance implication, when implemented together (i.e., interactions). Thus, we investigate these intertangled complex relationships by using the conflicting views of corporate sustainability [34-35], [39] as a theoretical lens.

The first of the conflicting views is a win-win (i.e., business case) perspective, which assumes that each pillar of TBL sustainability can be complementary [36-37]. That is, the improvement of one or two pillars of TBL can also enhance other pillar(s). One notable example is an instrumental logic suggesting that firms pursuing environmental and societal initiatives can also benefit from economic improvement. Numerous studies have empirically tested this association. For instance, [49] find an alignment between pursuing environmental initiatives and firms' competitiveness. They consider pollution as a form of economic waste and argue that pollution reduction often comes with improvement in overall competitiveness. For the economic–societal alignment, Porter and Kramer [55] show how societal initiatives by firms can also result in economic improvement. Indeed, this win-win approach suggesting a complementary relationship between each pillar of TBL is currently dominant in the sustainability literature.

The grounds of this approach can be explained by the nature of interconnected relationships between companies and their stakeholders [56]. As social and environmental issues receive increasing attention, stakeholders such as consumers, regulators place increasing emphasis on firms' sustainability. In this sense, firms must balance the need and expectations of their stakeholders [52], [57]. This means meeting stakeholders' needs and expectations has become another important source of firm's competitive advantage [58].

On the other hand, another group of researchers argue that attempts to enhance one pillar of TBL may have an adverse effect on other pillar(s) (e.g., [36]; [59]. For instance, trade-off between compliance of sustainability obligations and resulting negative financial outcomes has been widely reported and studied [36-37], [60]. This win-lose (or trade-off) outcome is often a result of firms' resource constraints or conflicts of interest. Implementation of sustainability practices may sometimes require firms to forgo or lower economic performance target because such practices can impose financial burdens to firms in the form of additional investment, operating expenses and opportunity costs [27]. Thus, due to firms' limited resources, they must make a trade-off when allocating resources for sustainability initiatives along with other existing economic initiatives [61-63]

Moreover, the implementation of sustainability initiatives can be more challenging than commercial ones due to their long-term horizon and return related [14]. This challenge, in turn, can lead firms to experience conflicts of interest. For example, engaging in sustainability initiatives can afford firms additional grounds to acquire social influence but often at the expense of shareholders' goals [58], [64-65]. In that sense, firms' investments in sustainability initiatives could be considered by some shareholders to be an inefficient use of resources. Investors might believe that resources for executing and monitoring such initiatives could be better utilized elsewhere to maximize economic outcomes. Unlike the win-win perspective, this win-lose perspective has only recently started to gain scholarly attention.

C. Hypotheses development

Our conceptual model is based on the two conflicting perspectives of corporate sustainability, which is the theoretical lens of this paper [Fig. 1]. The direct associations between LM, sustainability practices, and TBL performance are based on the win-win perspective of sustainability, while the interactions of LM with the sustainability practices for the TBL performance reflect the win-lose perspective.

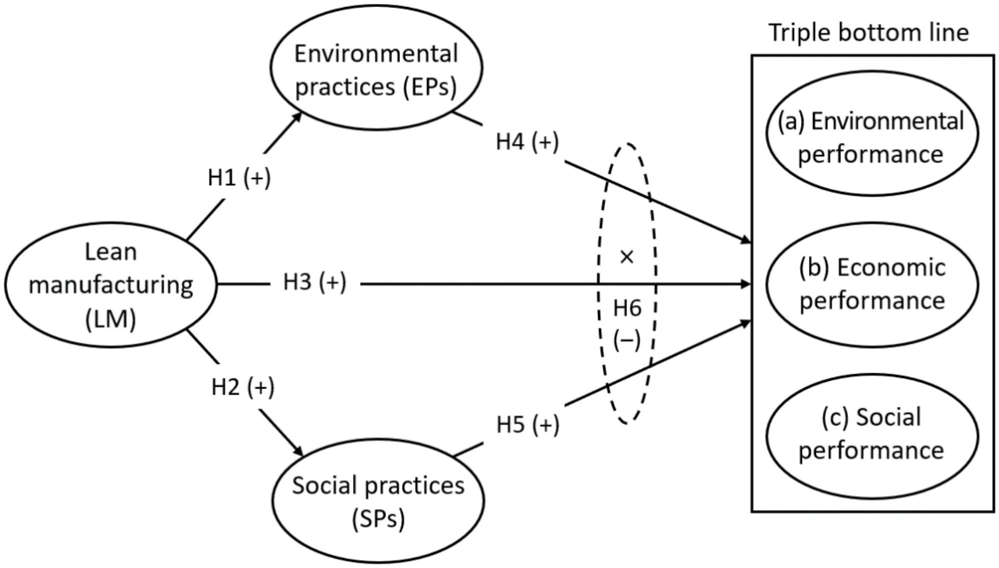

Fig. 1. Conceptual framework

1) LM and sustainability practices

LM and EPs share many characteristics in common, including their focus on waste reduction and resource conservation techniques. In fact, LM can act as a catalyst for EPs in manufacturing providing that they have been properly integrated [19], [44], [66], [67]. For example, value stream mapping, which provides a visualization of critical steps in a process, can reveal possible sources of energy or material wastage [68]. In addition, poka-yoke, which facilitates prevention and correction of mistakes, can also be used for energy conservation as well as reducing environmental wastage (e.g., materials) [69]. Furthermore, total quality management is known to improve energy efficiency and resource utilization by reducing scrap as well as need for rework [38]. Indeed, pollution can be considered a form of economic waste that can be reduced by LM [49]. Given this, we posit the following hypothesis:

H1. LM is positively associated with the implementation of EPs.

With regard to SPs, we can expect its positive association with LM as well. The extant literature suggests a mechanism for this complementary (win-win) relationship [70-71]. LM can facilitate SPs through improved labor relations that increase worker involvement [7]. One of the key facilitators of LM is respecting people through, for example, a high level of worker involvement in health and safety [72]. Improving such worker involvement requires continuous education and training, since its implementation needs maturity in technical and social competence of those involved. In this sense, implementing LM already involves many social practices as a pre-requisite, for example, improving labor standards. Another such example is problem-solving culture, which also requires welfare compensation for employees as a pre-requisite [73]. Therefore, we posit the following hypothesis:

H2. LM is positively associated with the implementation of SPs.

2) Association with TBL performance

LM contributes to the economic performance of a firm mainly through (1) reduced operational cost, (2) improved inventory cost, and (3) decreased environmental-related cost [12], [74-75]. For instance, waste in manufacturing incurs several direct and indirect costs including opportunity cost, storage cost, overhead, and disposal expenses alongside the material cost itself. With LM, such as Kanban techniques, firms can cut operational cost by reducing excess inventories, as well as storage and spoilage expenses. In a similar vein, LM can contribute to environmental performance as well. For example, LM in the forms of just-in-time (JIT) and lean processes for material delivery can lead to improved environmental performance mainly by reducing material obsolescence and the scrap rate [12], [19], [67], [76].

LM practices can also improve social performance, mainly because workforce and human development factors (e.g., empowerment, teamwork, motivation, and training) are at the core of continuous improvement processes in LM [77]. A related example is workplace safety. Accidents at work can be considered a type of waste because it disrupts workflows by introducing variability [78], which can be eliminated with LM tools. Another example is that LM can contribute to reducing the violation of labor standards, particularly in terms of salary and working hours [7]. This contribution can stem from firms' incentives to improve working conditions to retain a competent workforce, which is a crucial prerequisite for LM. Taken together, we posit the following hypothesis:

H3. LM is positively associated with (a) environmental, (b) economic and (c) social performance.

The literature shows that EPs can lead to a significant improvement in environmental performance. For instance, land waste management and resource conservation efforts at plants can enhance manufacturing firms' environmental performance by decreasing the use of toxic materials and improving resource efficiency, respectively [11]. Similarly, green manufacturing initiatives increase environmental performance through less pollution and resource consumption [20], [79-80]). Furthermore, implementation of EPs is sometimes driven by its potentials for economic gains. These gains consist of reduced operational costs and improved productivity, both of which stem from enhanced resource utilization [16], [43]. With regard to the link with social performance, however, a dearth of studies has investigated this win-win outcome [81]. In this study, we argue that social performance can be boosted when firms channel their efforts into pursuing EPs. For example, recycling initiatives to reduce landfill disposals of solid waste and hazardous materials can result in a significant improvement in the well-being of the surrounding communities by reducing a public health risk [82]. Considered altogether, we posit that:

H4. EPs are positively associated with (a) environmental, (b) economic and (c) social performance.

The relationship between SPs and environmental performance remains underexamined in the sustainability literature (cf. [11], [83]), which might be due to the dominance of the instrumental logic that links sustainability goals to economic outcomes. However, there are few exceptions. For example, Gimenez et al. [16] demonstrate that social initiatives, such as providing better labor conditions to workers and supporting the quality of life of external communities, can significantly improve firms' environmental performance. Likewise, Marshall et al. [84] find that firms with better working conditions tend to use less hazardous materials. A possible explanation for this positive association is that employees might have additional incentives to fulfil environmental obligations when their firms are willing to improve welfare and labor conditions in return.

The implementation of SPs, particularly those related to labor conditions and workplace health and safety, is known to yield various economic benefits [85-87]. For example, workplace health and safety practices, such as additional training, rigorous safety standards, and the installation of safety disconnects, are closely linked with superior quality outcomes [88]. In terms of its positive association with social performance, it has been well supported by the extant literature. As discussed earlier, the realization of social performance is primarily facilitated by dedicating resources to workplace health and safety, as it would improve firms' social performance by lowering the rates of accidents and worker turnover [83], [89]. Taken all together, we posit that:

H5. SPs are positively associated with (a) environmental, (b) economic and (c) social performance.

3) Interaction of LM, EPs, and SPs

Achieving corporate sustainability is often subject to tensions (trade-offs) around competing goals of TBL [39]. Given resource constraints, firms tend to prioritize one or two dimensions of TBL and achieve its goal(s) at the expense of the other(s). For example, Longoni et al. [61] find a potential trade-off between LM and the safety climate. Specifically, LM can hurt the safety climate if it is implemented without human resources (e.g., teamwork, training) and preventive maintenance practices. Rogers et al. [90] suggest that firms tend to favor safety improvements over emissions reductions because pursuing the EP, emission reductions, primarily can jeopardize the goals of the SP and other economic gains (e.g., lost sales). Managers of manufacturers tend to face trade-offs when forced to select among competing options [91]. Another reason for this trade-off lies in the different time horizons of various initiatives. For example, when an LM and sustainability initiative are implemented together, pursuing short-term business goals of LM while simultaneously trying to achieve long-term sustainability goals would create significant trade-offs [25].

Such trade-offs could occur in manufacturing firms at both the firm and employee level [36-37]. For example, as discussed earlier, LM and EPs tend to share many common objectives; however, when implemented together, the dynamics between them are not always complementary. While successful LM implementation requires flexible organizational structures and processes, environmental management systems are known for creating red tape in the system [92]. Indeed, Zhu and Sarkis [43] find that the implementation of JIT diminishes the effectiveness of the internal environmental management systems of Chinese manufacturers. Similar trade-offs can also be found in the relationship between EPs and SPs, which is mainly due to the conflict in the control requirement. For instance, although acquiring formal accreditation for ISO 14001 Environmental Management Systems requires implementing strict bureaucracy and controls, a certain degree of flexibility is permitted in the implementation of social standards such as ISO 26000.

At the employee level, implementing LM alongside sustainability practices can also lead to a trade-off in the manufacturer's TBL performance. Erosion of workforce well-being, such as stress and mental tenseness, is one of the most common trade-offs in implementing lean with sustainability practices [93]. That is, when slack removal initiatives are introduced to reduce cycle time through JIT, they can often lead to a significant increase in employee burnout, which may result in higher workplace safety accidents [61], [87]. Tensions from changes in workplaces or production procedures using other LM methods such as Kaizen are also reported to generate similar issues [93]. Furthermore, Longoni et al. [62] reveal that TBL performance trade-offs occur if safety and operational managers have incompatible attitudes. In this case, tensions between LM and sustainability practices may be highly likely, because the implementation of LM often requires close cross-functional cooperation between employees, whose specialties, perspectives, knowledge, and attitudes toward lean and sustainability issues can vary significantly. Taken all together, we posit that:

H6. There are conflicting interactions of LM, EPs, and SPs for (a) environmental, (b) economic, and (c) social performance.

III. Methodology

A. Data collection and sample

In this study, we test our hypotheses concerning the associations among LM, sustainability practices and TBL performance. Our data was collected via an e-mail survey of Indian manufacturing companies. The sampling frame was taken from a directory of the top 1,000 manufacturers in India published by Fundoodata. Of this list, 750 manufacturing companies were randomly selected. Random sampling has been utilized in our research work as it is one among the sampling techniques that has been predominantly used in the survey based empirical studies [94]. Out of the 750 questionnaires sent out, 96 responses were first returned. After a reminder, 81 responses were additionally returned, yielding a total sample of 177. This yielded us with response rate of 23.6%, which is analogous to the response rates in prior survey-based research (e.g., [67]). Our respondents include CEO/presidents (4.0%), vice presidents (9.6%), executive/directors (34.5%), general managers (41.8%) and managers (10.2%) from various industry sectors. Our sample data characteristics are observed to be normally distributed with less than 5% of missing values.

Using χ^2 and *t*-tests, we checked the nonresponse bias by comparing early and late groups of returned surveys. Significant differences were not identified, suggesting that non-response bias is not a serious issue for our study. Moreover, by following the recommendations of [95-96], we intended to lessen the potential threat from common method bias (CMB) by (1) safeguarding the anonymity of respondents, (2) ensuring that there are no correct or incorrect responses, (3) requesting that each and every question be responded to as fairly as possible and (4) giving no incentives for participating in the survey. Moreover, we checked the model with a common method factor [97] and found that the average explained variance of the indicators is 0.80, which is much greater than the average method variance (0.0003). While all the explained variance was significant, none of the method variance was insignificant. Given these factors, we contend that CMB is not a significant issue in our study.

B. Measures

To ensure the quality of measurement items, all measures in the study were adapted from the extant literature (see Appendix). First, measurement items for our dependent variables, namely TBL performance, were adapted from previously published studies [43], [98-99]. Each of the 19 items of TBL performance represents various sustainability outcomes that may be related to the implementation of environmental, economic and social practices. All items are reflective in nature and measured using a 7-point Likert scale (1: strongly disagree – 7: strongly agree) in response to the following question: 'Please indicate your degree of agreement to which the following sustainability outcomes'.

Similar to the dependent variable, the items for our independent and moderating variables, LM, EPs and SPs, were adapted from the extant literature. LM is a 6-item reflective measure adapted from [18]. Each measurement item represents one of the LM practices implemented in manufacturing companies measured using a 7-point Likert scale (1: none – 7: completely) in response to the following question: 'Please indicate the degree of the following action programs in your company'.

Likewise, our measurement items for sustainability practices were adapted from prior sustainability studies [11-12], [100]. Each measurement item represents one of the various social and environmental practices mainly implemented in a manufacturing set up, which was measured using a 7-item reflective scale (1: not applicable – 7: implemented) in response to the following question: 'Please indicate the status of the following sustainability practices by your company'.

C. Measurement validation

To ensure content and construct validity in our measures, the following steps were taken. First, for content validity, we only used the previously validated measurement items followed by an in-depth item-by-item expert review [94]. Next, we assessed construct validity by conducting a series of tests for convergent and discriminant validity (see Appendix). Specifically, we examined the convergent validity based on four criteria: (1) Cronbach's alpha (α), (2) construct reliability (CR), (3) values of the average variance extracted (AVE), and (4) all indicator factor loadings. As observed in the Appendix, all the values for α, CR, AVE and item loading exceeded the recommended thresholds [101]. Discriminant validity was accessed based on two criteria: (1) the square root of the AVE should be greater than the respective inter-construct correlations, and (2) the heterotrait–monotrait

TABLE I
DESCRIPTIVE STATISTICS, CORRELATION, AND DISCRIMINANT VALIDITY

	Mean	SD	1	2	3	4	5	6
1. Lean manufacturing (LM)	0.88	0.02	**0.88**					
2. Environmental practices (EPs)	0.81	0.03	0.63 (0.68)	**0.82**				
3. Social practices (SPs)	0.79	0.03	0.31 (0.34)	0.50 (0.58)	**0.80**			
4. Environmental performance	0.83	0.03	0.30 (0.32)	0.39 (0.44)	0.31 (0.32)	**0.83**		
5. Economic performance	0.81	0.03	0.51 (0.53)	0.530 (0.59)	0.38 (0.42)	0.40 (0.46)	**0.81**	
6. Social performance	0.85	0.07	0.13 (0.11)	0.24 (0.24)	0.27 (0.28)	0.42 (0.45)	0.49 (0.50)	**0.85**

(HTMT) ratio of the correlations must be less than 0.85 [102]. As can be seen from Table I, the square root of the AVE of the constructs (in bold) are greater than its respective inter-construct correlations. Also, it is evident from Table I that all correlations of the HTMT ratio (in bracket) are less than 0.85, suggesting that discriminant validity is not an issue in our measures.

IV. ANALYSIS AND RESULTS

A. *Analysis approach*

To test our hypotheses, we conducted ordinary least squares (OLS) regression analysis. We first regressed each sustainability practice on LM, while controlling for firm size (the number of employees transformed using the natural log), ownership structure (private, public or joint venture/MNC), and industry type (see [Table II] with the referent category of "automobile"). The control variables were entered first (Model 1), followed by LM (Model 2). We then regress each sustainability performance on LM, EPs and SPs. Likewise, the control variables were entered first (Model 1), followed by three predictors (Model 2), two-way interaction terms (Model 3) and three-way interaction terms (Model 4). We mean-centered the predictors (i.e., LM, EPs and SPs) before creating interaction terms to minimize potential multicollinearity. This approach is consistent with prior studies examining multilevel interaction terms for the variables of interest (e.g., [103-104]). In all regression models, variance inflation factors (VIF) were used to assess multicollinearity. As a result, all VIF scores were well below the cutoff value of 10, with a maximum score of 2.915.

B. *Regression results*

Table II shows the results of the regression analyses for our first and second hypotheses. We find that LM is positively associated with EPs with a regression coefficient of 0.57 ($p < 0.001$). The regression model is also highly significant at the 0.1% level, with an exploratory power of 36%. This result provides strong support for H1. For SPs, we also find a positive association with LM. As shown in Table II, we find a coefficient of 0.25 ($p < 0.001$) for the LM and SPs relationship. The F-value for the regression model is significant, significantly higher than that of Model 1 (with the controls). The regression model also shows a high corrected goodness-of-fit of the tested variables, with the adjusted R^2 value of 0.13. Based on the collective evidence, we also find strong support for H2.

The results for the direct association of LM with TBL performance are presented in Model 2 of Table III. We find a positive association of LM with economic performance, supporting H3b. However, we do not find an association of LM with environmental and social performance (H3a and H3c, respectively). This result is contrary to earlier findings (e.g., [7], [12]). We also find support for H4a, H4b and H4c, where positive associations of EPs with all three dimensions of TBL performance (all significant at the 5% level) are hypothesized. However, we do not find support for hypotheses H5a, H5b and H5c, where a positive association between SPs and TBL performance was postulated.

The results of the interaction effects of LM, EPs and SPs for TBL performance are presented in Models 3 and 4 of Table III. As expected, most of the coefficients for interaction effects are negative. We find a significant negative interaction of LM with SPs for economic performance ($\beta = -0.30$, $p < 0.05$) and EPs with SPs for social performance ($\beta = -0.30$, $p < 0.05$). For other two-way interactions for TBL performance, the results were insignificant. Furthermore, we find a negative three-way interaction effect of economic performance ($\beta = -0.31$, $p < 0.05$) but not for the other dimensions of TBL performance. This evidence provides only partial support for H6.

To corroborate the hypothesized interaction effects, we conduct simple slope tests using the Johnson–Neyman technique [105-106]. Fig. 2 shows a plot of the simple slope of LM (a) as the moderator for economic performance, and (b) EPs as the moderator for social performance. As Fig. 2a reveals, the simple slope of LM decreases as SPs increase for economic performance. The simple slope becomes insignificant when SPs reaches 6.0, which supports our earlier findings on the negative effect of SPs for the association between LM and economic

TABLE II
LM AND SUSTAINABILITY PRACTICES

	Environmental practices (EPs)		Social practices (SPs)	
	Model	Model	Model	Model 2
onics				
Fertilizer	0.23	0.03	0.41^{+}	0.32
Food	−0.21	−0.26	−0.37	−0.39^{+}
Paper	0.08	−0.04	0.01	−0.04
Pharmaceutical /health	0.11	−0.16	−0.00	−0.12
Textile	0.12	−0.03	0.03	−0.03
Predictor				
Lean manufacturing (LM)		0.57***		0.25***
F for the model	0.96	8.47***	1.95*	3.06***
F for the step	0.96	92.24***	1.95*	14.44***
Adjusted R-square	−0.00	0.36	0.06	0.13

Note: $n = 177$; $^{+}p < 0.10$, $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

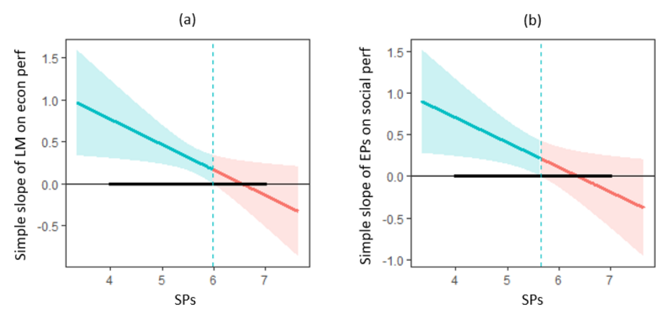

Fig. 2. Two-way interactions

TABLE III
ASSOCIATIONS OF LM, EPS AND SPS WITH TBL

	Environmental performance				Economic performance				Social performance			
	Model 1	Model 2	Model 3	Model 4	Model 1	Model 2	Model 3	Model 4	Model 1	Model 2	Model 3	Model 4
Constant	6.32^{***}	3.48^{***}	3.31^{***}	2.96^{**}	5.79^{***}	1.52^{+}	1.49^{+}	0.73	6.11^{***}	4.52^{***}	5.44^{***}	5.43^{***}
Controls												
Firm size	−0.03	−0.01	0.00	−0.00	0.01	0.03	0.03	0.02	−0.02	0.00	−0.04	−0.04
Public	0.11	0.05	0.04	0.02	0.12	0.02	0.03	−0.01	0.50^{***}	0.46^{**}	0.45^{**}	0.45^{**}
Joint venture/MNC	0.08	0.05	0.03	0.01	0.14	0.08	0.09	0.05	0.30^{*}	0.28^{+}	0.32^{*}	0.32^{*}
Aerospace	-0.80^{**}	-0.72^{**}	-0.71^{**}	-0.69^{**}	-0.53^{+}	-0.44^{+}	-0.40^{+}	−0.35	-1.11^{***}	-1.05^{***}	-1.13^{***}	-1.13^{***}
Cement	−0.06	0.04	0.04	0.05	0.01	0.14	0.13	0.17	−0.26	−0.19	−0.20	−0.20
Chemical	−0.26	−0.21	−0.21	−0.21	−0.00	0.10	0.08	0.07	−0.25	−0.23	−0.32	−0.32
Electrical/electronics	−0.18	−0.12	−0.13	−0.13	0.13	0.23	0.25	0.25	−0.04	−0.01	−0.08	−0.08
Fertilizer	0.01	−0.12	−0.13	−0.10	0.24	0.03	0.07	0.12	−0.21	−0.28	−0.19	−0.19
Food	−0.15	−0.05	−0.05	−0.03	−0.26	−0.18	−0.14	−0.10	-0.69^{*}	-0.59^{*}	-0.57^{*}	-0.57^{*}
Paper	−0.30	−0.34	−0.32	−0.33	−0.14	−0.22	−0.24	−0.28	−0.32	−0.32	−0.47	−0.47
Pharmaceutical/health	0.24	0.18	0.20	0.18	0.22	0.06	0.07	0.04	0.23	0.25	0.14	0.14
Textile	0.20	0.15	0.14	0.14	0.11	0.00	−0.02	−0.02	−0.08	−0.09	−0.10	−0.10
Predictors												
Lean manufacturing (LM)		0.05	0.03	0.05		0.27^{***}	0.23^{**}	0.27^{***}		−0.09	−0.07	−0.07
Environmental practices (EPs)		0.29^{**}	0.31^{**}	0.32^{**}		0.30^{***}	0.34^{***}	0.35^{***}		0.23^{*}	0.17	0.17
Social practices (SPs)		0.12	0.13	0.17^{+}		0.12	0.15^{+}	0.24^{**}		0.10	0.07	0.07
Two−way interaction												
LM × EPs			−0.04	−0.07			0.02	−0.05			−0.11	−0.11
LM × SPs			−0.04	−0.07			-0.30^{*}	-0.36^{**}			−0.08	−0.08
EPs × SPs			0.10	0.13			0.14	0.20			-0.30^{*}	-0.30^{*}
Three−way interaction												
LM × EPs × SPs				−0.15				-0.31^{*}				0.00
F for the model	1.68^{+}	3.78^{***}	3.15^{***}	3.03^{***}	1.02	6.94^{***}	6.23^{***}	6.31^{***}	3.05^{***}	3.18^{***}	3.43^{***}	3.23^{***}
F for the step	1.68^{+}	10.94^{***}	0.30	0.90	1.02	28.53^{***}	2.02	5.02^{*}	3.05^{***}	3.20^{*}	3.83^{*}	0.00
Adjusted *R*−square	0.04	0.19	0.18	0.18	0.00	0.34	0.35	0.37	0.12	0.16	0.20	0.19

Note: n = 177; $^{+}p < 0.10$, $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$

performance. This trade-off situation is also the case when EPs interact with SPs for social performance. As shown in Fig. 2b, the simple slope of EPs decreases as SPs increase, becoming insignificant when SPs reach 5.6. This finding provides further support for our earlier results as well. We also conduct a simple slope test for the three-way interaction effect with LM as the primary moderator. As shown in Fig. 3, as EPs increase, the simple slope of LM increases when SPs are low (−1 standard deviation, SD), but decreases when SPs are moderate (mean) and high (+1 SD). The slope becomes insignificant when EPs reach 6.7. This indicates that EPs strengthen the positive association of LM with economic performance when SPs are low. However, as SPs increase, EPs weaken the positive relationship between LM and economic performance.

C. Assessing endogeneity

Our predictors, LM, EPs and SPs, may be subject to endogeneity due to omitted variables, simultaneity and measurement errors [107]. To check this possibility, we conducted a two-stage least squares (2SLS) instrumental variable (IV) estimation. However, we were unable to find a valid (i.e., relevant and exogenous) instrument. We discovered that all our potential IV candidates, such

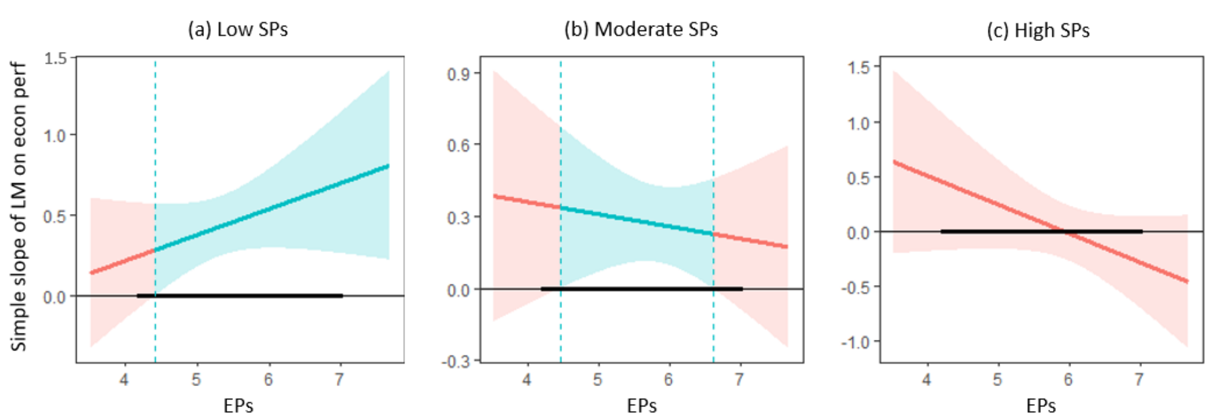

Fig. 3. Three-way interaction of LM, EPs, and SPs for economic performance

as cooperation with suppliers or annual sales (in INR), were weak instruments. Using such weak instruments could be problematic [108], therefore, we refrained from using the instrumental variable approach. We sought instead to include theoretically justified control variables, which could help reduce the endogeneity problem, particularly with respect to omitted variables. Firm size, ownership structure, and industry type are theoretically plausible factors influencing LM and sustainability practices for TBL performance, which were all controlled in our analyses. Considering this, our analysis may not be unduly influenced by omitted variable endogeneity. Nevertheless, we still must acknowledge that we could not rule out endogeneity concerns, which is a limitation of our study.

D. *Post hoc analysis*

Our conceptual model implies that LM is associated with TBL performance via sustainability practices. Although these mediation links are not the main focus of this study, we followed prior studies (e.g., [109-110]) and conducted a moderated mediation analysis using bootstrapping. The nontabulated results show an insignificant mediation by EPs for the association between LM and TBL performance, regardless of when LM is low (−1 SD), moderate (mean) or high (+1 SD). This result is somewhat unsurprising given our main regression results suggesting a limited association of predictors (LM, EPs and SPs) and its two-way interaction for TBL performance. This insignificant result is also the case for SPs, where none of the results are significant. In sum, our post hoc analysis suggests it is unlikely that LM is positively associated with TBL performance via sustainability practices, even if the implementation of LM is low, moderate or high. This finding provides further support for our main regression analyses pertaining to the direct and interactive association of the predictors with sustainability practices for TBL performance in manufacturing.

V. Discussion and conclusion

In this research, we seek to untangle complex associations among LM, sustainability practices and TBL performance. Currently, these associations are widely discussed in the sustainable operations and lean manufacturing literature; however, relatively little is known about how LM is associated with various sustainability practices and the performance implications of TBL when implemented together. As a result, the extant literature tends to have a rather skewed view of the LM–sustainability link, which is based on the win-win perspective. Using two conflicting views of TBL [34-36] as a theoretical lens, and considering Indian manufacturing as our main context, we reveal the paradoxical nature of these associations. In particular, LM is positively associated with sustainability practices for TBL performance (i.e., win-win). At the same time, LM conflicts with EPs and SPs when they are implemented simultaneously (i.e., win-lose). This paradoxical tension does seem to be commonplace in manufacturing industry; nevertheless, it has been often neglected in the lean–sustainability literature. In what follows, we discuss the theoretical and practical contributions of this paper.

A. *Theoretical contribution*

Our study provides empirical evidence that LM is positively associated with the implementation of sustainability practices, that is, EPs and SPs. The positive association aligns with prior studies (e.g., [66], [67], [19], [23], [70]) supporting a win-win perspective of sustainability. However, most of the prior findings are based on the data collected from US and European companies. Our study expands the extant studies by providing additional evidence of the synergistic relationship of LM with sustainability practices for TBL performance in an Indian context – a country regarded as the next global manufacturing hub [31-32]. Our study suggests that LM can be suggested to serve as a facilitator for the successful execution of manufacturers' sustainability practices.

Examining the associations of LM and sustainability practices with TBL performance results in mixed findings. Specifically, EPs were found to be associated with the performance of all three pillars of TBL. Meanwhile, LM was only associated with economic performance, and SPs had no relationship. Concerning EPs, consistent with past research (e.g., [79], [80]), our findings provide support for the win-win perspective of sustainability. In the case of LM, its association with environmental and social performance is still positive but statistically insignificant, which is contrary to prior findings (e.g., [7], [12]). Only economic performance is associated with LM, which is provided as new evidence from the context of the Indian manufacturing industry. Regarding SPs, their insignificant association with any TBL performance is rather counterintuitive. A possible explanation is that SPs might not be as thoroughly comprehended or properly implemented compared to other pillars of TBL in India, as goals from SPs might appear more intangible and harder to measure.

Albeit anecdotally, prior lean–sustainability studies suggest a positive interaction of LM with EPs or SPs for TBL performance (e.g., [7], [12]). However, our findings suggest the opposite. These conflicting associations may be due to possible opposing effects of LM with sustainability practices on TBL performance. Concerning the social performance, LM may harm health and safety in the workplace. For instance, pressure to improve line speed from LM often requires increasing work intensity and role-overload, which is linked to work exhaustion, illness and growing accident rates [61], [111]. Similarly, in the case of environmental performance, despite the possible benefits of reduced material obsolescence and a lower scrap rate, JIT can also demand more frequent delivery, which may increase the overall carbon footprint.

We find a negative interaction effect of LM, EPs and SPs for TBL performance. Concerning the two-way interaction, our results suggest a detrimental effect of LM with SPs on economic performance as well as a negative effect of EPs with SPs on social performance. That is, LM and SPs weaken each other's association with economic performance while EPs and SPs weaken each other's association with social performance. Regarding the three-way interaction, the results illustrate that firms' economic performance is negatively affected by the interactions of LM, EPs and SPs. This observation suggests that simultaneous increases in all three variables may create additional conflicts of interests or resource constraints for TBL performance. Thus, solely examining the direct associations among the variables may prevent firms from seeing the bigger picture of how combining LM and sustainability practices may together associate with TBL performance. Our study thus adds novel insights to the lean–sustainability literature by untangling complex associations among LM, sustainability practices and TBL performance.

B. Implications for practice

Our study provides empirical evidence of how LM collides with sustainability practices for the three pillars of TBL performance in manufacturing. Specifically, we find that the simultaneous implementation of LM and SPs tends to undermine economic performance. Moreover, we show that implementing EPs and SPs together may cause further degradation of firms' societal performance. Similarly, the implementation of all three together can diminish economic performance. Overall, our findings suggest that when the implementation of LM and sustainability initiatives are conducted separately, each practice seems to add up to firms' superior sustainability performance. However, when manufacturers execute LM and sustainability practices simultaneously, conflicts appear, and the beneficial association may disappear or even become negative.

Nevertheless, our findings do not necessarily indicate that manufacturers should give up either LM or sustainability practices for TBL performance because LM, EPs and SPs are all deemed essential for today's businesses. Therefore, managers should understand how to best accept and manage the trade-offs. This means that manufacturing firms should make efforts to properly understand these trade-offs (win-lose) to move towards win-win relationships.

Following the paradox perspective on corporate sustainability could be one way to manage the trade-offs [35], [39]. Decision-makers are strongly advised to resolve potential conflicts, including inevitable tensions on sustainability, rather than simply avoid them by prioritizing organizational goals (win-lose). Manufacturers can start with building a cognitive frame around LM and sustainability practices to guide their decision-making around these tensions [34]. Firms may also need to recognize the juxtaposition of TBL performance amid the differences in operational goals of implementing LM, EPs and SPs. In this regard, coaching and holding group discussions could be effective in breaking the vicious cycle of the tensions on LM because they guide the cognition and behaviors of the manufacturers [26]. Furthermore, employee engagement and experimentation can help promote the acceptance of LM practices [26], which can also be extended to the case of EPs and SPs. Consequently, these efforts should be made as a way for managers in manufacturing to pursue sustainability goals while implementing LM with fewer conflicts, thereby transforming potential trade-off (i.e., win-lose) situations into win-win outcomes.

C. Limitations and future research agenda

Several limitations to this study might be addressed in future research. One of the limitations is the use of cross-sectional survey design, where the data for all identified measurement items were gathered at the single point of time. Future researchers are encouraged to use longitudinal research design to estimate causal effects of the variables hypothesized in this study. Relatedly, our study could be subject to respondent bias given that we used single respondents for all measurement items. Following common practice (cf. [112]), we tried to relieve this potential bias by using constructs that are only monadic. Nevertheless, we encourage future studies to be conducted with stricter approaches (e.g., multiple respondents with monadic constructs) to validate our results.

Although we included several (e.g., firm size, industry) control variables that may mitigate potential omitted variable problems [107], we could not rule out potential endogeneity concerns. This limitation of study design indicates that readers should be careful in terms of interpreting our empirical results that might reflect endogeneity. Finally, our study's findings, particularly interaction-related results, suggest a 'paradox perspective' on corporate sustainability [35]. However, we could not delve into the conflicting views (i.e., win-win and win-lose) of sustainability from paradox theory, which has a more extensive view of the tensions (trade-offs) on corporate sustainability. This topic could be addressed by an in-depth qualitative case study in future research.

APPENDIX

APPENDIX. MEASUREMENT AND INDICATORS

Construct	Items	Loading	*t*-value
Lean manufacturing (LM) α = 0.944; CR = 0.955; AVE = 0.782	Restructuring manufacturing processes	0.87	30.54
	Implement pull production	0.87	46.74
	Quality improvement and control	0.96	165.30
	Improvement of equipment productivity	0.87	35.47
	Increase the level of delegation and knowledge of workforce	0.83	24.37
	Implementing the lean organization model	0.91	58.30
Environmental Practices (EPs) α = 0.874; CR = 0.909; AVE = 0.666	Designing for disassembly	0.75	17.10
	Re-using (recycling of) wastes for reduction	0.85	40.77
	Using re-usable packages to delivery materials	0.87	48.16
	Conserving water and energy	0.82	28.70
	Developing clear environmental standards	0.77	18.76
Social practices (SPs) α = 0.854; CR = 0.895; AVE = 0.631	Pursuing worker's welfare	0.82	23.73
	Ensuring fair labor conditions	0.75	18.37
	Providing continuing education programs to all employees	0.80	27.15
	Setting up clear labor standards	0.78	22.93
	Developing clear health and safety standards	0.82	28.66
Environmental performance α = 0.906; CR = 0.928; AVE = 0.682	Reduced CO_2 emissions	0.84	25.09
	Reduced waste water	0.84	28.30
	Reduced solid wastes	0.87	33.09
	Reduced energy consumption	0.79	21.57
	Decreased usage of hazardous/harmful/toxic materials	0.80	22.15
	Improved compliance with environmental standards	0.82	26.02
Economic performance α = 0.913; CR = 0.930; AVE = 0.654	Decreased costs for purchased materials	0.82	31.18
	Decreased costs for energy consumption	0.86	41.24
	Reduced manufacturing costs	0.82	36.21
	Reduced fees for waste treatment	0.80	24.31
	Reduced fees for waste discharge	0.79	17.92
	Improved product quality	0.78	17.67
	Improved order delivery and flexibility	0.80	22.94
Social performance; α = 0.911; CR = 0.930; AVE = 0.726	Improved relationship with local suppliers	n/a	n/a
	Improved relationship with the community	0.86	26.77
	Improved health and safety at work	0.87	10.12
	Improved working conditions	0.85	9.78
	Improved living quality of surrounding community	0.87	10.46
	Improved compliance with ethical, social standards	0.81	16.63

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