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ARE ALL LEAN PRINCIPLES EQUALLY ECO-FRIENDLY? A PANEL DATA STUDY

Abstract

We address the individual environmental impact of three pillars of Lean Manufacturing, Just-in-Time, Jidoka and Respect for People (RfP), from a shop-floor perspective. Moving away from the cross-industry and cross-country approach which has dominated the economic literature on emissions and climate change, we test our hypotheses at plant level with 9-year panel data (5,672 observations) from two official sources. In this way, we aim to highlight the relevant role of manufacturing plants, which are one of the main causes of greenhouse gas (GHG) emissions. This new approach also makes it possible to evaluate the different lean principles separately and to propose specific initiatives that may be really useful, going beyond the usual "one-size-fits-all" recommendations that characterize previous research. Our results show that the final environmental impact depends not only on the leanness level achieved by each plant, but also on each lean pillar in question: while Jidoka and RfP positively affect environmental performance, we find a major trade-off between JIT initiatives and the green goals.

Key words

Lean Manufacturing, environmental performance, eco-friendly, CO2 emissions, panel data study.

1. INTRODUCTION

Climate change, which is largely the result of anthropogenic emissions of CO2, is one of the main challenges faced by mankind today (Renukappa et al., 2013; Howard-Grenville et al., 2014). Since the Rio Summit (1992) and the Kyoto Protocol (1997), many initiatives have been adopted to reduce such emissions and hold back the negative consequences of global warming, but CO2 emissions have continued to increase and now stand at 60% above the 1990 levels (Hartmann et al., 2013).

Against this background, it is no surprise that academics and policy makers alike are making increasing efforts to design initiatives for the control of CO2 emissions (Martin et al., 2012) and to draw up public policies for decarbonization of the economy (Li and Altimiras-Martin, 2015). However, it may be that this commitment made by countries to reduce greenhouse gases (GHG) is the reason why much of the economic literature on emissions and climate change has focused on cross-country and cross-industry analysis (Li and Altimiras-Martin, 2015; Belkhir et al., 2017). In this vein, it is striking that the dominant approach adopted by industry has been to design and evaluate the supply chain, while underestimating the operations perspective linked to manufacturing plants (Golini et al., 2014; Böttcher and Müller, 2015), even though is the latter are acknowledged to be one of the main sources of GHG emissions (IEA, 2010).

On the other hand, the line of research that is closest to this issue, from the industrial sector, falls within the *Lean-Green* topic, a relatively recent research field (Garza-Reyes, 2015). Most of these studies focus on the compatibility between the two initiatives, i.e., they aim to determine “whether Lean makes me greener, and vice versa”, and are based either on case studies and conceptual models (Dües et al., 2013; Galeazzo et al. 2014) or on cross-sectional analyses (So, 2010; Yang et al., 2011);. While this approach may be useful for studying the aggregate effects of LM, it is unhelpful when we need to understand exactly what practices and interactions determine emissions and, above all, if we intend to develop specific initiatives at plant level. Although, from a global point of view, “Leaner may mean Greener”; not all LM practices and tools will necessarily be ecofriendly, so generic solutions are not valid. Individual proposals for each of the lean pillars —according to their specific objectives— are needed in order to really improve environmental performance and balance the trade-off between “efficiency” and “sustainable development”.

Here lies precisely the contribution of this paper which reveals, from shop-floor evidence, how managerial practices —individually, and as a whole— influences environmental performance. Since the literature assumes that LM is one of the most influential paradigms in manufacturing (Forrester et al., 2010), we use LM pillars (Just-in-time, Jidoka and RfP) in our research as examples of operational excellence practices (Monden, 1983; Ohno, 1988). Thus, unlike the generic Lean-Green approach, this separate diagnosis aims not only to empirically evaluate the synergies and trade-offs between each lean pillar and environmental performance, but also to focus on the actual unit that determines the relation between operational efficiency and green effects, the manufacturing plant.

Our study also offers two empirical strengths based on panel data comprising 1,025 manufacturing plants (SIC 20-39) with environmental and economic data covering nine years (5,672 observations). These data stem from two official databases: the Spanish Business Register (SBR) and the European Pollutant Release and Transfer Register (E-PRTR). Firstly, dynamic analyses are essential here not only for minimizing the problems of endogeneity that are so frequent in similar estimates using cross-sectional data, but also for considering time effects because of the well-known temporary nature of both Lean and Green initiatives. Secondly, when we use ad hoc surveys —usual in this area— we run the risk that survey participants may feel compelled to answer even though they do not actually have an opinion, may misjudge their own views or may even lie consciously to comply with accepted behavior (Bertrand and Mullainathan, 2001). However, the use of hard, objective indicators from official sources (SBR and E-PRTR), as proposed here, avoids all these potential problems and is, furthermore, a determining factor for generalizing our results.

The paper is structured as follows. Section 2 presents the literature review that leads to three testable hypotheses. Section 3 describes the sample of firms, the variables and the methodology used. In section 4 we cover the econometric analysis and discuss the results. Finally, we conclude with our main findings and their implications.

2. LITERATURE REVIEW AND HYPOTHESES

2.1. Background: the Lean-Green debate

Increasing competitive pressure over recent decades has led to an obsessive concern in industry to produce with higher quality, lower costs and shorter lead times which, in turn, has led to widespread adoption of management philosophies such as LM. Lean practices have been shown to be associated with improved competitiveness because they reduce inventories and improve productivity and quality (Womack and Jones, 2003; Shah and Ward 2003, 2007; Moyano-Fuentes and Sacristán-Díaz, 2012). However, the levels of wellbeing achieved in developed countries have also brought about greater social concern for the environment, forcing companies to go beyond efficiency-based management philosophies and to include environmental concerns in their management practices (Shen, 2014; Diego-Mas et al., 2016).

Since LM is considered the most influential new paradigm in manufacturing (Forrester et al., 2010), it is no surprise that various authors have attempted to explore how its practices affect environmental performance (Garza-Reyes, 2015). However, this impact of LM on environmental performance has been interpreted in many ways, some of which are contradictory. While LM is considered by some authors to be the most appropriate management system to internalize green considerations and balance the trade-off between "efficiency" and "sustainable development" (Dües et al., 2013; Carvalho and Azevedo, 2014), others openly question the complementarity of these two initiatives (Rothenberg et al, 2001; Yang et al., 2011).

The positive view postulates that, to the extent that LM aims to reduce inefficiencies and eliminate waste, adding environmental considerations to the basic principles should amount to a natural expansion in the search for possible synergies. The continuous effort through LM to reduce operational waste from discarded materials, energy consumption, or water usage may translate into lower environmental harm, thus enhancing environmental performance. There is thus a strong belief among scholars that a lean environment serves as a catalyst for achieving environmental purposes and therefore has a positive impact on environmental performance (e.g. King and Lenox, 2001; Vachon and Klassen, 2006; Sawhney et al., 2007; So, 2010; Dües et al., 2013). But other studies contradict this, giving evidence that some lean practices have a negative environmental impact because LM efforts to increase operational efficiency may go against environmental targets and actually result in more waste (e.g. Rothenberg et al, 2001; Venkat and Wakeland, 2006; Yang et al., 2011; Ugarte et al., 2016). In this regard, different trade-offs in production or logistics have been described in the past.

Venkat and Wakeland (2006), for example, suggest that, as the distance or complexity of consignments increase, conflicts arise in the supply chain that will require adjustments to JIT practices in order to reduce pollutant emissions. Similarly, Rothenberg et al. (2001) describe the commitment taken on by several automotive plants to replace certain paints and increase lot size in order to minimize their pollutant emissions. Along the same lines, Yang et al. (2011) and Pons et al., (2013) consider the possibility of complementing LM principles with certain green resources (e.g. practices, technologies), because LM alone does not significantly impact environmental performance. So, although we find that most studies support the positive impact of lean initiatives on the environment, there is not yet a consensus in the literature and different works continue appearing that question this complementarity (Garza-Reyes, 2015; Ugarte et al., 2016). We therefore need to know what these works have in common. While the positive viewpoint is characterized by more global and more conceptual research (e.g. Dües et al., 2013; Carvalho and Azevedo, 2014), the negative view is based on very specific studies that limit their analysis only to the impact of certain lean principles or tools (e.g. Venkat and Wakeland, 2006; Fahimnia et al., 2015; Ugarte et al., 2016). It could therefore be considered, from a conceptual point of view and in a generic way, that while LM is positively associated with environmental concerns, not all its practices are necessarily ecofriendly. This different approach used by various authors may be the reason behind the controversy still existing today in the literature.

Against this background, our study aims to combine both perspectives by undertaking an analysis in two steps: firstly, assessing the individual behavior of lean principles and, secondly, carrying out a comprehensive evaluation. Furthermore, in order to build a model based on what is permanent, and instead of focusing on tools, we address LM as it started out, with the Toyota Production System (TPS) pillars of JIT and Jidoka (Monden, 1983; Ohno, 1988;) and also recovering a third pillar, Respect for People (RfP), which was present explicitly in the foundations of the TPS but did not always figure in the subsequent dissemination of LM (Liker, 2004; Emiliani, 2008; Gajewski, 2014). Therefore, by moving away from the generic assessments that are so widely used in the Lean-Green literature, we propose a separate diagnosis for each pillar, which leads to each of the research hypotheses.

2.2. Influence of JIT practices on environmental performance

In LM, the JIT objective aims to produce only the products that are needed, when needed and in the amount needed (Sugimori et al., 1977). Irrespective of the different conceptualizations of JIT that can be observed in extant literature —as a manufacturing philosophy, or a simple set of practices— this pillar focuses on guaranteeing production flow, ultimately eliminating waste by cutting back excess inventories and overly large lot sizes (Sugimori et al., 1977). Thus, by implementing different practices and tools related to production flow —such as lot size reduction, cycle time reduction, quick changeover techniques or bottleneck removal, among others— it aims to eliminate the two major forms of flow wastes: work-in-process (WIP) inventory and unnecessary delays in process time.

When these objectives are considered, JIT does not seem to be particularly compatible with any type of environmental concern. While it is clear that such practices ensure tense flows throughout the supply chain, it also seems reasonable to assume that such transport frequencies will increase GHG emissions. In fact, the tools that are included within the JIT pillar have always been considered to be the main source of incompatibility between environmental requirements and the constant search for efficiency promoted by LM (Fahimnia et al., 2015, Ugarte et al., 2016). Some studies reflect this negative impact of JIT practices, mainly in relation to the supply chain. For example, in a simulation model of a generic supply chain, Venkat and Wakeland (2006) showed that JIT can lead to more CO_2 emissions due to increased transport rates and smaller order sizes. Similarly, Ugarte et al. (2016) used a simulation model of a manufacturing-retailer supply chain to find that, if JIT inventory management significantly increases transport frequency, it will also increase GHG emissions.

This same reflection can be applied to a manufacturing plant. All LM strategies that use JIT delivery with small lot sizes are likely to require increased transportation, packaging, and handling, and thus contradict a green approach (Rothenberg et al., 2001; King and Lenox, 2002, Mollenkopf et al., 2010; Dües et al., 2013). King and Lenox (2002) highlight the fact that smaller lots require greater adjustment of equipment with more frequent cleaning and maintenance, thus increasing waste and requiring management of cleaning materials and unused products. And, as stated by Sarkis (1995), smaller lots also require additional packaging. Similarly, Rothenberg et al., (2001) describe the commitment that automotive plants have taken on to adjust lot size and to replace their painting systems with others that are less cost-effective in order to reduce their emissions of Volatile Organic Compounds (VOC) into the atmosphere. In view of the above, we hypothesize the following:

***H1**: The lean practices and tools associated with the JIT pillar have a negative impact on environmental performance.*

2.2. Influence of Jidoka practices on environmental performance

Jidoka is often translated as *autonomation*, that is, “automation of quality control with a human touch” since, in case of any anomaly, it allows processes to be stopped so that no defective parts go on to the next stage (Sugimori et al., 1977; Ohno, 1988). But Jidoka today is much more than a simple set of tools for preventing and notifying failures. The Built-in-Quality pillar, as it is also known, involves a set of practices assuring that quality (zero defects) is maintained throughout the production process with continuous improvement and systematic elimination of waste (Liker, 2004). Since the ultimate goal of LM is to maximize customer value while minimizing waste, lean organizations use the tools under this pillar (Poka-yokes, 5 Whys, autonomation…) to embrace specific goals in scrap and rework reduction, machine performance improvement, and labor efficiency enhancement (Shah and Ward, 2003, 2007).

We can therefore expect that the greater the firm’s commitment to reduce waste, i.e., the more it adopts Jidoka, the greater the synergies will be with environmental performance. Although Jidoka and Green practices are different (Kleindorfer et al., 2005), they both aim to achieve the same goal of reducing waste. While LM focuses on “seven deadly wastes” (Ohno, 1988) and Green on different types of emission (Mollenkopf et al., 2010), a large proportion of such waste has the same origin - inventory management, transport, losses and emissions (Dües et al., 2013). So, when workers use different Jidoka tools to reduce losses and waste, they often cause an improvement – albeit unintended – in environmental performance. The expansion of “traditional wastes” not only does not restrict Jidoka objectives but actually expands opportunities for improvement by broadening the work spectrum.

Because of these similarities, many firms adopt both Lean and Green simultaneously, sharing resources. This maximizes the results obtained in terms of both efficiency and environmental performance (King and Lenox, 2002; Dües et al., 2013). Examples include typical lean initiatives such as the use of returnable containers (the Kanban system could apply here), the re-use of sub-products or equipment parts, and new technological and process improvement opportunities linked to energy consumption and emissions reduction (Melnyk et al., 2003).

In addition, some environmental management tools such as Sustainable Value Stream Mapping (SVSM) (Faulkner and Badurdeen, 2014) or Life Cycle Assessment (LCA) are based on Jidoka principles (Dües et al., 2013). These and the former initiatives provide excellent “breeding grounds" for the development of continuous improvement programs, subsequently enhancing industrial efficiency and environmental performance simultaneously. In fact, Dües et al. (2013 p.99) state explicitly that a “lean environment serves as a catalyst to facilitate Green implementations”. Accordingly, we posit the following hypothesis:

H2: The lean practices and tools associated with the Jidoka pillar have a positive impact on environmental performance

2.3. Influence of RfP practices on environmental performance

Workers in a lean environment are under great pressure to work at minimum cost, producing maximum quality and at exactly the right time (Gajewski, 2014). It is this that Ohno (1988) referred to when he identified the JIT+Jidoka pillars as "management by stress". Hence the third TPS pillar had a twofold purpose: to try to offset the emotional burnout associated with the other two pillars, and to complement them further with an explicit concern to improve labor conditions (Liker, 2004; Emiliani, 2008; Gajewski, 2014).

Although over the years RfP seems to have lost some of its relevance (Emiliani, 2008; Gajewski, 2014), the importance of this pillar was clear from the very beginning of TPS (Sugimori et al., 1977; Monden, 1983; Ohno, 1988). Classic authors such as Sugimori et al. (1977) or Ohno (1988) even claimed that the TPS was based on only two basic principles: 1) continuous improvement, and 2) “Respect-for-human System”. It is important to highlight here that, from the Toyota viewpoint, “showing respect for people” focuses more on workers’ abilities than on the actual individuals. For instance, referring to the RfP concept, Liker (2004) explained that it is not a question of “loving each other” but of fostering workers’ skills and motivation to achieve their individual success and that of their firm. So this pillar has a dual nature within the TPS. On the one hand, Toyota reveals a particular form of respect, based more on practical than moral reasons, and its goals are to enhance workers’ involvement and their voluntary efforts and to draw out their full capacity (Sugimori, 1977; Monden, 1983). On the other, and in relation to the former, we note that RfP allows the initial empowerment inherent in JIT+Jidoka to be complemented with an explicit concern to improve employment conditions by balancing out the wear and fatigue generated by the requirements of the other two pillars (Emiliani, 2008; Gajewski, 2014).

If we take both of these into account, we can expect RfP to have a positive effect on environmental performance. With regard to the first goal, the RfP pillar would implicitly include all the factors that today are associated directly with “High Performance Work Practices” such as empowerment, employee participation and involvement or training and development, among others (Womack and Jones, 2003). Although there have been no explicit studies on *RfP-Green performance*, there is extensive literature finding a positive relation between these factors —reflecting this Toyota concern— and environmental performance (Paillé et al., 2014; Benn et al., 2015). Considerable research reveals, for example, that high levels of employee participation (Zutshi and Sohal, 2004; Renwick et al., 2013) and involvement (Rothenberg et al., 2001) have been identified as drivers of improvements in environmental performance. Similarly, Daily et al., 2012 prove that empowerment and training result in a transformation towards management that maintains more environmentally sustainable operations. Likewise, other initiatives associated with RfP, such as employee motivation and responsibility, have also been shown to positively influence firms' competitive environmental advantage (Mollenkopf et al., 2010; Dües et al, 2013).

We also consider that achievement of the second objective of this pillar, that is, guaranteeing a stable truce to alleviate the emotional burnout related to lean practices and tools, should have a positive effect on environmental performance. We think that this concern to improve employment conditions —through of all sorts of incentives— not only helps to balance out the stress caused by other pillars but also guarantees certain rules of reciprocity between worker and employer, which are beneficial in the long term. This promotes the climate of trust needed to generate a greater emotional bond in workers, increasing their "voluntary efforts" and achieving an extra performance —also from the environmental viewpoint— which it would be impossible to obtain otherwise (Akerlof, 1982). This is the only way workers will be willing to yield the kind of strength required to improve certain aspects which, like the "*green commitment*", are less visible and more difficult to verify, especially in *high performance ambiguity environments* such as lean shop-floors (Arocena et al., 2010). Taking into account the two considerations described above, we hypothesize the following:

H3: The lean practices and tools associated with the RfP pillar have a positive impact on environmental performance.

3. DATA AND VARIABLES

To test our hypotheses, we built a data panel including economic and environmental microdata from two official sources: the Spanish Business Register (SBR) and the European Pollutant Release and Transfer Register (PRTR) for nine years (2001-09). SBR provides financial information on over one million Spanish firms, and PRTR is an annual census of the main pollutant emissions (to the air, water and land) of 6,188 individual industrial facilities in Spain in 65 different economic areas of activity. We thus created a single set of unbalanced panel data, with a total of 1,025 plants in the manufacturing sector (SIC 20-39) with more than 10 employees and 2 million euros of turnover, i.e., without microenterprises obtaining a total of 5,672 observations over nine years. Table A1 in Appendix describe our sample.

We operationalized our dependent variable, environmental performance (*Green*), as the inverse of *carbon intensity* (CO_2 emissions generated by the plant over materials consumed). Although measurement of CO_2 emissions is relatively recent in the area of operations, the “carbon intensity” parameter is being used increasingly to study the challenges of climate change and sustainable economic growth. It has already been used to measure the degree of environmental efficiency at country level (Ekins et al., 2012), environmental quality at sector level (Shen, 2014), and even for establishing international agreements in the fight against climate change (Agreement, 2015). This indicator makes a dual contribution: firstly, CO_2 is one of the main GHG causing global warming and a key performance indicator for the greenness level; secondly, it is appropriate for analyzing the environmental efficiency of a firm since there is a direct conversion from raw materials and energy consumption to CO_2 emissions (Table 1).

Regarding the independent variables, we use hard, objective economic ratios at shop-floor level as indicators of operational performance in relation to LM pillars: JIT, Jidoka and RfP. These ratios aim to summarize, from a dual economic and operational perspective, the degree to which the objectives associated with each of the pillars are achieved. This captures what is permanent in the lean philosophy, going beyond the mere adoption of tools and practices.

In the case of JIT, the economic ratio used is *Stock Turnover (Operating revenue/Stocks)* relativized by the sectoral average to make it comparable throughout the multisectoral sample. Thus, this indicator allows us to determine the plant´s efficiency in stock management, i.e., how tense flows are in raw materials, semi-finished products and finished products. This measure has already been widely used to measure the level of lean production in the supply chain (Gunasekaran et al., 2001) or to assess efficiency in the adoption of JIT practices (Swamidass, 2007; Wan and Chen, 2008).

Similarly, we designed an indicator for Jidoka — also based on economic parameters—to assess the level achieved in two main goals associated with this pillar, “built in quality” and “zero defects”. Since, from a processes approach, working with quality necessarily implies more efficient administration of resources, our Jidoka measure evaluates efficiency in the use of factors of production (materials + personnel expenses + amortizations) in relation to production volume. Jidoka is thus calculated as the ratio between *Total manufacturing costs divided by cost of materials then relativized by the sectoral average*. This ratio is easy to interpret: low values reflect more efficient processes — better use of resources— than competitors in the same sector, that is, less wastage and loss of materials, labor, equipment and products per manufactured unit which, essentially, is the ultimate aim of Jidoka. We have therefore recoded it so that higher values represent higher Jidoka (Table 1).

Finally, from the field of Labor Economics we take the concept of *Efficiency Wages* (*Average wage/Sectoral average wage*) as a proxy for *Respect for People* (RfP). The *Efficiency Wages* postulate argues that wages are determined by more than just supply and demand (Akerlof and Yellen, 1990). We assume that, when a company is willing to pay higher wages, this is for several reasons that are closely related to lean environments, in general, and the specific objectives of this pillar, in particular. Firstly, such an improvement in labor conditions reflects the firm's interest in stabilizing the workforce (an excessive personnel rotation could reduce productivity) and increasing workers' involvement and commitment. Such reasons are closely related to the lean philosophy and how "respect for people" is seen in Toyota environments in which investments in human capital are significant (Sugimori el al., 1977; Monden, 1983; Liker, 2004).

In addition, the *Efficiency Wages* concept also acts as a kind of "gift exchange" (Akerlof, 1982; Shapiro and Stiglitz, 1984), helping to bear the stress created by the JIT and Jidoka pillars (Ohno, 1988) while also yielding the kind of voluntary effort needed in aspects, such as the *"green commitment",* that are less visible and more difficult to verify. Thus, industrial environments such as lean shop-floors with high-performance ambiguity will tend to adopt *Efficiency Wa*ges to try to ensure an extra performance by employees in their jobs and avoid the possibility that they will shirk (Arocena et al., 2010) (Table 1).

Table 1. Description of the variables and the main descriptive statistics

Variable	Operationalization[1,2]	Obs	Mean	Std. Dev.	Min	Max
Environmental performance (Green): Environmental (and energy) efficiency of each plant considering the CO2 emissions generated according to materials consumed.	**Green** = Inverse of *CO2 Intensity ratio** *CO2 Intensity* = CO2 emissions (kg/year) / materials consumed(k€)*	5,774	17.38	617.92	0.00	38117.42
Just-in-time pillar: Set of practices that aim to produce the products required at the necessary time and in the right amount.	**Stock Turnover** = Operating revenue (k€) / Stocks (k€)	5,774	2.38	8.31	0.02	219.41
Jidoka pillar: Set of practices aiming to build quality during the production process ("Built-in Quality) and to achieve "zero defects" (minimum shrinkage in the process).	**Jidoka** = Total Production costs (k€) / Material costs (k€) *Recoded since the lower this ratio, more Jidoka are the processes	5,672	0.21	1.05	0.01	11.70
RfP pillar: Set of practices aiming to reduce disaffection from the stress generated by JIT and Jidoka and to maximize worker involvement.	**Efficiency wages** = Average wage (k€) / Sectoral average wage (k€)	5,774	1.06	0.34	0.54	7.25
Technological intensity in the sector	**Dummy**: High or medium-high technology sector (1) and low or medium-low technology sector (0)	5,774	0.17	0.37	0	1
Age of the facilities	**Dummy**: Young plants (1) and old plants (0)	5,774	0.32	0.47	0	1
Plant Size	**Size** = Total number of employees	5774	170.11	268.98	10	3,967

Notes: (1) All variables except control variables are measured as natural logs to deal with skewed data and avoid problems with outliers (Damanpour, 1992; Gupta, 1980). Based on this transformation, the log-log model allows us to interpret the coefficients as relative changes (percentages). (2) Both the Jidoka and JIT variables were relativized with respect to the sectoral average value.

We also included three control variables in the model: the sector, size and age of the firm. Firstly, we included technological intensity in the sector because the scientific and technological know-how that is relevant for each sector moves at different speeds and entails different levels of difficulty and, furthermore, firms in highly dynamic environments are also more likely to adopt environmental innovations (Rothenberg and Zyglidopoulos, 2007). The technological level of the sector is measured as a dummy taking value 1 if the firm belongs to a medium-to-high technology sector and 0 if it belongs to a low technology sector. We use the INE classification to group sectors by the type of technology they use.

Secondly, we considered it of interest to include plant size (measured by the number of employees) as larger firms can generate higher CO_2 emissions so are under greater external pressure to improve their environmental performance, but also have more resources to invest in clean technologies to reduce their environmental impact (Yang et al., 2011; Hajmohammad et al., 2013). Finally, following Shah and Ward (2003), we built a dummy to differentiate between new firms and old ones (more than 20 years old) to evaluate the age of facilities. This may affect the environmental performance of a manufacturing plant because its facilities may become obsolete (Rothenberg et al., 2001). In Table 2, which shows the correlations among the variables, we note that problematic values are not obtained in terms of multicollinearity in the model. All the same, we checked the Variance Inflation Factors (VIF) that had an average of 1.74, finding that all are lower than 10, the limit usually used to anticipate possible problems of multicollinearity (Kleinbaum et al., 1988).

Table 2. Correlation matrix

	1	2	3	4	5	6	7
1. Green	1						
2. JIT	-0.117**	1					
3. Jidoka	0.292**	-0.136**	1				
4. RfP	0.021	0.013	0.016	1			
5. Sector/tech	0.196**	-0.01	-0.001	0.020	1		
6. Age	0.004	0.062**	0.062**	-0.109**	0.032*	1	
7. Plant Size	0.170**	-0.024	0.053**	0.140**	0.125**	-0.039**	1

Note: ** Significant correlation at level 0.01 and * at level 0.05. Pearson's correlation coefficient is used except for the dichotomous variables for which Spearman's coefficient is used

4. RESULTS AND DISCUSSION

4.1. Model and method of estimation

In order to test our hypotheses, which suggest that lean practices are either positive or negative for environmental performance, we estimated a panel data model with the following specification (Equation 1):

$$\text{Green}_{it} = \beta_1 + \beta_2 JIT_{it} + \beta_3 Jidoka_{it} + \beta_4 RfP_{it} + \sum_{i=5}^{8} \beta_i Control\_Variables_{it} \quad \text{(Equation 1)}$$

Where Green is the environmental performance indicator of manufacturing plant i at time t, and JIT, Jidoka and RfP represent the lean pillars. As control variables we included size, age and technological intensity in the sector. According to the modified Wald test for heteroskedasticity, we can reject the null hypothesis that errors are homoskedastic ($\chi 2 = 35{,}417.74$, $p < 0.01$). In addition, the Wooldridge test (2002) indicates the presence of autocorrelation ($F = 53.46$, $p < 0.01$). In these circumstances, with both heteroskedasticity and autocorrelation, the use of OLS analysis might be problematic. Although the MCO estimators would still be unbiased and consistent, they would no longer be efficient, so the standard errors would not be correct (Han and Mithas, 2013). To solve these problems, we used Feasible Generalized Least Squares (Wooldridge, 2002). In addition, diagnostic tests were performed to determine the stability of the results. We tested for normality in wastes and outliers, and found no problems (Greene, 2003; Belsley et al., 2005). The large number of observations (5,619) facilitates normality in error distribution.

The results obtained are shown in Table 3. Regarding the working hypotheses, we observe that the principles associated with the JIT pillar (-0.07, p<0.01) damage the plant's environmental performance; that is, the more the plant processes are JIT, the worse the environmental result will be. Hypothesis 1 is therefore confirmed. The other two pillars, Jidoka (1.532, p<0.01) and RfP (0.395, p<0.01), have a positive effect on environmental performance, so hypotheses 2 and 3 are also confirmed.

Table 3. Specification of the model including all the variables

Cross-sectional time-series FGLS regression with heterokedastic and AR(1) coefficients for all panels

Estimated covariances	= 1,025	Number of obs	= 5,619
Estimated autocorrelations	= 1	Number of groups	= 1,025
Estimated coefficients	= 15	Obs per group (avg):	= 5,5
		Wald chi2(14)	= 3074.21
		Prob > chi2	= 0.0000

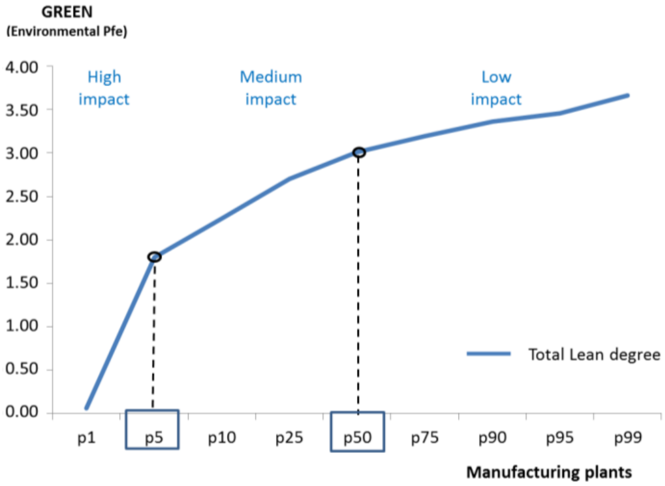
Variable	Coef.	Std. Err.	z	P>|z|	[95% Conf. Interval]	
JIT	-0.07	0.017	-4.13	0.000	-0.102	-0.036
Jidoka	1.532	0.041	37.30	0.001	1.452	1. 613
RfP	0.395	0.052	7.60	0.000	0.293	0.497
Sector	1.365	0.053	25.94	0.005	1.261	1.468
Age	0.023	0.043	0.52	0.602	-0.062	0.108
Size	0.002	0.000	24.56	0.000	0.002	0.002
Const_	-6.708	0.051	-132.27	0.000	-6.808	-6.609

In addition, by transforming the variables in a log-log model, we can empirically evaluate the behavior of each pillar separately. For example, we observe that a 1% increase in stock rotation (JIT pillar) worsens environmental performance by almost 0.1%. This reduction points to the conflict between the design of tense flows and a commitment to decarbonization. As the commitment to become leaner increases, firms find they have to reduce their lot size and increase delivery frequency, thus generating more CO_2 emissions. In the same way, since it is necessary to have more efficient equipment and materials, they give priority to this rather than to the use of other, less polluting materials. It is the other way round, however, in the case of Jidoka practices. The results obtained show that this same 1% increase in the use of factors of production (Jidoka) would amount to an increase of up to 1.5% in environmental behavior. In this case, the tools for improvement associated with this pillar seem to reinforce the commitment to reduce emissions by minimizing input consumption and intensifying improvement processes. Finally, in the case of RfP, the increase is only 0.3%. This type of analysis can undoubtedly optimize the use of resources in lean projects, promoting certain tools – in this case Jidoka and RfP – over others in order to maximize environmental performance.

For the control variables, as expected, we observe a positive effect of all three although in the case of plant *age* the effect is not significant. Firstly, *size* ($p < 0.01$) confirms that the largest firms have more resources for investing in clean technologies and practices that could reduce environmental impact (Hajmohammad et al., 2013). Similarly, our results suggest that younger manufacturing plants achieve a better environmental performance. Their facilities can be expected to be not only more modern but almost more efficient so they generate less waste and contamination (Rothenberg et al., 2001). Finally, the positive effect of *technological intensity in the sector* on environmental performance is consistent with prior studies that point to a greater predisposition among highly dynamic sectors to adopt environmental innovations (Rothenberg and Zyglidopoulos, 2007).

After evaluating the individual impact of each pillar on environmental performance, we can then determine their combined impact. We first estimated the overall lean impact for each plant using Equation 1, and then sorted the plants according to their environmental performance. Figure 1 plots the value for each percentile to facilitate the graphical analysis. It shows that the "Leaner a firm is, the Greener it is". So, while not all lean practices will necessarily be ecofriendly –as with JIT– overall, a positive Lean-Green behavior can be expected.

Figure 1. Analysis of the combined impact of lean pillars on environmental performance



Theoretically, these results are very valuable because they combine, for the first time and empirically, the two most usual views in the literature: the positive view that focuses on overall analysis, and the negative one that is limited to the analysis of certain lean practices that are usually associated with JIT tools and practices. In addition, this comprehensive analysis allows us to go a step further and identify three different Lean-Green behaviors. While for low-leanness values (below the 5th percentile) the impact of becoming more Lean has a very positive effect on environmental improvement (*High-impact area*), as the firm becomes leaner, this behavior becomes more moderate (Medium-impact area) until, for firms above the median (p50), any improvement in the leanness level will have hardly any impact on improved environmental performance (Low-impact area) (Figure 1). The consequences of these different situations are discussed below.

5. CONCLUSIONS

Our research proposes a model focused on the manufacturing plant which allows us to examine how each individual Lean pillar meets current environmental requirements and also to establish the overall impact of LM on environmental performance. Although the Lean-Green literature initially supports a positive impact of lean initiatives on environmental performance, there is no consensus on this and this complementarity is periodically questioned (Garza-Reyes, 2015; Ugarte et al., 2016). Our research aims to reconcile the two sides in this debate. Our results indicate, from a global point of view, that "Leaner means Greener" but that not all lean practices are necessarily ecofriendly. We test how the Jidoka and RfP pillars have a positive impact on improved environmental performance while JIT tools and practices have a negative impact.

We also identify a second important contribution: the effect on environmental performance differs depending on the degree of leanness achieved by the firm. For example, in "low-lean" environments, each lean improvement has a high impact on environmental performance, but this influence will decrease, and almost disappear, as the firm becomes leaner (Figure 1). These two aspects help explain the ambiguity still existing in the literature because analysis is not usually individualized, and such contextual factors are often not taken into account in evaluations of the relation between Lean and Green.

In addition to the theoretical contribution, these reflections should provide clear guidelines for business transformation projects based on lean methodologies that aim to achieve a sustainable model for operational excellence in a faster way. While our findings indicate that a lean environment may serve as a catalyst for green performance, our contributions nuance the traditional generic view summarized in statements such as that made by Dues et al (2013 p. 99): "it is rather undeniable that the ultimate Lean will be Green". While we do not refute this affirmation, it seems clear that in order to successfully incorporate environmental challenges in lean transformations, "one-size-fits-all" recipes like this are insufficient. In the end, the usual recommendations are so generic that they end up being useless for both practitioners and public policymakers. An individual road map is needed, considering not only the objectives of each firm but also the specific tools that would be used for each lean initiative and the plant´s level of leanness. As we have shown, environmental performance improvement will be determined by all these considerations, so taking them into account in today's competitive environments may determine the success or failure of any corporate strategy.

All practices associated with the RfP and Jidoka pillars should therefore be promoted. This is especially true for the Jidoka tools because not only do they have a greater impact on environmental performance but also there are already a considerable number of tools that have been designed with the dual purpose of eliminating waste and reducing emissions. These include tools such as Sustainable Value Stream Mapping (SVSM), Life Cycle Assessment (LCA) or energy management systems (e.g. ISO 50001). JIT practices, on the other hand, should be adopted with caution considering, in each case, their impact on emissions and other environmental factors. Moreover, since the effect will differ depending on the leanness degree achieved by each plant, in "high-lean" shop-floors the decision on which initiatives to adopt –JIT, Jidoka or RfP– becomes critical since the environmental return achieved will be minimal or even zero. Managers should take this into account when designing their investment policies.

Based on similar arguments, our results may also be relevant for the design of public policies that consider the integration of organizational analysis into CO2 abatement practices. Since public resources are limited, it is important that public aid and incentives focus on relevant projects (which otherwise might not be implemented) so that any money invested in regions will generate competitive advantages while balancing the trade-off between efficiency and sustainable development. Our evidence should therefore inspire customized public R&D programs that consider the specific features of each bundle of organizational routines: JIT, Jidoka and RfP. Managers often lack information and see organizational transformations as being more complex and involving longest deadlines, so they opt for technological solutions —e.g. end-pipe-technologies—that may be more immediate but will probably be less profitable in the long term since they do not solve the problem, they just keep it under control. Policymakers can turn this situation round by encouraging organizational solutions (based, for example, on incentives for Jidoka and RfP initiatives) that complement the investments in technology —so fashionable today around Industry 4.0 idea— with an explicit concern for improving organizational processes. This is the only way to minimize emisions, energy inputs and wastes in general, while improving industrial performance.

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APPENDIX

Table A1. Distribution of firms by size, turnover and sector

Characteristics	%
Size	
10 - 50 employees	32.7
51 - 250 employees	48.4
> 250 employees	18.9
Turnover	
From 2 to 10 m.	32.2
From 10 to 50 m.	39.9
From 51 to 100 m.	14.0
Over 100 m.	13.9
Sector	
High-technology	3.2
Medium-high-technology	13.5
Medium-low-technology	63.2
Low-technology	20, 1