JIT and Environmental Performance: an empirical analysis

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Abstract
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1. Introduction

Over the past decade there has been an increase in the research published on the synergies and trade-offs between lean manufacturing and environmental performance (Henao et al., 2019; Abualfaraa et al., 2020; Dieste et al., 2019; Lobo Mesquita et al., 2022; Garza-Reyes, 2015; King and Lenox, 2009).

These combined approaches, often dubbed 'lean-green', typically cites the Triple-Bottom-Line concept, which postulates the need for performance in economic growth, environmental preservation, and social responsibility, in order to achieve sustainability (Henao et al., 2019). Motivated by this body of research as well as our interest in sustainability studies, we have decided to study the effect of environmental and lean practices on environmental performance.

Abualfaraa et al. outline several research gaps and opportunities for those interested in lean-green manufacturing. In their Structured Literature Review of articles published between 2000 and 2018, they have identified several research directions in both the synergies and incompatibilities between environmental and lean practices (Abualfaraa et al., 2020). On one line, it is argued that lean practices may work as a catalyst for environmental practices and innovation through its focus on waste reduction and continuous improvement. On the other, the incompatibilities between the two approaches are also studied. Just in time (JIT) practices have been specifically highlighted. For example JIT manufacturing practices such as small lot sizes and high replenishment frequency implies more frequent transportation, higher CO2 emissions and more packaging waste (Dieste et al., 2019).

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Literature reviews also pointed out the need for more quantitative research with a focus on robust, well-defined sustainability metrics (Abualfaraa et al., 2020). Through an empirical analysis of JIT and environmental practices, our goal is to contribute to this research agenda.

2. Environmental Practices

A key concept in our research is environmental practices. In academic literature, 'environmental practices' is used to describe a wide range of different environmental practices (Montabon et al., 2007).

However, environmental practices are highly context-related, and in our paper, we will focus specifically on environmental practices in a manufacturing plant context. There are a lot of environmental practices present in the literature, and generating an exhaustive list would be impossible. Separating environmental practices from non-environmental practices is not simple, as many conventional practices can be perceived as environmental practices depending on the context.

There are also various other terms and concepts that are closely related to environmental practices depending on the context. Many articles include discussion about environmental management practices which can be seen as environmental practices. The term 'green practices' is also occasionally mentioned and is often interchangeable with the concept of environmental practices.

For the purpose of examining environmental practices, researchers have developed multiple sets of environmental practices that are used in the papers for analysis and surveys (Montabon et al., 2007; Zhu and Sarkis, 2004). In the literature, different categorizations for environmental practices have been displayed. Montabon et al. (2007) divided their list of environmental practices used in their study into operational, tactical, and strategic practices. This was done to recognize that different practices have different scopes and impacts (Montabon et al., 2007). In our research, we will consider environmental practices comprehensively and use a list of environmental practices developed by the HPM survey (**?**).

This list includes the following practices: water efficiency, carbon tracking of internal operations, pollution prevention, carbon tracking, and environmentally friendly packing.

3. Lean practices and JIT delivery

3.1. Lean as a concept

Lean manufacturing refers to manufacturing where lean has been implemented. There are a lot of different definitions for lean in academic literature (Sundar et al., 2014). Lean is often thought of as activities relating to waste reduction, but in practice the fundamental purpose of lean is to increase the value of output by reducing waste in production processes (Sundar et al., 2014). For this paper, lean is defined loosely as a system that aims at continuous improvement and elimination of all kinds of waste (Simpson and Power, 2005). Lean practices include for example Just-in-Time manufacturing, Kanban, value stream mapping, and push and pull systems (Sundar et al., 2014). The main benefits of lean relate to increased productivity and quality while costs are reduced (Bhamu and Singh Sangwan, 2014).

Lean manufacturing is a holistic way of working. (King and Lenox, 2009) point out that lean manufacturing includes numerous practices, which spread over the entire scope of the organisation. Lean manufacturing can thus be seen to cover aspects of product development, operations management, supply chain management, design and manufacturing (Bhamu and Singh Sangwan, 2014). (Sundar et al., 2014) add that lean implementation requires a proper sequencing and integration plan. For example, cultural change and employee training on lean concepts are needed to make the implementation successful.

3.2. Just-in-time delivery

In the literature, the concepts of lean and Just-In-Time are intertwined and many, such as (Bhamu and Singh Sangwan, 2014), (Belekoukias et al., 2014) recognize the close connection between them. Just-in-Time is a critical aspect of lean manufacturing practices, focusing on the efficiency of production timing and inventory management.

"Lean manufacturing has been widely implemented by manufacturing organisations to achieve operational excellence, and in this way meet both traditional and contemporary organisational objectives such as profitability, efficiency, responsiveness, quality and customer satisfaction" (Garza-Reyes, 2015). "JIT is based on producing the right goods at the right time" (Womack and Jones, 1997). This contributes in reducing space utilisation, inventory and wastes associated to the overproduction of goods.

4. Environmental performance

Environmental performance refers to an organization's performance with respect to their environmental responsibilities (Mao et al., 2017; Mollenkopf et al., 2010). It is often measured by how much natural resources have been consumed and by how much waste of water, gases, and poisonous materials are emitted (Mao et al., 2017).

In this study, the focus is on studying the environmental performance of manufacturing plants. In the manufacturing context, a more specific definition for environmental performance has commonly been based on the quantity of pollutants released from a plant, either as measured by a third party (**?**) or as reported to the federal government (**??**).

In the study, we limit the scope of examination to the plant level, and do not consider how the manufacturing plant contributes to the environmental performance of the whole supply chain. The specific performance indicators we use for our second research questions are toxic air emissions and solid waste generation, based on previously suggested reserach directions. (Dieste et al., 2019)

5. Relationship between JIT and environmental performance

Most of the existing literature states that lean practices used to decrease the environmental impact of a company are successful (Dieste et al., 2020). However, there are different opinions among scholars on whether lean practices have a positive impact on environmental performance and lean practices can according to the literature have both positive and negative impacts on environmental performance (Dieste et al., 2020).

According to the research conducted by (Dieste et al., 2020), the general trend seems to be that lean practices improve long term environmental performance. Lean processes can aid companies in achieving their environmental goals if they are committed to the goals and aware of the organisation's environmental impact (Dieste et al., 2020). Some researchers state that lean companies can improve their environmental performance since the lean practices also focus on waste reduction and process efficiency (Dieste et al., 2020). More specifically, JIT practices can improve the environmental supply chain performance (Cherrafi et al., 2018; Dieste et al., 2020) and decrease the fuel consumption since smaller vehicles can be used for smaller deliveries (Garza-Reyes et al., 2016). Further, JIT can reduce energy consumption of storage since it reduces the inventory volume (Garza-Reyes et al., 2018).

Additionally, since lean practices assert waste reduction, they can naturally lead to better environmental practices and an internal environment that supports the adaptation of these practices (Garza-Reyes et al., 2018). Further, aspects worth considering are that lean companies more likely adapt environmental innovations (Mollenkopf et al., 2010; Garza-Reyes et al., 2018).

However, being more productive and efficient in manufacturing does not equal more environmental sustainability and several papers address negative or mixed impacts of lean on air emissions, energy use and water use (Dieste et al., 2020). Out of the lean practices, JIT is the most problematic due to its nature of small deliveries which can increase additional waste and emissions (Rothenberg et al., 2009; Venkat and Wakeland, 2006; Dieste et al., 2020) and some scholars argue that JIT and positive environmental performance cannot be combined (Zhu and Sarkis, 2004; Dieste et al., 2020). To specify, according to (Sartal et al., 2018; Dieste et al., 2020), the larger amount of JIT processes at the plant, the worse the environmental impact. Even if JIT can have positive inventory effects, its effects on pollution are especially debated in existing literature (Garza-Reyes et al., 2018). To further specify, recurrent deliveries increase the transportation need, which in turn increases the air emissions (Dieste et al., 2020).

Moreover, (Garza-Reyes et al., 2018) point out that most of the previous research conducted has focused on very specific lean practices and the environmental measures have varied significantly between studies. Through this, they argue that how lean practices affect environmental performance can still be labelled as inconclusive (Garza-Reyes et al., 2018). (Garza-Reyes et al., 2018) call for further research regarding the effect of lean manufacturing practices on environmental performance in other industrial sectors. Building on this literature review of existing research, the research questions for this study are the following:

RQ 1: What effect do lean JIT practices have on environmental practices and environmental performance?

RQ 2: What is the effect of JIT practices on toxic air emissions and solid waste generation?

6. Hypothesis

Below are our hypotheses. We will test these hypotheses using the data from the HPM survey. We will use the data to test for complementarity between environmental practices and JIT practices. We will also test for the moderating effect of JIT practices on the relationship between environmental practices and emissions to air and solid waste generation.

H1: Environmental practices and JIT practices are complementary: the implementation of JIT practices increases the marginal return of environmental practices on environmental performance and vice versa.

H2: JIT practices negatively moderates the effect of environmental practices on emissions to air and solid waste generation.

7. Methodology

The data used in the research comes from the High Performance Manufacturing project (HPM), specifically the fourth round survey. The specific data needed for this research will be gathered in collaboration with Professor Kari Tanskanen.

Our research methodology is based on Furlan et al. (2011) who used bundles to test for complementarity amongst an aggregate of practices. We were also inspired by Mao et al. (2017) use of moderating variables to test for more specific environmental effects.

8. Results

Confirmatory Factor Analysis

Preliminary Discussion:

- In the base article Furlan et al. (2011), they have only six practices for each bundle.

- Should we create subsamples to get down to six per factor, or is it okay to include everything?

- The majority of loadings are above 0.8, and all statistically significant ($p < 0.01$).

- We tried bundling sustainability outcomes at some stage too, but in the end, it seemed irrelevant to our research questions.

- We also conducted an EFA to see if we could further breakdown the bundles (specifically environmental practices, which is a massive group).

- We did not include EFA results here as it did not seem relevant to the research questions (should we include it or better use this time to diagnose our other models).

TABLE 1
Confirmatory Factor Analysis

Bundle	HPM Code	Item Description	Loading	SE	t-value
Environmental Practices	ENVRTX21	Environmentally preferable packaging for the products that you produce (recycled content, less volume, reusable packaging)	0.63***	0.06	11.11
	ENVRTX37	Using a third party to monitor working conditions at supplier facilities	0.8***	0.08	9.75
	ENVRTX02	Water efficiency	0.88***	0.07	12.97
	ENVRTX22	Substituting environmental preferable direct materials or supplies for harmful or non-renewable ones	0.69***	0.06	11.44
	ENVRTX39	Providing design specification to suppliers in line with environmental requirements (e.g. green purchasing, black list of raw materials)	1.06***	0.08	13.5
	ENVRTX23	Environmental improvements in the disposition of your organization's scrap or excess material (re-use, recycling, etc.)	0.58***	0.05	10.82
	ENVRTX18	Working with customers to help them achieve environmental objectives	1.12***	0.08	14.25
	ENVRTX13	Complying with a customer's supplier code of conduct	0.91***	0.08	11.8
	ENVRTX33	Starting or maintaining a formal M/WBE supplier purchase program	1.0***	0.08	11.79
	ENVRTX03	Reducing waste in internal processes (e.g., improving yield or efficiency)	0.61***	0.05	11.79
	ENVRTX20	Life-cycle analysis of the "cradle to grave" environmental impact of materials/products	1.19***	0.08	14.62
	ENVRTX38	Incorporating environmental considerations in evaluating and selecting suppliers	1.16***	0.07	15.53
	ENVRTX08	Decreasing the likelihood or impact of an environmental accident	0.67***	0.05	12.3
	ENVRTX05	Pollution prevention (eliminating emissions or waste)	0.72***	0.06	12.89
	ENVRTX30	Giving preference to materials with third party certifications, such as Green Seal, FSC or Energy Star	1.02***	0.08	13.2
	ENVRTX24	Environmental improvements in the disposition of your organization's equipment	0.97***	0.06	15.36
	ENVRTX32	Purchasing from minority- or women-owned business enterprise (M/WBE) suppliers	0.98***	0.08	12.96
	ENVRTX34	Visiting suppliers' plants or ensuring that they are not using sweatshop labor	1.07***	0.09	12.5

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TABLE 1
Confirmatory Factor Analysis

Bundle	HPM Code	Item Description	Loading	SE	t-value
	ENVRTX04	Improving the workforce environment (e.g., indoor air quality)	0.57***	0.05	11.27
	ENVRTX29	Encouraging suppliers to improve the environmental performance of their processes	1.28***	0.08	16.88
	ENVRTX41	Involvement of suppliers in the re-design of internal processes (e.g. remanufacturing, reduction of by-products)	1.02***	0.07	14.73
	ENVRTX40	Co-development with suppliers to reduce the environmental impact of the product (e.g. eco-design, green packaging, recyclability)	1.09***	0.07	15.24
	ENVRTX09	Reduction/avoidance of land consumption	1.13***	0.09	13.24
	ENVRTX17	Carbon tracking/carbon footprint calculation of supply chain	1.11***	0.09	12.68
	ENVRTX07	Remediation projects, such as cleanup or restoration from past practices	1.18***	0.09	12.57
	ENVRTX11	Improvements in outbound transportation, such as fuel efficiency or load matching	1.12***	0.08	14.1
	ENVRTX10	Improvements in inbound transportation, such as fuel efficiency or load matching	1.1***	0.08	14.38
	ENVRTX01	Energy efficiency or renewable energy	0.77***	0.07	11.55
	ENVRTX14	Complying with an industry-wide code of conduct	0.87***	0.06	14.21
	ENVRTX15	Other compliance or auditing program focused on your plant (not on your suppliers)	0.88***	0.06	13.72
	ENVRTX12	Seeking or maintaining ISO14001 certification	0.85***	0.09	9.73
	ENVRTX31	Requesting that your suppliers sign a code of environmental conduct	1.16***	0.09	12.72
	ENVRTX35	Ensuring that suppliers comply with child labor laws	1.12***	0.1	11.7
	ENVRTX36	Asking suppliers to pay a “living wage”	1.04***	0.09	11.17
	ENVRTX06	Pollution control (scrubbing, waste treatment)	0.76***	0.07	11.27
	EPRACX01	Implementation of a certified environmental management system, such as ISO 14000.	0.96***	0.09	10.3
	EPRACX02	Implementation of internal environmental management procedures (e.g. environmental training program, internal environmental audit, newsletter).	0.96***	0.08	12.34

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TABLE 1
Confirmatory Factor Analysis

Bundle	HPM Code	Item Description	Loading	SE	t-value
	EPRACX03	Use of cleaner technologies in the production process (e.g. abatement equipment) to reduce pollution emissions and/or resource use.	0.98***	0.07	14.2
	EPRACX04	Environment-friendly product design.	1.21***	0.08	15.58
	EPRACX05	Environmental improvement of packaging.	1.0***	0.07	14.74
	EPRACX06	Use of environment-friendly raw materials.	0.99***	0.07	14.6
JIT Practices	LAYOUTN01	We have laid out the shop floor so that processes and machines are in close proximity to each other.	0.71***	0.06	11.66
	LAYOUTN02	The layout of our shop floor facilitates low inventories and fast throughput.	0.79***	0.07	12.04
	LAYOUTN03	Our processes are located close together, so that material handling and part storage are minimized.	0.88***	0.07	11.87
	LAYOUTN04	We have located our machines to support JIT production flow.	1.03***	0.08	13.77
	JITDELN01	Our suppliers deliver to us on a just-in-time basis.	1.09***	0.09	12.74
	JITDELN02	We receive daily shipments from most suppliers.	0.8***	0.09	9.13
	JITDELN03	Our suppliers are linked with us by a pull system.	1.1***	0.09	12.2
	KANBANN01	Suppliers fill our kanban containers, rather than filling purchase orders.	0.73***	0.09	8.39
	KANBANN02	We use a kanban pull system for production control.	1.05***	0.09	11.34
	KANBANN03	We use kanban squares, containers or signals for production control.	1.08***	0.09	11.56
	LINKCN01	Our customers receive just-in-time deliveries from us.	1.04***	0.08	12.82
	LINKCN02	We always deliver on time to our customers.	0.71***	0.06	10.97
	LINKCN03	We can adapt our production schedule to sudden production stoppages by our customers.	0.77***	0.07	11.39
	LINKCN04	Our customers have a pull type link with us.	1.18***	0.09	12.66
	LINKCN05	Our customers are linked with us via JIT systems.	1.24***	0.09	13.44
	SCHEDN01	We usually meet the production schedule each day.	0.75***	0.06	12.46

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TABLE 1
Confirmatory Factor Analysis

Bundle	HPM Code	Item Description	Loading	SE	t-value
	SCHEDN02	We usually complete our daily schedule as planned.	0.68***	0.05	12.59
	SETUPN01	We are aggressively working to lower setup times in our plant.	0.76***	0.07	10.88
	SETUPN02	We have low setup times of equipment in our plant.	0.81***	0.07	11.53
	SETUPN03	Our workers practice setups, in order to reduce the time required.	1.04***	0.09	11.84
Environmental Performance	EPERFX01	Overall environmental performance.	0.83***	0.06	14.96
	EPERFX02	Raw materials consumption.	0.77***	0.05	14.78
	EPERFX03	Energy consumption.	0.96***	0.06	16.74
	EPERFX04	Water consumption.	0.94***	0.06	17.02
	EPERFX05	Emissions to air.	0.89***	0.06	15.69
	EPERFX06	Releases to water.	0.81***	0.06	14.38
	EPERFX07	Solid waste generation (e.g. landfill capacity consumed).	0.7***	0.05	13.53
	EPERFX08	Waste recovery (e.g. recycling).	0.59***	0.05	11.7
	EPERFX09	Fines or other violations of environmental rules/regulations.	0.84***	0.07	11.57

Practice Adoption

Preliminary Discussion:

- Staying with Furlan et al. (2011), we have created dummy variables for the study as seen in Table 2.

- We will need to discuss how these dummy variables were created (splitting at the median point for high/low and then expanding to 4 categories based on the binary combinations).

- We still have not run a t-test to confirm statistically significant means between dummy variables as per Furlan et al. (2011).

TABLE 2
Practice Adoption and Environmental Performance

Category	Frequency	Percentage	Mean of Performance
High JIT & Environmental	68	38.86	3.90
Mainly Environmental	27	15.43	3.77
Mainly JIT	47	26.86	3.50
Low JIT & Environmental	33	18.86	3.33

Tukey Analysis

Preliminary Discussion:

- The Tukey analysis shows that the means of environmental performance differences are not statistically significant in certain cases.

- This fact seems to already reject H0 as we have no difference in performance between the combination and the singular (mainly environmental).

- For this reason, we probably do not need to run the OLS regression for complementarity as we can already see the marginal performance difference is not present.

- What can we do to validate the assumptions of this modeling?

TABLE 3
Multiple Comparison of Means - Tukey HSD, FWER=0.05

group1	group2	p-adj	lower	upper	reject
High JIT & Environmental	Low JIT & Environmental	0.00	-0.85	-0.28	True
High JIT & Environmental	Mainly Environmental	0.69	-0.43	0.18	False
High JIT & Environmental	Mainly JIT	0.00	-0.65	-0.14	True
Low JIT & Environmental	Mainly Environmental	0.01	0.09	0.79	True
Low JIT & Environmental	Mainly JIT	0.45	-0.13	0.48	False
Mainly Environmental	Mainly JIT	0.15	-0.59	0.06	False

Regression Models

Preliminary Discussion:

- For our regression models, we have taken means of our CFA bundles (JIT and Env) and used them as the independent variables.

- Again, we need to understand what the most important assumptions for this model are and how to validate them.

- So far (controlling for plant size), we see no statistically significant results for the regression models besides environmental practices as correlated to emissions to air.

- These results are surprising and make us question the validity of our models.

- Is the reason for these results the fact that we bundle over 40 practices, and the dependent variables are too singular?

- How can we diagnose and improve our models?

- General comment for all models: we have not checked the 6 assumptions of linear models.

- Where is most imporant to check for: normality, homoscedasticity, multicollinearity, autocorrelation, and linearity?

TABLE 4
Emissions to Air - Regression Results

Coefficient	Coef.	Std.Err.	t	P>|t|	[0.025	0.975]	Sig.
Intercept	-0.86	1.81	-0.48	0.63	-4.43	2.70	
Env_Score	1.26	0.52	2.42	0.02	0.23	2.28	**
JIT_Score	0.83	0.53	1.58	0.12	-0.21	1.87	
JIT_Env_Interaction	-0.22	0.15	-1.48	0.14	-0.51	0.07	
ACCTGX51	-0.00	0.00	-0.09	0.93	-0.00	0.00	

TABLE 5
Solid Waste Generation - Regression Results

Coefficient	Coef.	Std.Err.	t	P>|t|	[0.025	0.975]	Sig.
Intercept	1.50	1.58	0.95	0.35	-1.63	4.62	
Env_Score	0.46	0.45	1.02	0.31	-0.43	1.36	
JIT_Score	0.27	0.46	0.58	0.56	-0.64	1.18	
JIT_Env_Interaction	-0.02	0.13	-0.19	0.85	-0.28	0.23	
ACCTGX51	0.00	0.00	1.41	0.16	-0.00	0.00	

9. Discussion

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