JIT, Environmental Practices & Performance: an empirical analysis

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Abstract

Purpose - This paper aims to identify if there are complimentarity effects on environmental sustainability produced from JIT & environmental practices. Due to the increased delivery frequency and pacakging requirements implied by JIT we also investigate the moderating effect between JIT and environmental practices on air emissions and solid waste generation.

Design/methodology/approach - This paper uses the High Performance Manufacturing dataset (Round IV). This survey includes plants across 19 countries across Europe, Asia and the Americas. The industries included in the study are machinery, electronics and transportation.

Findings - Our results suggest that there is no complimentarity effect between JIT and environmental practices on environmental performance. Our study also finds no moderating effect between JIT and environmental practices on air emissions and solid waste generation.

Research limitations/ implications - We suggest more work to be done on the analysis, specifically on the robustness checks and the control variables used in the regression analysis.

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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

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(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).

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 emissions to air 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; **?**; 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. For the EFA section of the paper we have followed the recommendations provided by Beavers et al. (2013).

Exploratory Factor Analysis

The first step of our analysis was to identify the underlying factors of the data, we have a theoritical understanding of the underlying factors of the data, however, we have used exploratory factor analysis (EFA) to first validate our theoritical understanding. The EFA was conducted using the `FactorAnalyzer` package for Python (Persson and Khojasteh, 2021). The EFA was conducted on the various environmental practices, environmental

performance and Lean/JIT scales provided in the HPM round 4 dataset.
The EFA was conducted using the minimum residuals extraction method. This was due to the methods flexibility, and the underlying distribution of the data, excluding other methods such as Maximum Likelihood. Principal Axis Factoring has not been explored but may also be worth exploring in future research. We used an oblique rotation method due to the theoritical understanding that the factors will be correlated. The oblique rotation was conducted using the `promax` method `FactorAnalyzer`.
Following Schönrock-Adema et al. (2009) & Costello and Osborne (2005) we used multiple criteron to determine the number of factors to extract. This was an iterative process of extracting factors and examining the factor loadings and domain relevance of the factors.

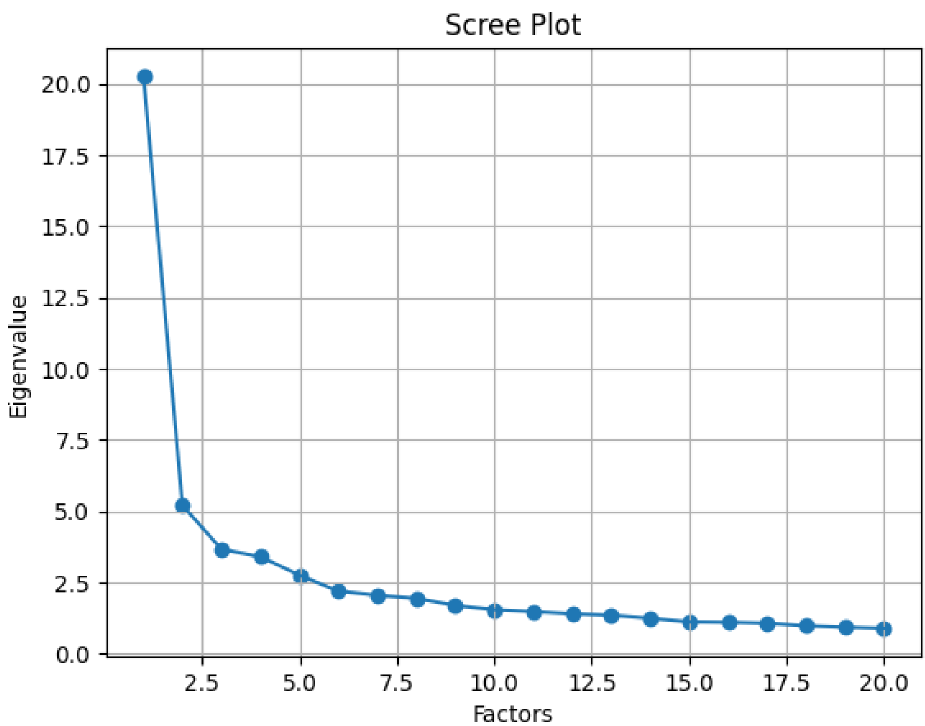

FIGURE 1: Scree plot indicated an elbow somewhere between 3 and 7 factors

The first method was the Kaiser criterion, which states that factors with eigenvalues greater than 1 should be extracted. This was first of all not feasable as it produced over 15 factors most of which with very low loadings and little domain relevance, with factors cross loading on multiple variables. The second method was the scree plot, which is a visual method of determining the number of factors to extract, from this we determined that the elbow was somewhere between 3 and 7 factors (Figure 1).
Working first with seven factors we examined the loadings and domain relevance, we found that the factors had little domain relevace as well as low loadings. Strikingly Factors 5, 6, 7 only contained 3 practices each with loadings above 0.50. (Table 1).

TABLE 1
Exploratory Factor Analysis - Highlighting loadings > 0.5

HPM Code	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7	Communality	Uniqueness
ENVRTX21	0.53	0.15	-0.0	0.13	-0.15	0.2	-0.02	0.387124	0.612876
ENVRTX37	0.14	0.6	0.06	0.08	0.03	0.06	-0.06	0.401213	0.598787
ENVRTX02	0.59	0.23	0.2	0.17	0.01	-0.17	-0.01	0.498194	0.501806
ENVRTX22	0.6	0.14	0.23	0.1	-0.15	0.13	-0.07	0.490537	0.509463
ENVRTX39	0.6	0.26	0.14	0.15	0.0	0.08	-0.05	0.474416	0.525584
ENVRTX23	0.65	-0.07	0.05	0.16	0.08	-0.15	0.2	0.526442	0.473558
ENVRTX18	0.53	0.42	0.05	0.15	0.19	0.04	-0.02	0.515498	0.484502
ENVRTX13	0.46	0.29	-0.05	0.13	0.19	-0.07	0.09	0.364410	0.635590
ENVRTX33	0.26	0.62	0.16	0.02	-0.03	0.09	0.02	0.493124	0.506876
ENVRTX03	0.6	0.12	0.16	0.25	0.09	-0.0	0.04	0.475674	0.524326
ENVRTX20	0.6	0.34	0.13	0.06	-0.02	0.09	0.07	0.506159	0.493841
ENVRTX38	0.6	0.36	0.15	-0.0	0.07	0.01	0.15	0.546286	0.453714
ENVRTX08	0.75	-0.04	0.06	0.05	0.01	-0.03	0.14	0.592730	0.407270
ENVRTX05	0.75	-0.02	0.12	0.09	0.04	-0.19	0.16	0.652066	0.347934
ENVRTX30	0.47	0.48	0.11	0.09	0.14	0.04	-0.05	0.491478	0.508522
ENVRTX24	0.66	0.22	0.31	0.07	-0.02	0.07	0.13	0.613468	0.386532
ENVRTX32	0.31	0.68	0.2	0.03	-0.04	0.14	-0.07	0.633967	0.366033
ENVRTX34	0.32	0.55	0.11	0.03	0.08	-0.0	0.1	0.428647	0.571353
ENVRTX04	0.54	0.09	0.2	0.02	0.04	0.06	0.17	0.371735	0.628265
ENVRTX29	0.55	0.57	0.15	0.11	0.16	0.04	0.03	0.694491	0.305509
ENVRTX41	0.5	0.49	0.2	-0.01	0.24	0.16	-0.03	0.616388	0.383612
ENVRTX40	0.46	0.54	0.23	-0.01	0.07	0.21	0.04	0.609872	0.390128
ENVRTX09	0.56	0.35	0.18	0.16	0.1	0.04	-0.04	0.516182	0.483818

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TABLE 1

Exploratory Factor Analysis - Highlighting loadings > 0.5

HPM Code	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7	Communality	Uniqueness
ENVRTX17	0.29	0.5	0.31	0.11	-0.11	0.13	0.15	0.490870	0.509130
ENVRTX07	0.45	0.31	0.28	0.08	-0.0	0.09	0.05	0.388896	0.611104
ENVRTX11	0.47	0.43	0.18	0.1	0.14	0.2	-0.07	0.513124	0.486876
ENVRTX10	0.44	0.47	0.18	0.16	0.23	0.17	-0.07	0.554014	0.445986
ENVRTX01	0.47	0.13	0.26	0.1	-0.06	0.16	0.19	0.377254	0.622746
ENVRTX14	0.69	0.2	0.03	0.06	0.22	-0.05	0.07	0.576579	0.423421
ENVRTX15	0.64	0.25	0.01	0.07	0.17	-0.16	0.14	0.546207	0.453793
ENVRTX12	0.27	0.04	0.13	0.11	0.02	0.02	0.78	0.710872	0.289128
ENVRTX31	0.29	0.51	0.19	0.18	-0.1	-0.06	0.37	0.560730	0.439270
ENVRTX35	0.17	0.67	0.06	0.2	0.02	-0.21	0.23	0.621047	0.378953
ENVRTX36	0.1	0.69	0.22	0.19	0.08	-0.08	0.13	0.597819	0.402181
ENVRTX06	0.5	0.02	0.26	-0.01	0.08	-0.01	0.32	0.434361	0.565639
EPRACX01	0.23	0.12	0.08	0.05	0.01	0.23	0.81	0.781392	0.218608
EPRACX02	0.5	0.08	0.2	-0.0	0.06	0.1	0.6	0.659780	0.340220
EPRACX03	0.62	0.11	0.31	0.05	-0.09	0.16	0.17	0.557559	0.442441
EPRACX04	0.58	0.31	0.25	0.06	-0.03	0.35	0.06	0.624820	0.375180
EPRACX05	0.53	0.28	0.21	0.17	-0.12	0.37	0.08	0.586183	0.413817
EPRACX06	0.52	0.36	0.21	0.16	0.02	0.27	-0.03	0.539612	0.460388
EPERFX01	0.37	0.17	0.62	0.05	0.09	-0.04	0.14	0.585140	0.414860
EPERFX02	0.25	0.31	0.65	0.11	0.06	0.11	-0.07	0.609480	0.390520
EPERFX03	0.21	0.23	0.78	0.13	0.09	-0.13	-0.06	0.747198	0.252802
EPERFX04	0.17	0.16	0.78	0.12	0.08	-0.13	-0.03	0.705412	0.294588
EPERFX05	0.21	0.1	0.78	0.05	0.03	0.04	0.04	0.668555	0.331445

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TABLE 1

Exploratory Factor Analysis - Highlighting loadings > 0.5

HPM Code	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7	Communality	Uniqueness
EPERFX06	0.05	0.02	0.73	0.07	-0.02	0.01	0.11	0.550325	0.449675
EPERFX07	0.18	0.2	0.62	0.13	0.09	0.13	0.05	0.501326	0.498674
EPERFX08	0.26	0.11	0.52	0.07	0.11	0.11	0.2	0.418796	0.581204
EPERFX09	0.15	0.02	0.52	0.1	-0.02	-0.01	0.09	0.312394	0.687606
LAYOUTN01	0.16	-0.01	0.09	0.69	0.04	-0.02	0.06	0.514815	0.485185
LAYOUTN02	0.22	0.06	0.1	0.66	-0.07	0.08	-0.04	0.503373	0.496627
LAYOUTN03	0.12	0.18	0.05	0.65	-0.07	0.04	0.07	0.485319	0.514681
LAYOUTN04	0.18	0.09	0.06	0.6	0.01	0.25	0.02	0.473988	0.526012
JITDELN01	0.08	0.17	0.19	0.27	0.34	0.39	0.06	0.414861	0.585139
JITDELN02	0.0	0.18	0.26	0.03	0.33	0.26	-0.01	0.278420	0.721580
JITDELN03	-0.02	0.24	0.14	0.29	0.32	0.23	-0.05	0.316878	0.683122
KANBANN01	-0.04	0.11	0.01	-0.0	0.15	0.51	0.1	0.306588	0.693412
KANBANN02	0.06	-0.03	-0.06	0.25	0.15	0.55	0.05	0.399152	0.600848
KANBANN03	0.09	-0.04	-0.04	0.18	0.2	0.67	0.04	0.530976	0.469024
LINKCN01	0.2	-0.02	0.13	0.28	0.54	0.27	-0.01	0.500219	0.499781
LINKCN02	0.09	-0.07	0.04	0.42	0.3	0.01	0.11	0.294498	0.705502
LINKCN03	-0.01	-0.01	0.08	0.48	0.37	-0.01	-0.04	0.377006	0.622994
LINKCN04	0.05	0.06	0.0	0.23	0.73	0.13	0.05	0.616880	0.383120
LINKCN05	0.08	0.09	0.02	0.21	0.74	0.29	0.04	0.689089	0.310911
SCHEDN01	0.05	0.07	0.04	0.59	0.15	0.1	0.08	0.395107	0.604893
SCHEDN02	0.01	0.09	0.03	0.6	0.15	0.1	0.05	0.402938	0.597062
SCHEDR03	0.07	-0.21	0.09	-0.05	-0.14	-0.15	-0.0	0.103053	0.896947
SETUPN01	0.17	0.05	0.02	0.53	0.12	0.0	0.01	0.324477	0.675523

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TABLE 1

Exploratory Factor Analysis - Highlighting loadings > 0.5

HPM Code	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7	Communality	Uniqueness
SETUPN02	-0.04	0.18	0.16	0.57	0.04	0.05	-0.04	0.390410	0.609590
SETUPN03	0.17	0.21	0.15	0.46	0.35	0.02	-0.09	0.435804	0.564196

We then reduced the number of factors to 6 and then 5, and found that the factors had a higer domain relevant and had higher loadings, but still faced many cross loading issues especially with the Lean/JIT groups. The domain relevance of these factors are also questionable as JIT was broken down into multiple factors with insufficient loadings to build a domain relevant factor. Eventually we settled on 4 factors, which had high loadings and were domain relevant, revealing a domain relevant breakdown of the environmental practices while retaining the domain relevance of the Lean/JIT and enviromental performance groups. 3 factors also had high loadings and domain relevance, but as we had no reason to reject the breakdown in environmental practices suggested by the EFA we decided to continue with 4 factors. See Table 2, 3, 4 & 5 below for a breakdown of our final bundles.

TABLE 2
Environmental Practices 1 (General)

HPM Code	Description	Loadings
ENVRTX08	Decreasing Environmental Accident Impact	0.851406
ENVRTX05	Pollution Prevention	0.846418
ENVRTX23	Environmental Improvements for Scrap/Excess Materia...	0.775964
EPRACX02	Internal Environmental Management Procedures	0.671973
ENVRTX14	Industry-wide Code Compliance	0.653831
ENVRTX15	Plant Compliance/Auditing Program	0.629963
EPRACX03	Cleaner Production Technologies	0.601676
ENVRTX24	Environmental Improvements for Equipment Dispositio...	0.596048

TABLE 3
Environmental Practices 2 (Suppliers)

HPM Code	Description	Loadings
ENVRTX32	Purchasing from M/WBE Suppliers	0.823226
ENVRTX33	Formal M/WBE Supplier Purchase Program	0.721714
ENVRTX37	Third Party Monitoring of Supplier Working Conditio...	0.703129
ENVRTX36	Asking Suppliers for Living Wage	0.662381
ENVRTX29	Encouraging Supplier Environmental Improvement	0.641546
ENVRTX40	Co-development with Suppliers for Environmental Imp...	0.620094
ENVRTX34	Ensuring No Sweatshop Labor in Supplier Plants	0.605227
ENVRTX35	Ensuring Supplier Child Labor Law Compliance	0.600539

TABLE 4
JIT Practices

HPM Code	Description	Loadings
LINKCN05	Our customers are linked with us via JIT systems.	0.623435
SCHEDN02	We usually complete our daily schedule as planned.	0.621872
SCHEDN01	We usually meet the production schedule each day.	0.619473
LINKCN03	We can adapt our production schedule to sudden prod...	0.609956
LINKCN04	Our customers have a pull type link with us.	0.594620
LINKCN01	Our customers receive just-in-time deliveries from ...	0.592328
LAYOUTN01	Equipment Layout - Proximity	0.591347
LAYOUTN04	Equipment Layout - JIT Production	0.579354

TABLE 5
Environmental Performance

HPM Code	Description	Loadings
EPERFX06	Releases to Water	0.812363
EPERFX04	Water Consumption	0.810310
EPERFX05	Emissions to Air	0.804205
EPERFX03	Energy Consumption	0.784988
EPERFX02	Raw Materials Consumption	0.608603
EPERFX07	Solid Waste Generation	0.607016
EPERFX01	Overall Environmental Performance	0.584450
EPERFX09	Fines or Violations	0.543801

TABLE 6
Variance Explained by EFA

Factor	Eigenvalue	Variance Explained %	Cumulative Variance Explained %
Factor 1	20.274239	26.770974	26.770974
Factor 2	5.197752	6.296780	33.067754
Factor 3	3.654683	4.362066	37.429821
Factor 4	3.393518	3.945660	41.375481
Factor 5	2.746089	3.003128	44.378609
Factor 6	2.184200	2.426975	46.805584
Factor 7	2.040140	2.098922	48.904506

One remaining point on the EFA process recommended by (Beavers et al., 2013) is to check the amount of variance explained by the factors. We found that the 4 factor model explained 41% of the variance in the data, while the 7 factor model explained 49% of the variance in the data. Due to the lack of domain interpretability and the little contribution to overall variance of the factor above 4 we decided to continue with this model. (Table 6) Although (Furlan et al., 2011) used a CFA to identify the factors, we have used an EFA to identify smaller bundles and validate theoretical assumptions. We also performed a CFA based on the relevant HPM round 4 scales. The results of the CFA analysis are included in the appendix.

Complimentarity Analysis

The first step in the complimentarity analysis as demonstrated by (Furlan et al., 2011) was to create a dummy variable for each bundle based on the factors. Dummy variables were created for each bundle, with the dummy variable being 1 if the firm scored above the median on all practices in the bundle, and 0 otherwise. From these 2 pairs of 2 binaries we created the following dummy variables to represent our practice bundles:

- High JIT & Environmental
- Low JIT & Environmental
- Mainly Environmental
- Mainly JIT

Each company was then assigned to one of these four categories based on their scores on the environmental practices and JIT scales. See tables 7 & 8 below for an overview.

TABLE 7
Practice Adoption (Environmental Practices 1 - General)

Category	Frequency	Percentage	Mean of Performance
High JIT & Environmental	67	38.29	3.87
Mainly Environmental	50	28.57	3.68
Mainly JIT	20	11.43	3.62
Low JIT & Environmental	38	21.71	3.30

TABLE 8
Practice Adoption (Environmental Practices 2 - Suppliers)

Category	Frequency	Percentage	Mean of Performance
High JIT & Environmental	45	25.71	4.00
Mainly Environmental	35	20.00	3.74
Mainly JIT	42	24.00	3.61
Low JIT & Environmental	53	30.29	3.36

The next step was to conduct a Tukey HSD test to determine if there was a significant difference between the mean environmental performance of the four groups. The results of the Tukey HSD test will be discussed in the results section.

Regression Analysis

The final step in the analysis was to conduct a regression analysis to determine if there was a significant moderating effect of JIT on the relationship between environmental practices and environmental performance. The regression analysis was conducted using the `statsmodels` package for Python (Seabold and Perktold, 2010).

8. Results

Complimentarity Analysis of JIT & Environmental Practices

First we run an ANOVA to test for statistically significant difference between the mean environmental performance outcomes of our four categories. First we checked for a statistically significant difference, then we a Tukey HSD test to determine which categories are significantly different from each other. See table 9 below for the results of our complimentarity test for the general environmental practices and JIT bundles.

TABLE 9
Multiple Comparison of Means - Tukey HSD, FWER=0.05 (Env Practices 1 - General)

group1	group2	p-adj	lower	upper	reject
High JIT & Environmental	Low JIT & Environmental	0.00	-0.85	-0.30	True
High JIT & Environmental	Mainly Environmental	0.20	-0.44	0.06	False
High JIT & Environmental	Mainly JIT	0.22	-0.60	0.09	False
Low JIT & Environmental	Mainly Environmental	0.00	0.09	0.67	True
Low JIT & Environmental	Mainly JIT	0.12	-0.05	0.69	False
Mainly Environmental	Mainly JIT	0.97	-0.42	0.29	False

From the results we can see that there is no statistically significant difference between the means for High JIT & High Env Practices and Mainly Environmental. There is also no statistically significant difference between the means for High JIT & Environmental and Mainly JIT. Based on these results we can conclude that there is no marginal gains from the combination of JIT and environmental practices on our environmental performance bundle. It is worth noting that our environmental practices bundle was limited during the EFA to the top 8 with the highest loadings, despite this fact we similar results when running the same analysis on the full set of environmental peformance outcomes (see appendix).
For our second environmental practices bundle, focused on suppliers activity there was no statistically significant differences among categories based on ANOVA ($p<0.05$), so we did not run a Tukey HSD test.

Moderating Effect on Specific Environmental Outcomes

Using mean of environmental performance outcomes as a dependent variable, we run a regression analysis to test for the moderating effect of JIT on the relationship between environmental practices and environmental performance. The results are presented in the tables below.

TABLE 10
Emissions to Air - Regression Results (Environmental Practices 1 - General)

Coefficient	Coef.	Std.Err.	t	P>|t|	[0.025	0.975]	Sig.
Intercept	2.28	2.03	1.12	0.26	-1.73	6.29	
Env_Score	0.27	0.51	0.53	0.60	-0.74	1.28	
JIT_Score	-0.05	0.59	-0.08	0.93	-1.21	1.11	
JIT_Env_Interaction	0.04	0.15	0.25	0.80	-0.25	0.32	
ACCTGX51	-0.00	0.00	-0.05	0.96	-0.00	0.00	

TABLE 11
Solid Waste Generation - Regression Results (Environmental Practices 1 - General)

Coefficient	Coef.	Std.Err.	t	P>|t|	[0.025	0.975]	Sig.
Intercept	1.89	1.80	1.05	0.29	-1.66	5.44	
Env_Score	0.32	0.45	0.70	0.48	-0.58	1.21	
JIT_Score	0.23	0.52	0.45	0.65	-0.79	1.26	
JIT_Env_Interaction	-0.02	0.13	-0.16	0.87	-0.28	0.23	
ACCTGX51	0.00	0.00	1.86	0.07	-0.00	0.00	*

It is clear from the results that there is no statistically significant moderating effect of JIT on the relationship between environmental practices and environmental performance for the general environmental practices bundle.
Below we will also present the results of the regression analysis for the supplier orientated environmental practices bundle.

TABLE 12
Emissions to Air - Regression Results (Environmental Practices 2 - Suppliers)

Coefficient	Coef.	Std.Err.	t	P>|t|	[0.025	0.975]	Sig.
Intercept	2.28	2.03	1.12	0.26	-1.73	6.29	
Env_Score	0.27	0.51	0.53	0.60	-0.74	1.28	
JIT_Score	-0.05	0.59	-0.08	0.93	-1.21	1.11	
JIT_Env_Interaction	0.04	0.15	0.25	0.80	-0.25	0.32	
ACCTGX51	-0.00	0.00	-0.05	0.96	-0.00	0.00	

Again, there is no statistically significant moderating effect of JIT on the relationship between environmental practices and environmental performance for the supplier orientated

TABLE 13
Solid Waste Generation - Regression Results (Environmental Practices 2 - Suppliers)

Coefficient	Coef.	Std.Err.	t	P>|t|	[0.025	0.975]	Sig.
Intercept	1.89	1.80	1.05	0.29	-1.66	5.44	
Env_Score	0.32	0.45	0.70	0.48	-0.58	1.21	
JIT_Score	0.23	0.52	0.45	0.65	-0.79	1.26	
JIT_Env_Interaction	-0.02	0.13	-0.16	0.87	-0.28	0.23	
ACCTGX51	0.00	0.00	1.86	0.07	-0.00	0.00	*

environmental practices bundle. It is worth noting that we do have a statistically significant result at $p < 0.05$ for our control variable of plant size in the regression analysis for solid waste generation in the supplier orientated environmental practices bundle.

Discussion

8.1. Complimentarity & Moderating Effects

We were suprised to find that there was no statistically significant difference between the means for High JIT & High Env Practices and Mainly Environmental. This suggests that there is no complimentarity between JIT and environmental practices. There was also no statistically significant moderating effect or individual effect of JIT on the relationship between environmental practices and environmental performance. It is also worth noting that there should be more robustness checks done on the regression analysis. This could include checking for multicollinearity and checking for heteroskedasticity.

In the future we would like to run a VIF test specifically and to look for correlations between the independent variables. There is also some questions about the control variables needed for the regression analysis.

8.2. Findings & Limitations

The lack of complimentarity does not suggest a negative relationship between JIT and environmental performance but it does suggest that there is no marginal gains from the combination of JIT and environmental practices on our environmental performance bundle.

The way we have formed our bundles in the EFA may have contributed to this result, but it is worth noting that the outcomes were the same for our Hypothesis when running a CFA on the full set of practices from the relevant HPM round 4 scales (see appendix). The question of JITs impact on environmental performance is still an open one. We suggest more work to be done both on the analysis but also on the data collection that can support further research on the specific relationship between JIT and environmental performance. It may also be useful to go back the literature to help identify the most salient independant variables related to JITs environmental effects, in order to develop a more informed model.

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Appendix

TABLE 14
Multiple Comparison of Means - Tukey HSD, FWER=0.05 (Based on CFA Bundles)

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

TABLE 15
Emissions to Air - Regression Results (Based on CFA Bundles)

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 16
Solid Waste Generation - Regression Results (Based on CFA Bundles)

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	

TABLE 17
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

Continued on next page

TABLE 17
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

Continued on next page

TABLE 17
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 17
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