Academia Revista Latinoamericana de Administración

The role of information technology in the environmental performance of the firm: The interaction effect between information technology and environmental practices on environmental performance

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Received 16 October 2014
Revised 19 December 2014
14 February 2015
Accepted 16 March 2015

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El rol de las tecnologías de información en el rendimiento ambiental de la empresa

El efecto moderador de las tecnologías de información en la relación entre prácticas medio ambientales empresariales y rendimiento ambiental de la empresa

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Abstract

Purpose – The purpose of this paper is to explore the role of information technologies (IT) in the impact of environmental practices on environmental performance.

Design/methodology/approach – The authors use data from the fifth (2009) round of the International Manufacturing Strategy Survey (IMSS) which includes responses from manufacturing plants within the manufacturing industry in Brazil, China, Germany, Hungary and USA. The authors use multiple regression analysis to test the relationship between environmental practices and environmental performance and the moderating effect of IT.

Findings – The paper finds evidence that IT strengthens the relationship between environmental practices and environmental performance. The IT construct is operationalized through IT-enabled control and IT-enabled coordination. The results confirm the established relationship between environmental practices and environmental performance and show that IT-enabled coordination moderates the relationship between environmental practices and environmental performance.

JEL Classification — M11, M19

This paper was one of the best papers awarded at 2014 CLADEA Conference held at ESADE, Barcelona. The authors acknowledge the financial support from Research Grant No. ECO2010-16840 from the Spanish Ministry of Science and Innovation. The authors would also like to thank the participants of the 2012 Euroma workshop on journal publishing for non-native English-speaking researchers for the comments to an earlier draft of this paper.

Academia Revista Latinoamericana de Administración
Vol. 28 No. 2, 2015
pp. 273-291

1012-8255
DOI 10.1108/ARLA-08-2014-0113

Originality/value – This research contributes to the literature of green operations in the following ways: First, this paper offers an alternative explanation about the role of IT; the authors provide evidence that existing IT resources that support the coordination between product design and manufacturing strengthen the effect of environmental practices. Second, this paper provides evidence that environmental practices can take advantages of the IT resources embedded in daily plants' routines to enhance plants' environmental performance. Overall, this research provides suggestions to managers about the role that IT plays in the implementation of environmental practices.

Key words CLADEA-2014, Environmental practices, Green operations, Information technology, IT-enabled production control and coordination

Paper type Research paper

Resumen

Propósito – Este artículo explora el rol que las tecnologías de información tienen en la relación entre prácticas medio ambientales empresariales y el rendimiento ambiental de la empresa.

Diseño/metodología/enfoque – Este artículo utiliza datos de la quinta ronda (2009) de la encuesta internacional de estrategia de manufactura (IMSS por sus siglas en inglés), la cual incluye datos de plantas manufacturadoras en Brasil, China, Alemania, Hungría y Estados Unidos. Se utiliza análisis de regresión múltiple para evaluar el efecto entre prácticas medio ambientales empresariales y el rendimiento ambiental de la empresa; y el efecto moderador de tecnologías de información en la relación anterior.

Resultados – Este artículo encuentra que las tecnologías de información fortalecen la relación entre prácticas medio ambientales empresariales y el rendimiento ambiental de la empresa. El constructo de tecnologías de información es operacionalizado a través de indicadores de tecnologías de la información que facilitan el control de la producción y la coordinación. Los resultados confirman la relación positiva entre prácticas medio ambientales empresariales y el rendimiento ambiental; y evidencian que tecnologías de información que facilitan la coordinación moderan la relación anterior.

Originalidad/valor – Esta investigación contribuye a la literatura de "operaciones verdes" de la siguiente forma: Primero, esta ofrece una explicación alternativa sobre el rol de tecnologías de información; se provee evidencia que tecnologías de información existentes en la empresa que apoyan la coordinación entre diseño de producto y manufactura hacen más efectivas a las prácticas medio ambientales empresariales. Segundo, este artículo presenta evidencia que la implementación de prácticas medio ambientales empresariales puede apalancarse sobre la tecnología de información existente para mejorar el rendimiento ambiental de la empresa. En general, esta investigación ofrece sugerencias a los empresarios sobre el rol que las tecnologías de información tienen en la implementación de prácticas medio ambientales.

Palabras Clave CLADEA-2014, Prácticas ambientales, Operaciones verdes, Tecnología de Información, Tecnología de Información para el control de producción y coordinación

Tipo de papel Trabajo de investigación

1. Introduction

During the last decade, the adoption of environmental practices has been exacerbated by the enactment of governmental regulation and the pressure from watchdog organizations and society. This situation is reflected in the number of firms concerned about their environmental footprint: about 80 percent of the world's largest 250 companies reported on their social and environmental performance in 2008 (KPMG, 2008). Nonetheless, despite the increasing relevance of environmental sustainability, translating this concern into action seems to be a difficult task to practitioners (KPMG, 2011). Information technologies (IT) such as environmental enterprise resource planning (ERP) systems have been suggested as a tool for the implementation of environmentally sustainable practices (Melville and Whisnant, 2012); in this sense, companies such as Microsoft have developed software to support the implementation of such practices (Microsoft, 2014). However, there is little understanding insofar as the role of IT in the implementation of environmental practices in firms.

Environmental practices have been studied in the literature of operations management (OM) and IT. In the realm of OM, environmental practices refer to actions, projects, or initiatives undertaken by firms to minimize their footprint on the environment (Pagell and Gobeli, 2009). The following are some of the environmental practices studied in the literature: environmental audits, eco-design, eco-labeling, environmental management systems, ISO 14000 certifications (Karlsson and Luttropp, 2006; Klassen and Vachon, 2003; Vachon, 2007; Zhu *et al.*, 2008). There is a consensus in the OM community about the positive relationship between environmental practices and environmental performance (i.e. the reduction of greenhouse gas emissions, savings on energy, or water consumption) (Zhu and Sarkis, 2004, 2007). On the other hand, in the realm of IT, previous studies have addressed environmental issues from the perspectives of green IT, and green information systems (IS). Green IT refers to the redesign of hardware and components to reduce the amount of energy and waste through the product life cycle, while green IS refers to the indirect impact of IT through the improvement of manufacturing, inventory management, and transportation. Although our contribution is in OM, we take insights from the literature on green IS.

We posit that IT strengthens the effect that environmental practices have on environmental performance; in other words, there is a positive interaction effect between IT and environmental practices. In our study, we consider IT that supports production control (e.g. RFID) and IT that enables the coordination of operations with other functional areas (e.g. ERP and shared databases). We provide empirical evidence that manufacturing plants with a higher degree of IT that enables coordination exhibit higher environmental efficiency. This research contributes to the literature of green operations in the following ways: first, although the role of IT has been recognized in previous studies (Green *et al.*, 2012a, b), we offer an alternative explanation about the role of IT, which suggests that IT moderates the effect of environmental practices on firms' environmental performance. We provide evidence that existing IT resources that support the coordination between product design and manufacturing strengthen the effect of environmental practices. Second, following Pagell and Gobeli's (2009) recommendation, we examine individual plants because they are closer to daily decisions; therefore, we are able to provide managerial guidelines that facilitate the implementation of environmental practices. Finally, we argue that environmental practices can take advantages of the IT resources embedded in plants' daily routines to enhance plants' environmental performance.

This paper is structured as follows: first, we present a review of the literature of green operations and green IT and green IS. Second, we present our research model. Third, we present the methodology used to test our hypotheses and the discussion of the results. Finally, we end with some implications for future research, limitations, and concluding remarks.

2. Literature review and hypotheses development

2.1 The impact of environmental practices on environmental performance

Environmental practices entail a great variety of actions implemented at various levels of the firm. Previous research suggests that environmental considerations should be integrated into the corporate culture and business planning at all levels: design, manufacturing, distribution and disposal (O'brien, 1999; Zhu *et al.*, 2008). In product design, the integration of environmental considerations is known as eco-design; it refers to the changes in product, systems and services that minimize negative and maximize positive sustainability impacts throughout the life cycle (Karlsson and Luttropp, 2006). In manufacturing, green operations are related to clean production, a term defined as "the conceptual and procedural approach to production that demands that all phases of the life-cycle of a product or of a process should be addressed with the objective of prevention or the minimization of short and long-term risks to humans and the environment" (Baas, 1995, p. 56). In logistics, the environmental practices are related to: the decisions on transportation, inventory, packaging and their impact on CO_2 emissions (Quariguasi Frota Neto *et al.*, 2008) and the implications of reverse logistics on the environment (Sarkis *et al.*, 2004). In this regard, we follow previous studies, and focus on environmental practices related to product and process design, and aspects related to transportation and outsourcing.

Prior literature has drawn upon the natural resource based view to link environmental practices to environmental performance (Aragon-Correa and Sharma, 2003; Hart, 1995), for instance: Rao (2002) and Zhu and Sarkis (2004, 2007) have found that the adoption of environmental practices (e.g. waste management, environmental management systems, total quality environmental management, design of environmentally friendly products, supplier assessment, etc.) leads to better environmental performance. Accordingly, we also build on the natural resource-based view and hypothesize the following:

H1. Environmental practices have a positive impact on environmental performance.

2.2 The impact of IT on environmental performance

IT can help to drive the transformative agenda towards a low-carbon and resource light economy (EU-SUST, 2011). There are two main research streams in the IT literature that study the contribution of IT to reduce firms' energy footprint (Jenkin *et al.*, 2011). The first stream, called green IT, focusses on how to redesign the hardware, networks and their components in order to reduce the amount of waste and energy consumption throughout their life cycle; the second stream, called green IS, looks at the indirect impact that IT can have on environmental sustainability through the improvement of supply chain activities such as manufacturing, inventory management and transportation. Although green IS scholars acknowledge the importance of IT for improving firms' environmental performance by shaping their operational and supply chain activities, previous research has rarely considered the interrelation between environmental practices, IT and environmental performance.

Furthermore, in the green IS research stream it is argued that IT can enhance environmental sustainability through energy eco-efficiency as well as through instilling changes in the behavior and actions of organizational actors with regard to the firm's environmental sustainability (Jenkin *et al.*, 2011). On the one hand, IT improves energy eco-efficiency because it integrates, systematizes and captures data and meta-data (i.e. temperature, geographical location) that allow the firm to optimize transport routing (Chen *et al.*, 2008; Erdmann *et al.*, 2004; Melville, 2010) and energy management in its facilities (Erdmann *et al.*, 2004). On the other hand, IT instills changes in the actors' behavior by making visible indicators which encourage organizations to commit to sustainability actions (Bengtsson and Agerfalk, 2011) and by providing information to employees about their footprint in the environment (Jenkin *et al.*, 2011).

From another streamline, OM scholars that have studied the impact of environmental practices on firms' environmental performance argue that collaboration with members of the supply chain can help to reduce the overall impact of the firm on the environment (Klassen and Vachon, 2003). Geffen and Rothenberg (2000) found that strong partnerships with suppliers and their staff were successful elements in the application of innovative environmental technologies; Vachon and Klassen (2008) claimed that joint planning and knowledge sharing about environmental matters have a positive effect on firms' environmental performance; Handfield *et al.* (1997) found that environmental strategies are more likely to be successful when they are integrated across the stages of the supply chain (i.e. procurement, product design, manufacturing, etc). In short, collaborative activities, information sharing, and the integration of different processes along the supply chain are expected to enhance the performance of environmental strategies, projects or technologies. Therefore, it is reasonable to expect that IT supporting collaboration activities, information sharing, and integration of different processes might have an effect on environmental performance.

Green *et al.* (2012a, b) found that green IS has a positive direct effect on green purchasing, environmental cooperation with customers, environmental monitoring with suppliers, and eco-design. They measured green IS as the use of IT for reducing transportation costs, tracking environmental performance, reducing energy consumption, among other environmental practices; however, this research has the underlying assumption that IT for environmental purposes may differ from IT resources for supply chain applications. Instead of considering IT resources exclusively designed for environmental purposes, we argue that IT resources that enhance coordination and control of production strengthen the relationship between environmental practices and environmental performance.

This research uses an IT construct that contains indicators about technology that supports the control and visibility of activities during the production process such as: inventory control, information sharing with suppliers and technology that supports the management of interdependences between different functional areas such as product design and manufacturing teams. Hence, our model builds upon previous findings on the relationship between supply chain integration, supply chain collaboration and environmental performance (Klassen and Vachon, 2003). We posit that IT-enabled control and coordination strengthen the effect of environmental practices because they facilitate the integration of processes along the supply chain and they make visible metrics concerning the volume of materials, transportation costs, and other production-related indicators; showing in which operational practices environmental efforts should be made to enhance the firm's environmental performance. Therefore, we hypothesize that:

H2. IT-enabled production control and coordination strengthens the relationship between environmental practices and environmental performance.

The model and the hypotheses are displayed in Figure 1.

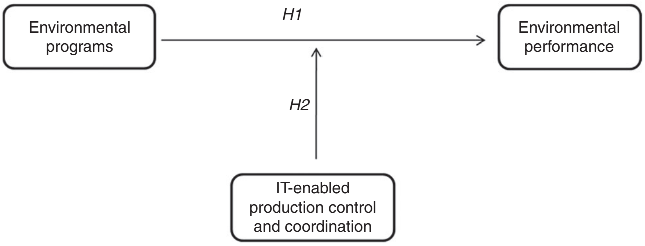


Figure 1.
Theoretical model and hypotheses

3. Methods

3.1 Data collection and measures

To test the hypotheses presented above, we used data from the fifth (2009) round of the International Manufacturing Strategy Survey (IMSS-V). IMSS is carried out by an international network of researchers in more than 20 countries. It studies manufacturing and supply chain strategies within the assembly industry (ISIC 28-35 classification). Questionnaires were administered simultaneously in each country and were mailed or e-mailed to the Director of Operations/Manufacturing or the person with the equivalent position in the organization.

The IMSS-V sample consists of 678 manufacturing plants from 19 countries with an average response rate of 18.3 percent. Non-response bias tests were performed in each country by the local research coordinators; no noticeable pattern among the variables that could indicate the existence of a non-response bias was found. For the purposes of this study, we considered responses from those countries with at least 30 responses in order to have balanced groups and be able to apply Generalizability theory (G-theory). The countries with at least 30 responses were the following: Brazil, China, Germany, Hungary, Italy, Spain and USA.

The items of the IMSS questionnaire are divided into various sections, starting with some general information (size, industry, etc.) and then focussing on different strategies, programs (organizational, lean, quality, supply chain, etc.) and performance. The list of items used in this study is provided in Table I; all of them were measured through a five-point likert scale. The items employed to measure environmental practices are the ones that include environmental actions aiming at improving the

Table I. Items used in the questionnaire for measuring the variables

Environmental practices[a]
Improving the environmental performance of processes and products (e.g., environmental management system, life-cycle analysis, design for environment, environmental certification)
Improving the environmental impact of products through appropriate design measures, e.g., design to recycle
Improving the environmental impact generated by transportation of materials/products and outsourcing of process steps
IT-enabled coordination[b]
Using enterprise resource planning (ERP) systems to coordinate the design and manufacturing
Using shared databases to coordinate the design and manufacturing
IT-enabled control
Engaging in product/part tracking and tracing programs (bar codes, RFID)
Implementing ICT supporting information sharing and process control in production
Performance[c]
Environmental performance
Control variables
Size (number of employees)
Industry classification
Country

Note: [a]In the questionnaire, performance was measured as performance changed over the last three years. A 1-5 Likert scale was used in which 1 = compared to three years ago, the indicator has deteriorated more than 5 percent, and 5 = compared to three years ago, the indicator has improved more than 25 percent. [b]Level of use to technologically coordinate design and manufacturing, being 1 = no use and 5 = high use. [c]In the questionnaire, these action programs were measured as the effort dedicated over the last three years. A 1-5 Likert scale was used in which 1 = none and 5 = high environmental performance of products and processes (following Zhu and Sarkis, 2004; Zhu *et al.*, 2008) and actions to improve the environmental impact generated by transportation of materials/products (following the "Business guide to a sustainable supply chain" published by the New Zealand Business Council for Sustainable Development, 2003).

Regarding IT, we used indicators of enablers of coordination and control: the use of ERP systems and shared databases to coordinate design and manufacturing, the implementation of product/part tracking and tracing programs (bar codes, RFID), and the use of IT to support information sharing and process control in production.

Although previous studies have considered constructs with multiple items, the team of researchers responsible for designing the IMSS questionnaire decided to measure environmental performance using a single item ("environmental performance"). Although using single items to measure environmental performance may be a limitation, the need to keep the IMSS questionnaire to a reasonable length justified this decision. This item has been previously used in the literature (e.g. Gimenez *et al.*, 2012; Pullman *et al.*, 2009).

Table II shows the descriptive of the different items measures in each country.

3.2 Measurement assessment and cross-national applicability

This section addresses the analysis of cross-national applicability in terms of configuration invariance. This means that we assessed how well the selected measures capture our concepts; and whether the measures are comparable across countries. This process essentially involved two steps: (a) measurement assessment, and (b) test for measurement invariance between countries.

Step (a): measurement assessment. Testing the measurement assessment implied analyzing the factorial structure of the measures and testing for their internal consistency and validities across countries. Internal consistency, convergent and discriminant validity of the measures were assessed using three measures: item reliability, construct reliability and average variance extracted (AVE).

We ran an exploratory factor analysis with all items related with IT and environmental practices. Three factors were extracted with 75.7 percent of explained variance (43.8, 18.2 and 13.7 percent, respectively on the whole sample). Evaluating the size of the loadings (see Table III), items 1, 2 and 3 represent the environmental practices construct. Items related with IT (items 4, 5, 6 and 7) configure two distinct factors that we have named IT-enabled control (items 4 and 5) and IT-enabled coordination (items 6 and 7). This three-factor structure is kept between countries (see Table III).

Item reliability was evaluated by the size of the loadings of the measures on their corresponding constructs. In order to have high convergent validity, high factor loadings are needed in order to enhance reliability and internal consistency in each country and cross-country. The environmental practices construct configuration remains between countries but two items concerning the IT constructs show differences between Italy and Spain compared to the rest of the countries analyzed. Particularly, Italy presents confusion in item 4, while Spain does so in item 7.

The reliability of each construct was satisfactory with a Cronbach α value and composite reliability values of at least 0.70. The AVE value, which is a summary indicator of convergence, was higher than 0.60 for the three constructs, showing that convergent validity was adequate considering the whole sample. Regarding each country, IT-enabled coordination shows non-acceptable reliability levels in Italy and Spain (Cronbach α 0.294 and 0.095, respectively). Based on this lack of reliability

Table II. Descriptive of measures per country

	Brazil ($n=30$)	China ($n=42$)	Germany ($n=34$)	Hungary ($n=60$)	Italy ($n=44$)	The Netherlands ($n=43$)	Spain ($n=36$)	USA ($n=60$)	Whole sample ($n=349$)
Perform									
Mean	3.63	3.57	2.97	2.83	2.70	2.84	3.19	2.78	3.02
SD	0.81	0.99	0.94	0.74	0.79	0.97	0.82	0.74	0.90
Environ. practices									
Item 1									
Mean	3.57	3.24	2.74	2.42	2.48	2.09	3.47	2.50	2.74
SD	1.01	1.05	1.08	1.12	1.34	1.00	1.03	1.16	1.20
Item 2									
Mean	3.17	3.12	2.26	2.13	1.86	2.02	2.89	2.27	2.41
SD	1.09	.97	1.29	1.11	.98	1.03	1.14	1.07	1.16
Item 3									
Mean	3.10	3.29	2.12	2.07	1.98	2.09	2.39	2.35	2.38
SD	1.09	1.11	1.04	.99	1.05	.95	1.10	1.15	1.14
IT-enabled									
Item 4									
Mean	3.53	2.86	2.97	2.43	2.37	2.47	3.37	2.73	2.77
SD	1.22	1.14	1.16	1.29	1.20	1.28	1.19	1.23	1.27
Item 5									
Mean	3.40	3.24	3.36	2.33	2.67	2.88	3.23	2.58	2.88
SD	1.07	1.12	1.03	1.08	1.19	1.20	1.17	1.09	1.17
Item 6									
Mean	4.03	3.40	4.09	2.69	3.53	4.09	4.44	3.32	3.59
SD	1.02	1.48	1.07	1.38	1.33	1.11	0.89	1.41	1.37
Item 7									
Mean	3.83	3.43	3.94	3.32	3.66	3.56	3.92	3.46	3.60
SD	1.00	1.27	1.07	1.15	0.99	1.03	0.84	1.02	1.07

Table III. Measurement assessment

	Whole sample			Brazil			China			Germany			Hungary			Italy			The Netherlands			Spain			USA		
	F1	F2	F3	F1	F2	F3	F1	F2	F3	F1	F2	F3	F1	F2	F3	F1	F2	F3	F1	F2	F3	F1	F2	F3	F1	F2	F3
Environmental practices																											
Item 1	*0.75*[a]	0.30	0.10	*0.55*	0.33	0.35	*0.75*	0.32	0.12	*0.78*	0.08	0.03	*0.56*	0.45	0.01	*0.89*	0.05	−0.01	*0.8*	0.16	0.11	*0.74*	−0.07	−0.26	*0.82*	0.32	0.08
Item 2	*0.85*	0.17	0.14	*0.9*	0.11	0.09	*0.82*	0.17	0.21	*0.87*	0.21	0.13	*0.83*	−0.08	0.25	*0.82*	0.22	−0.06	*0.82*	0.33	0.02	*0.83*	0.19	0.15	*0.83*	0.05	0.35
Item 3	*0.85*	0.10	0.07	*0.88*	0.06	0.1	*0.83*	0.09	0.2	*0.79*	−0.22	−0.01	*0.78*	0.17	0.01	*0.77*	0.05	0.35	*0.86*	−0.02	0.01	*0.71*	0.28	0.27	*0.83*	0.27	−0.03
IT-enabled control																											
Item 4	0.22	*0.87*	0.06	0.12	*0.91*	−0.07	0.13	*0.91*	0.17	0.02	*0.87*	−0.18	0.12	*0.91*	0.03	0.51	0.59	0.08	0.33	*0.85*	−0.08	0.29	*0.68*	−0.25	0.19	*0.91*	0.2
Item 5	0.20	*0.83*	0.22	0.13	*0.69*	0.43	0.36	*0.79*	0.28	0.03	*0.7*	0.31	0.07	*0.85*	0.24	0.07	*0.91*	0	0.02	*0.93*	0.09	0.43	*0.52*	−0.39	0.48	*0.7*	0.2
IT-enabled coordination																											
Item 6	0.08	0.13	*0.86*	0.01	0.21	*0.88*	0.21	0.13	*0.93*	−0.02	0.1	*0.82*	0.14	0.16	*0.88*	0.22	−0.2	*0.71*	−0.15	−0.02	*0.91*	0.1	−0.01	*0.86*	0.18	0.06	*0.85*
Item 7	0.14	0.12	*0.86*	0.32	−0.05	*0.85*	0.24	0.31	*0.87*	0.13	−0.04	*0.88*	0.07	0.07	*0.89*	−0.11	0.26	*0.8*	0.33	0.06	*0.85*	−0.05	*0.76*	0.21	0.03	0.28	*0.82*
Cronbach α	0.801	0.739	0.706	0.764	0.605	0.753	0.793	0.820	0.890	0.750	0.528	0.739	0.619	0.794	0.785	0.806	0.593	0.294	0.797	0.792	0.715	0.694	0.637	0.095	0.835	0.646	0.771
AVE	0.715	0.793	0.772	0.671	0.,702	0.791	0.709	0.844	0.904	0.629	0.637	0.718	0.557	0.834	0.814	0.731	0.679	0.582	0.710	0.818	0.532	0.621	0.733	0.514	0.752	0.815	0.745
Composite reliability	0.882	0.884	0.871	0.859	0.822	0.883	0.880	0.915	0.950	0.832	0.637	0.832	0.790	0.909	0.897	0.891	0.804	0.730	0.879	0.900	0.650	0.829	0.846	0.632	0.900	0.898	0.854

Notes: [a]Rotated loadings. F1, environmental practices factor; F2, IT-enabled control factor; F3, IT-enabled coordination factor and confusing factor structure, we decided to remove these two countries from further analysis.

Discriminant validity was analyzed comparing the square root of the AVE for each construct and cross-loadings. As shown in Table IV, the values of the square root of the AVE for every construct were greater than the highest correlation between the other constructs, suggesting sufficient discriminant validity.

Overall, after removing data from Italy and Spain, the measurement model results provided support for convergent and discriminant validity of the measures used.

Step (b): multi-group measuring equivalence. G-theory (Cronbach *et al.*, 1972), examines the generalizability of the scales developed to measure latent constructs across groups of interest (six countries). It is essentially an approach to the estimation of measurement precision in situations where measurements are subject to multiple

	F1 environmental practices	F2 IT-enabled control	F3 IT-enabled coordination
Whole sample			
F1	*0.85*		
F2	0.45**	*0.89*	
F3	0.26**	0.30**	*0.88*
Brazil			
F1	*0.82*		
F2	0.25	*0.84*	
F3	0.42*	0.27	*0.89*
China			
F1	*0.84*		
F2	0.50**	*0.92*	
F3	0.48**	0.50**	*0.95*
Germany			
F1	*0.79*		
F2	0.08	*0.8*	
F3	0.13	0.08	*0.85*
Hungary			
F1	*0.75*		
F2	0.34**	*0.91*	
F3	0.21	0.21	*0.90*
The Netherlands			
F1	*0.84*		
F2	0.36*	*0.90*	
F3	0.15	0.07	*0.73*
USA			
F1	*0.87*		
F2	0.58**	*0.90*	
F3	0.31*	0.38**	*0.86*

Notes: Italics diagonal figures are the square roots of AVE. *,**Correlation is significant at the 0.05 and 0.001 levels, respectively

Table IV.
Correlations and discriminant validity

sources of error. In our design, we considered three different facets: Items in each scale, countries, and subjects in each country. In our design, the items and countries are completely crossed facets because subjects in each country respond to the same items. The subject facet, however, is nested within country. Such a design, consisting of both nested and crossed facets, is referred to as a mixed design. We provide the results of the G-theory analysis in Table V. To test cross-national applicability, we analyzed the percentage of total variance due to the different sources of variation and the generalizability coefficient (GC) for every construct (environmental practices, IT-enabled control and IT-enabled coordination):

- The largest amount of variance is due to subjects within countries (42.6, 53.34 and 52.28 percent, respectively). This is not surprising as one would expect subjects' responses to vary within countries. Also, the percentage of total variance due to countries is relatively small (16.4, 7.24 and 5.86 percent) suggesting that the means of the scales do not vary substantially across countries.
- Variance due to the items is quite low (1.4, 0.14 and 0.01 percent) suggesting that the scales have internal consistencies and reliability (Cronbach's $\alpha > 0.7$, as we tested in the previous step).
- Variation due to the items per country interaction is also low (0.22, 1.91 and 4.15 percent), suggesting that the pattern of responses is the same across countries and therefore the scale can be generalized across countries.
- The overall GC for each scale is equal to 0.82, 0.76 and 0.74 which are quite high (Rentz, 1987), thus lending support to the generalizability of these scales across Brazil, China, Germany, Hungary, The Netherlands, and USA.

Source of variance	Variance component	% of total variance	*G* index	Reliability
Environmental practices			*0.815*	*0.801*
Country	0.226	16.04		
Item	0.020	1.40		
Subject: country	0.600	42.60		
Country × Item	0.003	0.22		
Error	0.560	39.73		
Total	1.409	100		
IT-enabled control			*0.755*	*0.739*
Country	0.109	7.24		
Item	0.002	0.14		
Subject: country	0.803	53.34		
Country × Item	0.029	1.91		
Error	0.563	37.37		
Total	1.505	100		
IT-enabled coordination			*0.735*	*0.706*
Country	0.094	5.86		
Item	0.001	0.01		
Subject: country	0.837	52.28		
Country × Item	0.066	4.15		
Error	0.603	37.69		
Total	1.600	100		

Table V.
Generalizability theory results

3.3 Common source biases

Since each questionnaire was answered by only one person in each firm, common method bias (CMB) might be a threat to the validity of our results (Podsakoff *et al.*, 2003). In other words, the fact that only one person answers all the question could add noise to the interpretation of our results. To minimize this type of bias some actions were taken in the design of the study (Conway and Lance, 2010): respondent anonymity was protected, and the items of interest were distributed in different sections of the questionnaire (i.e. some questions were in the operational performance section, some were in the quality section and others were in the supply chain practices part).

We conducted two analyses to study whether CMB might be a threat to the validity of our results: examination of the correlation matrix: any highly correlated variables are evidence of CMB; Harman's one-factor test: evidence for CMB exists when a general construct accounts for the majority of the covariance among all constructs. Table VI shows the correlation coefficients between constructs/variables. None of the correlation coefficients reaches the set value of 0.9 suggested by Bagozzi *et al.* (1991). Harman's one-factor method was performed using hierarchical CFA analyses of three different models, comparing them in terms of goodness-of-fit (see Table VII). The first model combined all of the seven items in one factor. The second model combined the items of the two IT factors: IT-enabled control and IT-enabled coordination. The last model was a three-factor model including all the constructs in this study. As a result of the comparison, the three-factor measurement structure turned out to be, by far, the best measurement model in terms of all indices. The results of the CFA offered further validity for the instrument. All procedures tested do not suggest any significant CMB.

Table VI. Correlations between items and environmental performance

	Perform.	Item 1	Item 2	Item 3	Item 4	Item 5	Item 6
Environ. practices							
Item 1	0.481**						
Item 2	0.442**	0.592**					
Item 3	0.418**	0.544**	0.624**				
IT-enabled control							
Item 4	0.249**	0.418**	0.305**	0.269**			
Item 5	0.268**	0.385**	0.356**	0.340**	0.618**		
IT-enabled coordination							
Item 6	0.126*	0.215**	0.214**	0.135*	0.213**	0.338**	
Item 7	0.164**	0.234**	0.288**	0.200**	0.211**	0.347**	0.635**

Notes: *,**Correlation is significant at the 0.05 and 0.01 levels, respectively

Table VII. Comparison of CFA results

	χ^2	df	RMSEA	NNFI	CFI
One factor structure	218.6**	14	0.237	0.658	0.669
Two-factor structure[a]	123.2**	13	0.181	0.807	0.822
Three-factor structure	10.771	11	0.017	0.983	0.999

Notes: [a]Combining the items of the two IT factors (IT-enabled control and IT-enabled coordination). $**p < 0.01$

4. Data analysis and results

We used the ordinary least square estimation to test our model. The underlying assumptions of regression analysis – linearity, homoscedasticity, normality and independence of errors – were tested to ensure that there were no serious violations of these assumptions. We used firm size as control variable, and environmental practices, IT-enabled control and IT-enabled coordination as independent variables. The results of the regression analyses are presented in Table VIII.

In the first step, we entered the control variable. The results show that size has a statistically significant effect on environmental performance and explains 2.4 percent of its variance. The addition of environmental practices as predictor in the second step explains a significant amount of additional variance (change in $R^2 = 22.5$ percent). The F statistic for the regression is significant ($p \leqslant 0.001$), and the adjusted R^2 is 24.7 percent. The independent variable of interest in this step is environmental practices, which is positively and significantly associated to environmental performance ($p \leqslant 0.001$), providing support for *H1*. In the third step of our analysis, the addition of the IT-enabled control and IT-enabled coordination explains an additional variance in environmental performance of 3.6 percent. The F statistic for the regression is significant ($p \leqslant 0.001$), and the adjusted R^2 is 27.7 percent. The environmental practices construct remains statistically significant ($p \leqslant 0.001$) with a positive impact on environmental performance. Regarding the IT constructs, only IT-enabled control has a statistically significant and positive effect on environmental performance ($p \leqslant 0.001$).

Finally, in the fourth step, the interaction terms were included. The addition of these variables explains an additional variance of 2.5 percent. The F statistic for the regression is significant ($p \leqslant 0.001$), and the adjusted R^2 is 29.4 percent. The environmental practices and IT-enabled control constructs remain statistically significant ($p \leqslant 0.001$) with a positive impact on environmental performance. The interaction of IT-enabled coordination and environmental practices is statistically significant ($p \leqslant 0.05$) whereas the interaction of IT-enabled control and environmental practices is not statistically significant. Therefore, *H2* is partially supported. This result provides evidence that IT strengthens the impact of environmental practices on environmental performance.

We checked for multicollinearity in our model, and the tolerance of the estimators ranges from 0.851 to 1. This allows us to make inferences about the direct effect of the variables on the dependent variable. Furthermore, we performed correlation analysis between the residuals of Step 4 of the regression and industry variable in order to see whether there were any patterns across industries that had not been included in our model. The results showed that there is no pattern across industries. Additionally, we tested for differences between the estimators of the regression across countries (see Figure 2). We found that there are no differences between the countries of our sample.

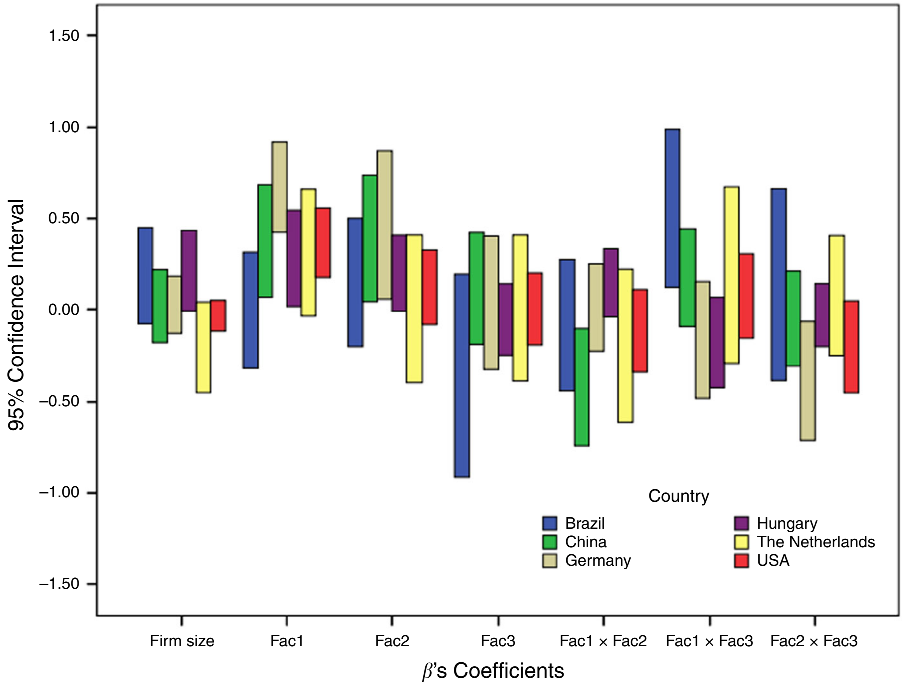
5. Discussion

Our results show that environmental practices have a positive impact on environmental performance; this corroborates the findings of the OM literature (Rao, 2002; Zhu and Sarkis, 2004, 2007); meaning that the implementation of environmental practices (i.e. designing products taking into account their environmental impact, considering the environmental impact of production, manufacturing and logistics) is positively associated to improvements in the environmental performance of the firm. Furthermore, our results also show that the relationship between environmental practices and environmental performance is stronger when there is a high use of

Table VIII. Impact of environmental practices and IT-enabled control and coordination on environmental performance

	Step 1			Step 2			Step 3			Step 4		
	β Coeff	SE	*t*-stat	β Coeff	SE	*t*-stat	β Coeff	SE	*t*-stat	β Coeff	SE	*t*-stat
Firm size[a]	0.167**	0.035	2.71	0.038	0.031	0.67	−0.006	0.032	−0.11	−0.012	0.032	−0.20
Env. practices				0.491***	0.051	8.77	0.504***	0.050	9.16	0.483***	0.050	8.79
IT-enabled control							0.177***	0.049	3.32	0.191***	0.050	3.54
IT-enabled coord.							0.081	0.050	1.48	0.078	0.050	1.43
Env. pract. × IT-enabled control										−0.025	0.049	−0.46
Env. pract. × IT-enabled coord.										0.129**	0.050	2.44
IT-enabled control × IT-enabled coord.										−0.089*	0.048	−1.67
F-stat	7.35**			43.23***			25.76***			16.37***		
Adjusted R^2	0.024			0.247			0.277			0.294		
ΔR^2	0.028			0.225			0.036			0.025		

Notes: [a]Ln of the firm size was used. ***$p \leqslant 0.001$; **$p \leqslant 0.05$; *$p \leqslant 0.10$



Notes: Fac1, environmental performance; Fac2, IT-enabled control; Fac3, IT-enabled coordination

Figure 2. Environmental 95 percent confidence interval for the β's coefficients

IT-enabled coordination in the plant. In particular, the integration of processes through ERP systems and shared databases increases the impact of environmental practices on environmental performance.

Previous research that has looked at the relationship among green manufacturing, green logistics practices and environmental performance has generally used predictors such as: eco-design, pollution prevention, lean manufacturing, supply chain integration, the degree of collaboration with suppliers, institutional pressures, etc. (Geffen and Rothenberg, 2000; Quariguasi Frota Neto *et al.*, 2008; Zhu *et al.*, 2008). Our research suggests that IT that enables production control may explain additional variance in the successful implementation of these green operations practices. Future research should study the role that IT resources that enable control (e.g. RFID, traceability technology, etc.) have in the relationship between green manufacturing and green logistics in the environmental footprint of firms.

Previous research in the realm of Green IS has found that IT improves environmental changes through the transformation of behaviors in employees, and the capture of meta-data which allows a better optimization of resources (Jenkin *et al.*, 2011; Melville, 2010). Our research provides a different perspective for supporting the role of IT in the environmental performance of the firm: IT moderates the effect of environmental practices on the environmental firm's performance; IT creates synergies that allow firms to reach higher environmental performance levels. Our research also supports the previous findings in the literature, which asserts that IT has a direct effect on environmental performance (Green *et al.*, 2012a, b). However, depending on the range of application of IT, the role of IT in environmental performance might be a moderator or an antecedent of environmental performance, for example: our research found that IT-enabled control is positively related to environmental performance, but it does not interact with environmental practices. This finding suggests that the redeployment of IT resources is constrained by the nature of the environmental practices. The environmental practices under study are focussed on the design of products, processes and transportation aspects. Since IT that enables control is related to production, it makes sense the absence of an interaction effect between them. In this sense, we suggest that future research should analyze the types of IT resources that are drivers or moderators of environmental performance.

Additionally, we recommend future research to analyze the interaction between IT resources on environmental performance. We included this relationship in our model, but found that it was not significant at the 5 percent confidence level. It would be relevant that future research would look at the interaction effects between IT resources once taken into account the contingent relationship between IT resources and environmental practices. The complementary nature among IT resources may enhance our understanding of how IT supports the implementation of environmental practices of firms, for instance: future research may look at the interaction of the re-deployment of logistics systems such as: transportation management systems and energy management systems.

6. Conclusions

The aim of this paper was to study the role of IT in the impact of environmental practices on environmental performance. Our results provides evidence that IT-enabled control is positively associated with environmental performance, and that the relationship between environmental practices and environmental performance is stronger when firms have in their plants IT-enabled coordination in place. These findings are useful for managers because it tells them that environmental practices are more effective when they are implemented within the operational routines and social ties (between personnel of product design and manufacturing) enabled by IT-enabled coordination. Additionally, our results also tell managers that IT-enabled control has a direct effect on environmental performance. In other words, IT has at least two roles in the context of environmental operations: the sole implementation of IT which enables control has a positive effect on the environmental performance of the firm, whereas the IT which enables coordination interacts with environmental practices, making them more effective. Therefore, regarding IT, managers should apply their environmental practices supported by IT-enabled coordination, and should apply IT-enabled control independently of their environmental practices in order to achieve higher environmental performance.

Additionally, this paper suggests that IT resources have the potential to be redeployed for different applications from what they were originally intended. This finding has strong implications for future research on the implementation of green operations practices. However, more research is needed about the conditions and the process of IT redeployment. As it was observed above, future research might need to contemplate the fit between the IT and the environmental practices. Furthermore, the redeployment of IT has implication for managers about the design and budget of environmental projects: Our research suggests that prior the acquisition of new IT for implementing environmental actions, managers should look at their IT resources for coordinating their business process; this type of technology gathers and consolidates relevant information that could be used by managers in the planning and implementation of environmental practices.

Finally, there are some limitations that the reader needs to consider: First, the IT-enabled control and IT-enabled coordination constructs need to be validated in future empirical research. Second, the outcome variable (environmental performance) was measured with a single item; future research should corroborate the findings of our research with objective measures of environmental performance. Therefore, we caution the reader to deem the findings of this paper as exploratory.

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