An empirical examination of the relationship between globalization, integration and sustainable innovation within manufacturing networks

Ruggero Golini

Department of Management, Information and Production Engineering, Università di Bergamo, Bergamo, Italy

Jury Gualandris

Operations Management Group, Ivey Business School, Western University, London, Canada

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Abstract

Purpose – While controlling for supply chain effects, this research investigates if globalization and collaborative integration within a firm-wide manufacturing network have significant implications for the adoption of sustainable production and sustainable sourcing practices at the plant level.

Methodology – We conceptualize sustainable production and sustainable sourcing as process innovations with moderate degrees of innovativeness and apply 'Organizational integration and process innovation' theory to build our conceptual model. Then, we use primary survey data from 471 assembly manufacturing plants operating in the US, Europe and Asia to test our hypotheses rigorously.

Findings - This research finds that the adoption of *sustainable production* practices at the plant level is significantly and positively associated with globalization and integration of the firm-wide manufacturing network. On the contrary, the adoption of sustainable *sourcing practices* is more strongly affected by integration in the external supply chain and benefits from the manufacturing network only indirectly, through the association with sustainable production practices.

Originality – Operations Management literature devoted to sustainability has studied sustainable practices mostly from a risk management angle. Also, there exists contrasting evidence in the Operations Strategy literature about the positive and negative effects that globalization of a manufacturing network may have on the adoption of sustainable practices at the plant level. Moreover, several studies show how integration with supply chain partners helps manufacturing plants transition into more sustainable production and sustainable sourcing practices; however, related literatures have neglected that collaborative integration within a firm-wide manufacturing network may also help to develop, or adapt to, new sustainable practices. This research represents a first attempt to resolve discordance and unveil the positive effects that manufacturing networks may have on sustainable innovations at the plant level.

Author Keywords - sustainable supply chain management, integration mechanisms, manufacturing networks, process innovation, IMSS

1 Introduction

Within manufacturing industries, green technologies and social standards evolve rapidly under the pressure from diverse stakeholder groups (Gualandris et al., 2015; Jamali, 2010). In this context, Operations Management scholars have remained focused on the role of the external supply chain in fostering the adoption of sustainable production and sustainable sourcing practices at the plant level (Awaysheh and Klassen, 2010; Hajmohammad et al., 2013; Klassen and Vachon, 2003). However, a plant may also be part of a firm-wide manufacturing network (Ferdows, 2006; Monteiro et al., 2008; Vereecke et al., 2006), whose characteristics can also deeply affect, positively or negatively, its ability to develop sustainability-related innovations.

To illustrate, Unilever promotes the development of *novel and more sustainable production practices* at the plant level through the *Small Actions Big Difference* program. Once ideas have turned into projects and are implemented in the local facility, they are then spread to the other plants of the network[1]. Similarly, BMW spreads *sustainable sourcing* guidelines throughout its manufacturing network, thus providing direction to individual plants on how to collaborate with suppliers and sub-suppliers and improve their collective impacts on society and the natural environment[2]. Still, the complexity of global manufacturing networks can undermine such efforts (Ferdows et al., 2016), resulting in uneven implementations across sister facilities, or worst, in environmental or social scandals. Hence the general research question that we address in this paper is the following: *to what extent do the characteristics of a firm-wide manufacturing network affect the ability of its plants to adopt sustainability-related innovations in production and sourcing?*

The reason to ask this question, is first of all, related to the geographical dispersion of a manufacturing network, which may represent a relevant enabler (or barrier) to sustainability.

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[1] https://www.unilever.com/sustainable-living/reducing-environmental-impact/eco-efficiency-in-manufacturing/our-manufacturing-sustainability-strategy-and-activities/

[2] https://www.bmwgroup.com/en/responsibility/supply-chain-management.html

On the one hand, plants operating within global manufacturing networks are directly or indirectly subject to the pressures of a broader array of global and local stakeholders to advance sustainability practices (Christmann, 2004; Jamali, 2010; Venaik et al., 2005). On the other, recent studies suggest that as manufacturing networks keep expanding their geographical boundaries, their individual plants run the risk to become too isolated and over-specialized, confronting more difficulties with the adoption of, and adaptation to, greener and safer production and sourcing practices (Ferdows et al., 2016; Golini et al., 2016; Husted and Allen, 2006).

Secondly, a plant belonging to a manufacturing network may be able to learn more about technology, customers, products or processes from other plants than it can learn by itself. However, in order to profit from this opportunity, a plant needs to be well-integrated in the manufacturing network, i.e., it has to acquire, share and consolidate the management skills and product-process development knowledge possessed by sister facilities in the same network (Ferdows and De Meyer, 1990; Cheng et al., 2015; Swink et al., 2007). Therefore, collaborative integration within the manufacturing network may represent an important sustainability enabler because it enriches plants' individual perspectives and knowledge base.

Given the contrasting and fragmented evidence about the role of manufacturing networks in the adoption of sustainable practices at the plant level, pursuing this nodal level of analysis, our paper contributes to Operations Strategy literature (Ernst and Kim, 2002; Ferdows, 2006; Vereecke et al., 2006; Gunasekaran and Spalanzani, 2012; Cheng et al., 2015; Ferdows et al., 2016) by empirically investigating if and how the geographic dispersion of a manufacturing network (hereafter *network globalization*) and the presence of integration mechanisms between sister facilities (hereafter *internal manufacturing network integration*) are significantly associated with a plant's adoption of sustainable production and sustainable sourcing practices. In particular, we have conceptualized sustainable production and sustainable sourcing as *process innovations* with moderate degrees of innovativeness

(Bigoness and Perreault, 1981; Dewar and Dutton, 1986; Garcia and Calantone, 2002; Longoni and Cagliano, 2016) and applied *organizational integration and process innovation theory* (Barki and Pinsonneault, 2005; Ettlie and Reza, 1992; Zahra and Nielsen, 2002) to inform our conceptual model. We have then used primary survey *data from 471 assembly plants* operating in the US, Europe and Asia to test our hypotheses and run all the necessary statistical tests and robustness checks.

In so doing, we provide evidence to the positive association between network globalization and plant sustainability; then, we find support to the hypothesis that internal integration within the manufacturing network provides distinctive advantages for the development of sustainability-related innovations at the plant level; finally, we conclude that only sustainable production is directly impacted by network globalization and internal network integration, while sustainable sourcing benefits only indirectly. Therefore, we advance Operations Strategy literature by showing how multinational firms can nurture and leverage the innovation potential of their manufacturing networks for the development of sustainability at the plant level. Overall, our paper offers sound theoretical arguments and initial empirical evidence that complement existing studies and that can help decision-makers within manufacturing networks to devise network design strategies in synergy with the sustainable development of their plants.

2 Literature review and hypotheses development

We begin by presenting recent research on sustainable production and sustainable sourcing, which are here conceptualized as *process innovations* (a concept pioneered by Bigoness and Perreault, 1981) that advance the social, environmental and economic dimensions of the "triple bottom line" (Elkington, 1998). Then, we present the concept of external supply chain integration, a relevant control in our study, and the theoretical and empirical studies that postulate its enabling role in the sustainable development of a plant. Finally, we theoretically examine the complex association between network globalization, internal manufacturing network integration and the adoption of diverse bundles of sustainable practices at the plant level of analysis.

2.1 Sustainable production and sustainable sourcing as process innovations

Sustainable production and *sustainable sourcing* represent two distinct groups of intra- and inter-organizational practices that have been largely investigated by the Operations Management literature devoted to sustainability (De Giovanni, 2012; Gavronski et al., 2011; Gualandris and Kalchschmidt, 2016).

Sustainable production refers to the institutionalization of environmental management systems, formal occupational health and safety systems, pollution emission reduction and recycling practices within a plant. The adoption of this bundle of practices requires a plant to recognize green market opportunities and accumulate technical expertise regarding quality management and lean management practices (Florida, 1996; Pagell et al., 2013). In contrast, *sustainable sourcing* refers to supplier evaluation and development practices implemented by a plant to improve environmental and social performance in its supply base (Klassen and Vereecke, 2012; Vachon and Klassen, 2006; Zhu et al., 2013). While sustainable production practices are considered the first step in a plant's sustainable development process, sustainable sourcing builds on a richer technical understanding of social and environmental issues and usually comes as a second step (De Giovanni, 2012; Gavronski et al., 2011; Gualandris and Kalchschmidt, 2016).

Sustainable production and sustainable sourcing practices can be seen as *process innovations with moderate levels of innovativeness* (Longoni and Cagliano, 2016). "Innovativeness" is often used to measure the degree of newness of an innovation (Garcia and Calantone, 2002): some innovations heavily rely on new knowledge and produce radical change to existing systems whereas others embody a modest amount of new knowledge and introduce only incremental improvements (Dewar and Dutton, 1986). In this framework, sustainable production and sustainable sourcing can be fully considered as innovations as they require a plant to absorb new knowledge from the outside (Vachon and Klassen, 2006; Lee and Klassen, 2009) and introduce significant and unique changes in existing production and sourcing technologies (Pagell and Wu, 2009). As witnessed by other innovations such as lean production and flexible manufacturing (Ferdows, 2006; Lee et al., 2011; Gunasekaran and Spalanzani, 2012), sustainable production and sustainable sourcing practices change over time and require continuously upgrading procedures and human resources, which complicate their adoption. It has been documented, in fact, that many plants fail in their attempt to achieve high degrees of adoption of sustainable production and sustainable sourcing because they do not see ways to successfully adapt their organization to these practices and vice-versa (Gualandris and Kalchschmidt, 2015; Longoni and Cagliano, 2016). Still, they are seldom considered radical innovations as they mostly relate to changes in the processes (e.g., reducing energy consumption in the plant or at suppliers'), do not necessarily require considering and reconnecting the expectations and capabilities of multiple diverse stakeholder groups (Gualandris et al., 2015), and do not generate completely new product-service offerings, business models or value chains (e.g., Vurro et al., 2010).

The theory of organizational integration and process innovation (Barki and Pinsonneault, 2005; Ettlie and Reza, 1992; Zahra and Nielsen, 2002) offers appropriate lenses to explain why and how process innovations such as sustainable production and sustainable sourcing may develop within plants. These process innovations are based on technical and organizational changes that are unique and require sourcing *procedural knowledge* in the supply chain (and possibly in the internal manufacturing network too). Procedural knowledge is a "recipe for action" and differs from information about things or situations (declarative knowledge) or scientific knowledge about how one variable affects another (causal knowledge) (Kogut and Zander, 1992). Procedural knowledge refers to the know-how about product design, process design and functioning, new technology implementation, or even the application of new administrative routines (Gupta and Govindarajan, 2000). According to this theory, the continuous development and successful organizational adaptation to sustainable production and sustainable sourcing will depend upon the degree of integration a plant achieves simultaneously with diverse partners, which allows them to efficiently absorb *multiple types of procedural knowledge*.

2.2 Exchanging knowledge to advance sustainability

A manufacturing plant can obtain and combine multiple types of procedural knowledge coming from the supply chain and from the manufacturing network. While a supply chain is composed by suppliers and customers as inter-connected legal entities, a manufacturing network represents a group of plants that are not necessarily inter-connected but are part of the same legal entity (Rudberg and Olhager, 2003).

Von Hippel (1986) showed that both customers and suppliers represent a primary source of ideas, solutions and technical capabilities a plant might tap to augment its innovation performance. External integration with supply chain partners helps to source *procedural knowledge that extends the overall functional expertise* of a manufacturing firm (Barki and Pinsonneault, 2005) and in turn enables the adoption of sustainable production and sourcing practices. On the one hand, plants that are well-integrated with supply chain partners will more effectively implement greener and safer production processes because of the know-how that has been sourced from outside the boundaries of the firm (Hajmohammad et al., 2013; Wu, 2013). External supply chain integration also contributes to transforming the supply chain into a unified whole through visibility and alignment of mutual expectations, which in turn has been shown to foster the adoption of sustainable sourcing practices at the plant level of analysis (Vachon and Klassen, 2006; Walker et al., 2008).

Differently, sister facilities within the manufacturing network can exchange *procedural knowledge about product-process co-design and mutual adaptation* and, as witnessed in the case of lean production and flexible manufacturing practices, become highly effective at process innovations of moderate and high innovativeness (Boscari et al., 2016; Ferdows, 2006; Vereecke et al., 2006). Operations Strategy literature, however, has paid limited attention to the role of manufacturing networks in fostering (or retarding) the adoption of sustainable practices at the plant level. Particularly, the complex relationship involving network globalization, internal manufacturing network integration and diverse groups of sustainable practices demands further theoretical and empirical development. Here, we review the existing literature and provide a testable set of hypotheses that fill this gap.

With the advent of globalization, firms have expanded the scope of their reach and influence. They can spread to every corner of the globe through manufacturing networks that transcend geographic, economic and political divides. Some scholars draw attention to the fact that certain plants of a global manufacturing network may have very limited functions and competences (Ferdows, 1997b; Vereecke and Van Dierdonck, 2002). Low competence, isolated plants may find themselves unable to respond successfully to the call for new and more environmentally and socially sustainable practices (Golini et al., 2014; Husted and Allen, 2006) as they lack the knowledge, skills and mind-set to undertake complex changes.

Although this reasoning has merit, Ernst and Kim (2002) suggested that global manufacturing networks accumulate disperse knowledge and boost its international diffusion so to provide new opportunities for capacity formation at the local level. In accordance, some scholars have found positive relationships between a firm’s *size* and *international diversification* and its overall sustainable development (Bansal, 2004; Christmann, 2004; Jamali, 2010). Large firms operating in multiple regions have *larger resource pools* and *diversified competences* to develop greener and safer technologies (Grant et al., 2002) as well as to invest in the sustainable development of their suppliers (Lee and Klassen, 2008). Finally, sustainability demands, expectations and barriers vary significantly among countries because of differences in local regulations, community preferences, available technologies and even suppliers’ ideologies and capabilities (Gualandris et al., 2015; Jamali, 2010); plants embedded in manufacturing networks whose boundaries span across countries and continents may be able to bear with this condition of ambiguity by leveraging a *larger* and *more heterogeneous* knowledge base to successfully adapt to new (sustainable) practices and help their suppliers do the same (Ettlie and Reza, 1992; Zahra and Nielsen, 2002). Thus, our first hypothesis:

H1. Plants belonging to a global manufacturing network adopt their sustainable production practices (H1a) and sustainable sourcing practices (H1b) to a greater extent than plants belonging to a regional manufacturing network.

The presence of rich transmission channels between sister facilities (Ghoshal and Bartlett, 1988; Gupta and Govindarajan, 2000) should also be associated with the adoption of sustainable practices. *Internal manufacturing network integration* refers to the extent to which a plant makes use of integration mechanisms, such as sharing employees, network performance management systems and joint decision making with other sister facilities, in order to co-develop products and processes in a way consistent with the plant's internal and external requirements (Colotla et al., 2003; Jansen et al., 2005; Rabbiosi, 2011). Internal manufacturing network integration supplements external supply chain integration and cross-functional integration within a plant (Cheng et al., 2015; Schmenner, 1982; Shi and Gregory, 1998). Literature on internal manufacturing network integration focuses on the management of relations among sister facilities and studies potential implications for knowledge transfer, process innovation and operational performance. Key results from these studies suggest that internal manufacturing integration can facilitate the exchange of both codified information and tacit procedural knowledge within a manufacturing network and help a plant to reach broader business objectives (Cheng et al., 2015; Ferdows, 2006; Venaik et al., 2005).

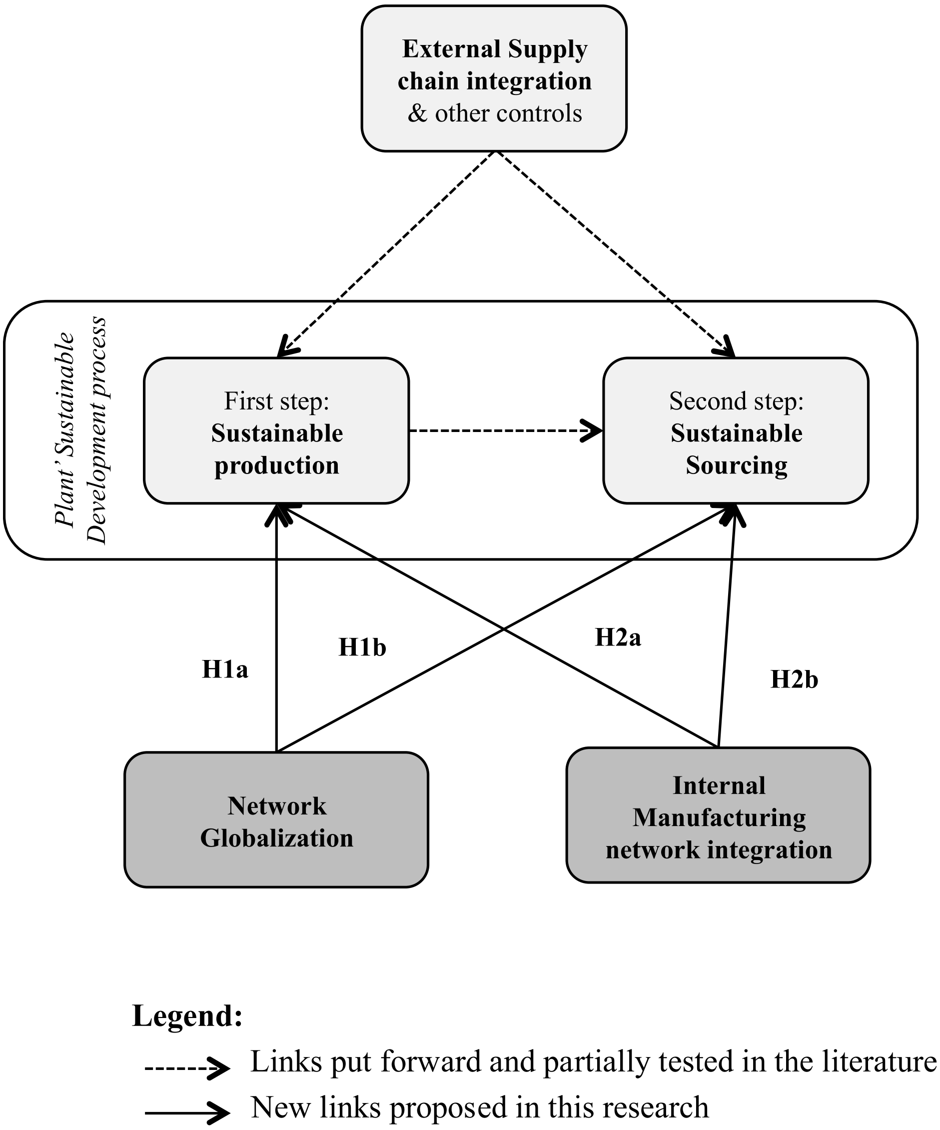
In order to achieve technical and economic success, process innovations depend greatly on the integration of procedural knowledge about R&D (design) and manufacturing (implementation) (Ettlie and Reza, 1992), which are often dispersed in different parts of a manufacturing network (Feldmann and Olhager, 2013; Ferdows, 1997a; Vereecke and Van Dierdonck, 2002). Ettlie and Reza (1992) find that R&D-manufacturing integration complements the role of other dimensions of integration, such as with suppliers, in promoting the successful adoption of process innovations. In a similar fashion, internal manufacturing network integration allows sharing specifications and constraints about products and processes so that new production and sourcing processes may incorporate a better understanding of product requirements and new products can be designed or adapted in order to expand process capabilities (Ferdows, 2006; Swink et al., 2007). Conversely, a lack of rich communication and the infrequency of contact between sister facilities have been found to represent typical barriers to process innovations within manufacturing networks (Monteiro et al., 2008). Thus, the following hypothesis:

H2. Internal manufacturing network integration is positively associated to the adoption of sustainable production practices (H2a) and sustainable sourcing practices (H2b) within a plant.

Figure 1 presents our theoretical model. In line with prior SSCM literature, the central part of our model assumes a progression in the adoption of sustainable practices from sustainable production to sustainable sourcing; the upper part of Figure 1 summarizes the contribution of supply chain integration as the gateway through which external procedural knowledge about new, greener and safer technologies flows into the plant.

Most importantly, the bottom part of the model depicts our key contribution. First, because knowledge richness and diversity are supposed to be larger in global manufacturing networks than in regional ones, and because plants in global networks should maintain a greater ability to use this knowledge to confront technological uncertainty and stakeholder ambiguity, network globalization could be positively associated to the adoption of sustainable production and sustainable sourcing at the plant level (H1a,b). Finally, internal manufacturing network integration allows procedural knowledge about product-process co-design and mutual adaptation to flow from the manufacturing network into the plant and, thus, enables the adoption of sustainable process innovations (H2a,b).

Figure 1 *– Conceptual model (dotted arrows represent relationships already established in the literature)*



3 Research methodology

3.1 Data collection and cleaning

To test our research hypotheses, we employed data from the sixth edition of the International Manufacturing Strategy Survey (see www.manufacturingstrategy.net). This project studies the manufacturing and supply chain strategies of firms producing assembled products, which include machinery, transportation equipment, automotive and electronics industrial sectors (i.e., ISIC codes 25-30 described in Table 1). A global network of researchers uses a common questionnaire administered simultaneously in many countries by local research groups (Lindberg et al., 1998).

The sample used for this paper comes from the sixth edition of the project (IMSS-VI) and meets two important conditions needed for this research: (i) 75% of plants declared facing high rates of technological change and being subject to high environmental and social pressure from external stakeholders; and (ii) all the plants operate in the assembly manufacturing industries, thus constituting a homogeneous sample. Using IMSS as a source of data presents some limitations, such as the single respondent and cross-sectional data, which do not allow testing endogeneity using lagged variables. On the other side, there are several advantages that make this dataset particularly suitable to test our hypotheses. First of all, the database includes plants that are part of regional and global networks in sufficient number to check for significant differences among the subgroups while controlling for all the relevant variables. Finally, IMSS has been used for a long time to study the supply chain and more recently sustainability, making it a perfect starting point to add the effect of the manufacturing networks.

From the original sample of 931 cases available in IMSS-VI, we dropped (i) those collected in Taiwan, as country-level information is not available; (ii) those with fewer than 50 employees and (iii) those not providing information for the variables investigated in the present study. Next, we dropped 247 cases as they represent stand-alone plants. Finally, we dropped all the German cases, as Germany was the only country with less than 9 entries and, thus, was insufficient to support controls at the country level and to perform the construct generalizability tests discussed in the next section. This choice is not affecting the final results and is in line with other IMSS-based studies (Gimenez et al., 2012; Golini et al., 2016). Thus, we ended up with 471 usable cases, of which 130 are part of a regional network, and the remaining 341 are part of a global network. Very few plants, roughly 2%, are part of the same network thus minimizing the effect of correlated errors in our analysis. Table 1 reports the distribution by country, industry and plant size of the sample.

Table 1 *– Distribution by country, industry and company size*

Country	Frequency	Percent
Belgium	22	4.67
Brazil	22	4.67
Canada	10	2.12
China	48	10.19
Denmark	20	4.25
Finland	13	2.76
Hungary	28	5.94
India	45	9.55
Italy	24	5.1
Japan	49	10.4
Malaysia	12	2.55
Netherlands	27	5.73
Norway	21	4.46
Portugal	23	4.88
Romania	16	3.4
Slovenia	9	1.91
Spain	17	3.61
Sweden	24	5.1
Switzerland	16	3.4
USA	25	5.31
Total	**471**	**100.0**

Company Size (employees)	Frequency	Percent
Medium (50-250)	153	32.48
Large (250-500)	81	17.2
Very Large (500+)	237	50.32
Total	**471**	**100.0**

ISIC Code	Frequency	Percent
25: Manufacture of fabricated metal products, except machinery and equipment	138	29.3
26: Manufacture of computer, electronic and optical products	53	11.25
27 Manufacture of electrical equipment	82	17.41
28 Manufacture of machinery and equipment not elsewhere classified	111	23.57
29 Manufacture of motor vehicles, trailers and semi-trailers	65	13.8
30 Manufacture of other transport equipment	22	4.67
Total	**471**	**100.0**

Type of network	Frequency	Percent
Plants part of a regional network	130	18.1
Plants part of a global network	341	47.5
Total	**471**	**100**

3.2 Respondents checks and common method bias

The survey was administered according to the literature's recommendations (Forza, 2002). The overall response rate was 36.1%, signaling that respondents could easily answer the survey. Moreover, IMSS-VI obtained a low rate of missing data, with an average of 6% per respondent. Next, the average experience of the respondents in operations is 12 years, with an average of 13 years spent in the same plant, thus constituting a proper experience to assess the variables used in the present study, even in retrospective terms. Finally, t-tests performed at the country level and focusing on demographic variables such as size, industry, and sales found no evidence of non-respondent bias.

Concerning common method bias, anonymity reduced ex ante the likelihood of social desirability, while clarity in item formulation and questions' brevity preventively reduced item effects. Ex post, the principal component of data used for this study accounted for only 40% of the total variance and a confirmatory factor analysis based on only one factor obtained a very poor fit ($\chi2/df = 19.792$; RMSEA = 0.162; NFI = 0.623; CFI = 0.634) (Podsakoff et al., 2003). Noteworthy, for 250 randomly selected plants in our sample, we compared survey data about the Returns On Sales in 2012 with secondary information collected by the different partners from economic databases (e.g., Aida, Amadeus). We found a statistically significant correlation between the declared value in IMSS-VI (expressed on a five-point Likert scale) and the actual ROS value (0.41; p-value < 0.000), thus providing evidence of limited social desirability.

3.3 Measures

In this section, we discuss our measures, while the complete outline of our questions is reported in the Appendixes. We built the constructs by averaging their underlying reflective items. Validity and reliability tests for our key constructs follow in the next section.

Sustainable production (SP) was assessed using a four-item, five-point Likert scale that captured the current level of adoption of (SP1) environmental certifications (e.g., EMAS or ISO 14001); (SP2) energy- and water-consumption-reduction programs; (SP3) pollution-emission-reduction and waste-recycling programs; and (SP4) formal occupational health and safety-management systems. Similar measures were developed and tested in several studies (De Giovanni, 2012; Golini et al., 2014; Hajmohammad et al., 2013).

Sustainable sourcing (SS) was assessed by a three-item, five-point Likert scale that captured the current level of adoption of (SS1) suppliers' sustainability performance assessment through formal evaluation, monitoring and auditing using established guidelines and procedures; (SS2) training/education in sustainability issues for suppliers' personnel; and (SS3) joint efforts with suppliers to improve their sustainability performance. Similar measures were developed and tested in several studies (De Giovanni, 2012; Gavronski et al., 2011; Hajmohammad et al., 2013).

Network globalization was assessed using a dummy variable: 0=all the plants in the manufacturing network are located within one continent, 1=the plants are located in different continents.

Internal manufacturing network integration (MNI) was assessed by a four-item, five-point Likert scale that captured the effort put in the last three years into (MNI1) improving joint decision making to define production plans and allocate production in collaboration with other plants in the network; (MNI2) improving innovation sharing/joint innovation with other plants; (MNI3) improving the use of technology to support communication with other plants of the network; and (MNI4) developing a comprehensive network performance-management system. Similar measures were developed and tested in several studies (Golini et al., 2016; Jansen et al., 2005; Rudberg and Olhager, 2003; Vereecke et al., 2006).

External supply chain integration (SCI) was measured as a second-order reflective construct composed of two first-order constructs capturing the extent to which a plant adopted diverse integration mechanisms with supply chain partners. Measuring SCI as a single construct including supplier and customer integration is not new to the literature (Byrne and Stewart, 2006; Danese et al., 2013). This procedure is also supported from a statistical point of view, as supplier integration and customer integration constructs, in line with other studies (Wiengarten et al., 2014; Wong et al., 2011), are significantly correlated (.631, sig. 0.000). Each first-order construct was assessed by a three-item, five-point Likert scale that captured the effort put in the last three years into implementing (SI1/CI1) sharing information with key suppliers/customers; (SI2/CI2) developing collaborative approaches with key suppliers (e.g., supplier development, risk/revenue sharing, and long-term agreements)/customers; and (SI3/CI3) joint decision making with key suppliers/customers. Similar measures were developed and tested in several studies (Flynn et al., 2010; Frohlich and Westbrook, 2001).

It is important to highlight that, in our conceptual model (Figure 1), MNI and SCI are the independent variables, while SP and SS sourcing are dependent variables. In particular, our model implies that effort put in MNI and SCI translates into a higher adoption of SP and SS. Therefore, we purposefully measured our MNI and SCI in terms of 'effort put in the last three years', while SP and SS measure the 'current level of adoption'.

Notably, we control for a number of alternative explanations in this study: *plant size*, *industry*, *quality of national regulation*, *sustainability orientation, plant responsibility* and *internal purchases*. Plant size, here measured as the logarithm of the number of employees, has been previously related to sustainability-related investments (Vachon and Klassen, 2006). Additionally, the industry, measured by the ISIC code, can be a source of variability, as different industries can be subject to different dynamism and stakeholder pressure. Furthermore, for each country, we controlled for the *quality of national regulations*, as provided by the World Bank (2013), to control for country-specific effects. Then, we controlled for *sustainability orientation,* which measures the environmental and social priorities of a plant, on a three-item, five-point Likert scale (Cronbach's alpha: 0.839). Other scholars employed similar measures when studying the development of flexible manufacturing practices (Ketokivi and Schroeder, 2004). *Plant responsibility* is a three-item, five-point Likert scale capturing the extent to which the plant is responsible for production, supply chain management and R&D (Cronbach's alpha: 0.647). This variable simultaneously relates to supply chain integration and the adoption of sustainable practices (Ferdows, 1997b; Golini et al., 2014), and can also be seen as reflective of a plant's absorptive capacity; therefore, its exclusion would result in spurious models. Finally, we controlled for *internal purchases*, measured as the percentage of inputs (goods and services) sourced from sister facilities in the manufacturing network. The advantage a plant derives from SCI and MNI can vary in relation to the amount of goods coming from external suppliers compared to those coming from sister facilities in the manufacturing network. For example, in vertical manufacturing networks, plants are specialized in specific stages of production; therefore, there are significant flows of goods exchanged among plants, and the role of external supply chain partners in the overall development of the plant can be marginal (Egelhoff, 1982; Rudberg and Olhager, 2003).

3.4 Measures' validity and reliability

We have validated our measurements in multiple ways. First, confirmatory factor analysis showed a good level of fit (CMIN= 240.2 DF=111 CMIN/DF = 2.164; NFI=0.945; CFI=0.970; RMSEA=0.050) (Hair et al., 1998; Sharma, 1996), and the constructs appeared reliable, with Average Variance Extracted (AVE) greater than 0.5 and a Critical Ratio (CR) greater than 0.7 (Table 2). Calculating the square root of the average variance extracted and comparing it with inter-construct correlations also signaled satisfactory discriminant validity (Fornell and Larcker, 1981)(Table 3).

Table 2 *– Results of the confirmatory factor analysis*

Factor	Variable	Std. Loadings	AVE	CR
Supply Chain Integration	Supplier Integration[1]	0.845	0.687	0.81
	Customer Integration[2]	0.813		
Manufacturing network integration	NI1	0.735	0.590	0.85
	NI2	0.783		
	NI3	0.756		
	NI4	0.798		
Sustainable Production	SP1	0.635	0.546	0.83
	SP2	0.823		
	SP3	0.844		
	SP4	0.626		
Sustainable sourcing	SS1	0.799	0.703	0.88
	SS2	0.837		
	SS3	0.877		
[1] Supplier Integration	SI1	0.783	0.649	0.85
	SI2	0.852		
	SI3	0.780		
[2] Customer Integration	CI1	0.840	0.648	0.85
	CI2	0.832		
	CI3	0.739		

***Table 3** - Discriminant validity analysis and descriptive statistics of first-order constructs*

	(1)	(2)	(3)	(4)
(1) External supply chain integration	**0.829**	0.748	0.535	0.601
(2) Internal manufacturing network integration	0.748	**0.768**	0.452	0.458
(3) Sustainable production	0.535	0.452	**0.739**	0.680
(4) Sustainable sourcing	0.601	0.458	0.680	**0.838**
Mean	3.080	3.171	3.223	2.790
Standard deviation	0.842	0.938	0.997	1.067

Note that bold values are squared-root of AVE, others are correlations.

Second, because IMSS-VI is a multi-country study, it is important to assess constructs' equivalence across countries (Durvasula et al., 2006). Given the limited number of cases per each country, we employed the generalizability theory method (Malhotra and Sharma, 2008; Sharma and Weathers, 2003) to determine whether our measures are robust to perceptive differences across countries. This method considers countries as a random or fixed effect and can be applied at the levels of multiple or single constructs. Following the approach suggested by the literature (Malhotra and Sharma, 2008; Sharma and Weathers, 2003), we calculated the generalizability index as a proxy of construct equivalence across countries; values above 0.7 are considered sufficient to support the cross-national applicability of a construct (e.g., Durvasula et al., 2006). As shown in Table 4, all the values range between 0.8 and 0.9, thus supporting the generalizability of our constructs across countries.

***Table 4** – Application of the generalizability theory to the identified constructs*

	Variance Component					Generalizability coefficient
	Cases	Countries	Items	Items x Countries	Error	
MNI	0.675	0.086	0.008	0.019	0.507	0.853
Supplier Integration	0.647	0.030	0.010	0.013	0.363	0.844
Customer Integration	0.696	0.094	0.001	0.008	0.426	0.845
SP	0.696	0.067	0.023	0.032	0.648	0.818
SS	0.671	0.278	0.084	0.023	0.409	0.868

Third, the meanings of MNI and SCI can change across managers working in vertical networks (i.e., high *internal purchases*) as opposed to horizontal networks (i.e., low *internal purchases*). For instance, if a plant sources 100% of its goods and services from sister facilities and 0% from external suppliers (vertical network), the two concepts of MNI and SCI could potentially overlap in the mind of the respondent. As a consequence, we split the sample in two based on the median value of the *internal purchases* variable (i.e., 20%), and we run a multi-group CFA. We adopted a procedure similar to that described by Arbuckle (2005). Our analysis showed that respondents at plants characterized by high or low internal purchases perceive MNI and SCI similarly.

4 Results

First of all, we performed a t-test comparing the mean of sustainable production (3.22 on a 5 point scale) and sustainable sourcing (2.79 on a 5 point scale). In line with our baseline model we found that the difference in the means was significant (p-value < 0.01), suggesting that sustainable production represents a more mature bundle of practices relative to sustainable sourcing.

Second, we test our hypotheses by means of a set of regression models. Tables 5 shows the results for sustainable production and Table 6 for sustainable sourcing. In each table, four models are presented: in Model 1 we introduce only control variables (including SP as a control when SS is the independent variable) and SCI; in Model 2, which tests HP1a and HP2a, we add network globalization; in Model 3, which tests HP2a and HP2b, we remove network globalization and add MNI. Finally, in Model 4, we add both network globalization and MNI, to verify that H1a,b and H2a,b hold simultaneously. Variance inflation factors for these regression models and all the following were always lower than 5, and the condition indexes were always below 12 (Hair et al., 1998; Menard, 2002). As shown in Tables 5 and 6, our baseline model considering SP, SS and SCI found empirical support. Most importantly, the analysis showed that plants belonging to a global network (rather than a regional one) are better equipped to address SP, while no significant effect is found for SS. A Sobel-Goodman test showed that the indirect effect of network globalization on SS through SP was statistically significant (sig. = 0.024).

Table 5 *– The determinants of sustainable production*

	Model 1		Model 2		Model 3		Model 4	
	Std. Beta	Sig.	Std. Beta	Sig.	Std. Beta	Sig.	Std. Beta	Sig.
(Constant)		.000		.000		.000		.000
Size (ln. z)	.189	.000	.167	.000	,184	.000	.164	.000
Regulatory Quality (z)	.273	.000	.269	.000	.257	.000	.254	.000
Sustainability Orientation (z)	-.131	.003	-.184	.000	-.132	.003	-.182	.000
ISIC-25	-.040	.647	-.050	.562	-.045	.603	-.055	.527
ISIC-26	-.052	.437	-.058	.387	-.047	.486	-.052	.433
ISIC-27	-.061	.419	-.074	.325	-.061	.415	-.074	.327
ISIC-28	-.094	.254	-.107	.195	-.091	.267	-.103	.208
ISIC-29	-.035	.617	-.033	.635	-.032	.648	-.030	.663
Plant Responsibility (z)	-.008	.841	-.013	.746	-.002	.955	-.007	.856
Internal purchases	-.033	.412	-.024	.561	-.040	.321	-.031	.449
SCI (z)	.313	.000	.306	.000	.247	.000	.244	.000
Network Globalization			**.113**	**.014**			**.107**	**.020**
MNI (z)					**.119**	**.017**	**.112**	**.025**
R^2	.351		.360		.360		.368	
N	471		471		471		471	

Table 6 *– The determinants of sustainable sourcing*

	Model 1		Model 2		Model 3		Model 4	
	Std. Beta	Sig.	Std. Beta	Sig.			Std. Beta	Sig.
(Constant)		.000		.000		.000		.000
Size (ln. z)	-.028	.430	-.021	.561	-.029	.896	-.021	.556
Sustainability Orientation (z)	.202	.000	.202	.000	.200	.746	.199	.000
Regulatory Quality (z)	-.171	.000	-.150	.000	-.172	.788	-.150	.000
ISIC-25	-.069	.268	-.064	.384	-.070	.201	-.066	.376
ISIC-26	-.005	.856	-.003	.963	-.004	.340	-.001	.980
ISIC-27	-.018	.923	-.012	.847	-.018	.268	-.012	.846
ISIC-28	-.025	.482	-.020	.777	-.025	.225	-.019	.784
ISIC-29	-.018	.877	-.018	.758	-.017	.309	-.018	.766
SP (z)	.372	.000	.377	.000	.369	.640	.375	.000
Responsibility (z)	-.081	.129	-.079	.022	-.080	.926	-.078	.025
Internal purchases	.072	.036	.069	.047	.071	.925	.067	.054
SCI (z)	.226	.000	.227	.000	.213	.557	.213	.000
Network globalization			**-.044**	**.261**			**-.045**	**.249**
MNI (z)					**.025**	**.604**	**.028**	**.520**
R^2	.537		.539		.538		.539	
N	471		471		471		471	

Thus, *H1a found empirical support, while H1b found only partial support*. Then, we observed that MNI was positively and significantly associated with SP, but not with SS; still, the indirect effect of MNI on SS through SP was significant (sig. = 0.027). These results provided *support for H2a and partial support for H2b*. As an additional check, we introduced the interaction effects SCI*MNI and Network Globalization*MNI in our last two regression models, but these factors were not significant.

Finally, we checked if our results could be affected by endogeneity. An underlying assumption for our theoretical model was that the adoption of sustainable production practices at the plant level could provide the necessary initial knowledge for sustainable sourcing practices to develop. However, one could still argue for reverse causality: through supplier evaluation and development, the focal plant might learn ways to enhance its own internal production practices. A Durbin Wu-Hausman (DWH) test (Davidson and MacKinnon, 1993) indicated that endogeneity was likely, so we performed two-stage least squares (2SLS) to verify the validity of our hierarchical regression approach. Before the 2SLS was executed, we had to identify instrumental variables that met validity requirements and made theoretical sense. Among the variables available in the IMSS-VI survey, the following could theoretically be associated to sustainable production:

- *Blue-collar ratio* (Number of blue-collar workers/size). As the portion of blue-collar workers in a plant increases, the plant becomes more production-oriented;
- Investment in the last three years in *new forms of work organization (NWFO)*, namely, delegation and knowledge of the workforce, open communication between workers and managers, and continuous improvement programs in the shop floor (e.g., kaizen, improvement teams, and improvement incentives). Existing literature demonstrates that this category of investment tends to result in organizational change that facilitates

overcoming sustainability-related trade-offs along a plant's production line (Longoni et al., 2014).

Because these variables were strongly correlated with SP (sig. < 0.001) and not directly correlated with SS (at the 10% significance level), they could be used as instruments of sustainable production in our 2SLS test, whose results are reported in Table A2 in appendix. The 2SLS analysis for SS supported the findings of our hierarchical regression model, thus enhancing our confidence in the overall results and final considerations.

5 Discussion and conclusion

5.1 Theoretical implications

Our paper provides empirical evidence and a rigorous test of two effects studied in the current literature: (a) *sustainable practices* develop within a plant and evolve from internally oriented practices (SP) to include externally oriented practices (SS) (De Giovanni, 2012; Gavronski et al., 2011; Gualandris and Kalchschmidt, 2016); (b) *external supply chain integration* significantly supports a plant's sustainable development by facilitating the absorption of external knowledge necessary to innovate production and sourcing (Hajmohammad et al., 2013; Vachon and Klassen, 2006). The positive association between external supply chain integration and sustainable practices is in line with what has been found in other studies using the IMSS database but focusing on lean production, digitalization and sustainability performance (Cagliano et al., 2006; So and Sun, 2010; Wiengarten and Longoni, 2015).

Second, in light of their continuous adaptation process and the significant alterations they introduce in a plant technologies and procedures, we have conceptualized sustainable production and sustainable sourcing as *process innovations with moderate degree of innovativeness,* which provides a new angle on the study of sustainability in Operations Management (Gao et al., 2016; Gualandris and Kalchschmidt, 2015; Longoni and Cagliano, 2016). Future research could analyze the idiosyncratic characteristics of these peculiar innovations and compare them with those that present higher (lower) degrees of innovativeness (Vurro et al., 2010). Future qualitative studies could also concentrate on the development path through which plants continuously re-adapt technologies, administrative procedures and sustainable practices over time.

Third, we found that network globalization is positively and significantly associated with the adoption of sustainable production practices (H1a). Therefore, our paper resolves existing ambiguities regarding the role of network globalization by proving that global manufacturing networks bring more heterogeneous knowledge to bear along the sustainable development of its individual plants. Hence, we challenge the idea that plants within global manufacturing networks may find themselves unable to respond successfully to the call for new and more environmentally and socially sustainable production practices (Ferdows et al., 2016; Husted and Allen, 2006). Future studies could test if knowledge richness and diversity as well as an ability to face and resolve ambiguity (Bansal, 2004) fully mediate the relationship between network globalization and a plant's sustainable development.

Fourth, we analyzed whether a plant's collaborative integration with sister facilities could support the adoption of novel sustainable practices. While previous IMSS-based studies found a positive relationship between manufacturing network integration and operational performance (e.g. Szász et al., 2016), its effect over the adoption of sustainable production and sourcing is new to the Operations Strategy literature. We hypothesized that rich transmission channels with sister facilities complement the role of external supply chain integration: while the latter allows acquiring knowledge about new technologies and solutions that develop upstream and downstream in the extended supply chain (e.g., Flynn et al., 2010), the first facilitates the acquisition of procedural knowledge about product-process co-design and mutual adaptation, which is necessary in order to alter existing technologies and administrative procedures and accommodate innovative production practices. Our results show that internal manufacturing network integration adds to the effect of supply chain integration and network globalization in developing, and adapting to, new sustainable production practices. Future studies can expand our research by building more complex measures of internal manufacturing network integration; for example, social network analysis (Wasserman, 1984) can allow exploring important effects related to plant's frequency of engagement over time and overall network interconnectedness. This analysis will help to understand what different forms of integration exist within manufacturing networks and which ones foster a plant's sustainable development.

Finally, our results suggest that the benefits of network globalization and internal manufacturing network integration are confined to sustainable production practices, whereas sustainable sourcing benefit only indirectly (H1b, H2b). We elaborated the following explanation for this result. Because global networks are generally more *footloose* than regional ones and present higher rates of supplier turnover (Ferdows, 2008; Ferdows et al., 2016), purchasing and supply management tends to be centralized at the headquarter level (Monczka et al., 2008); under such circumstances, plants have less knowledge and solutions to share in regards to sustainable sourcing practices. Furthermore, some scholars have suggested that knowledge flows between sister facilities may well remain squarely focused on product and process development (Ernst and Kim, 2002; Venaik et al., 2005), limiting the direct effect of internal manufacturing network integration on sustainable sourcing. Our explanation appeals to the concept of *manufacturing network configuration*, which addresses strategic decisions in designing a network. The fact that manufacturing networks can be vertical or horizontal (Egelhoff, 1982; Rudberg and Olhager, 2003), footloose or rooted (Ferdows, 2006; Ferdows et al., 2016) may have important implications in terms of a plant's ability to advance its sustainability. Future studies could significantly expand Operations Strategy literature by examining what manufacturing network configurations hinder the development of sustainable practices and what managerial levers can be adopted to neutralize such effects.

5.2 Managerial implications

Plants operating within a manufacturing network can be located in countries where environmental and social regulations are lacking or not enforced (Jahns et al., 2006), and they are expected to self-regulate their environmental and social conduct and adopt production and sourcing practices that exceed local requirements (Christmann, 2004). We believe that our findings can help decision-makers within manufacturing networks to devise managerial policies that are better suited to address the above challenges.

First, managers at the headquarter level should approach the development of, and adaptation to, sustainable production and sustainable sourcing practices as a complex innovation journey, rather than a pure risk management exercise. Simulating the technological and administrative changes that could be faced along the journey will help them to understand what procedural knowledge is needed to smoothly manage sustainability transitions.

Second, while preparing for the journey, globalization must *not* be seen as a barrier but instead as a unique opportunity. Firms with a global footprint or firms which are expanding globally should take advantage of the large, heterogeneous stock of knowledge that accumulates in their networks and turn it into a source of ideas for sustainability-related innovations, especially at the production level.

Third, because most advanced plants in a manufacturing network can try out new greener and safer solutions and eventually help other plants to improve, managers at the headquarter level should stimulate worker mobility across sister facilities, foster the establishment of social ties between employees at different plants and develop benchmarking activities at the network level; these integration mechanisms will facilitate the exchange of tacit knowledge between plants and, in turn, foster the adoption of sustainable production and (indirectly) of sustainable sourcing. For instance, in 2004, Nestlé implemented a cogeneration system in a plant in Japan (Himeji). Soon thereafter, once the benefits became more evident, a similar system was built in Nestlé Japan’s second coffee factory, and now, the firm is extending the system to the Philippines (Nescafé, 2016). Pre-existing collaborative integration between these sister facilities is proving to be an essential enabler along Nestlé's sustainable innovation journey.

Finally, managers at the headquarter level should recognize that sustainable innovations are fostered by collaborative integration with partners operating upstream and downstream in the extended supply chain. Although it may make managerial sense to centralize operational coordination with suppliers and customers at the headquarter level (Monczka et al., 2008), individual plants should still nurture collaborative ties with some supply chain partners. Such ties will foster their individual ability to innovate production and guarantee that local suppliers will do the same.

5.3. Limitations

Focusing on the adoption of sustainable practices, this paper provides evidence of the advantages that a plant that is well integrated within a global manufacturing network has over plants loosely connected within regional networks. However, there are a few limitations worth mentioning. Future studies should consider having more refined measures that could more precisely capture the 'excellence' of adoption rather than the 'extent' of adoption; also future work could collect data from multiple respondents to mitigate any source of common method bias. Finally, we do not measure the sustainability performance of the plant nor of the firm-wide network, which could be enhanced by the spreading of best practices but also hampered by the inefficiencies of network globalization (e.g., international logistics). Our contribution is rather focused on the plant level and provides a positive view on the potential of global, well-integrated networks for the development of sustainable practices. We hope Operations Management scholars will build on our paper and will further extend our understanding of how successful sustainable, and especially radical, innovations emerge and diffuse within manufacturing networks.

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Appendixes

Questionnaire items

Indicate the effort put in the last 3 years into implementing action programs related to (1:none; 5:high):		
Manufacturing network integration	NI1	Improve joint decision making to define production plans and allocate production in collaboration with other plants in the network (e.g. through shared procedures, shared forecasts)
	NI2	Improve innovation sharing / joint innovation with other plants (through knowledge dissemination and exchange of employees inside the network)
	NI3	Improve the use of technology to support communication with other plants of the network (e.g. ERP integration, shared databases, social networks)
	NI4	Developing a comprehensive network performance management system (e.g. based on cost, quality, speed, flexibility, innovation, service level)

Indicate the current level of implementation of, action programs related to:		
Sustainable production	SP1	Environmental certifications (e.g. EMAS or ISO 14001)
	SP2	Energy and water consumption reduction programs
	SP3	Pollution emission reduction and waste recycling programs
	SP4	Formal occupational health and safety management system
Sustainable sourcing	SS1	Suppliers' sustainability performance assessment through formal evaluation, monitoring and auditing using established guidelines and procedures
	SS2	Training/education in sustainability issues for suppliers' personnel
	SS3	Joint efforts with suppliers to improve their sustainability performance

Indicate the effort put in the last 3 years into implementing action programs related to external integration (1:none;5:high)		
[1] Supplier integration	SI1	Sharing information with key suppliers (about sales forecast, production plans, order tracking and tracing, delivery status, stock level)
	SI2	Developing collaborative approaches with key suppliers (e.g. supplier development, risk/revenue sharing, long-term agreements)
	SI3	Joint decision making with key suppliers (about product design/modifications, process design/modifications, quality improvement and cost control)
[2] Customer integration	CI1	Sharing information with key customers (about sales forecast, production plans, order tracking and tracing, delivery status, stock level)
	C2	Developing collaborative approaches with key customers (e.g. risk/revenue sharing, long-term agreements)
	C3	Joint decision making with key customers (about product design/modifications, process design/modifications, quality improvement and cost control)

Table A1 *- Results of the first and second stage of the 2SLS procedure.*

	First Stage (SP)		Second Stage (SS)	
	Coef.	sig.	Coef.	Sig.
Plant Size (ln, z)	0.133	0.001	-0.031	0.523
Sustainability Orientation (z)	0.227	0.000	0.228	0.000
Regulatory Quality (z)	-0.195	0.000	-0.175	0.004
ISIC-25	-0.021	0.902	-0.183	0.332
ISIC-26	0.024	0.901	-0.047	0.823
ISIC-27	-0.056	0.754	-0.028	0.884
ISIC-28	-0.138	0.446	-0.070	0.720
ISIC-29	-0.001	0.995	-0.008	0.968
Plant Responsibility (z)	-0.005	0.909	-0.085	0.015
Internal purchases	0.000	0.808	0.002	0.032
Network Globalization	0.203	0.025	-0.089	0.367
SCI (z)	0.179	0.000	0.233	0.001
MNI (z)	0.067	0.209	0.036	0.535
Instrumented variable				
SP(z)			0.369	0.071
Instrumental Variables				
Blue collars ratio	0.002	0.000		
NFWO	0.398	0.000		
R^2	0.402		0.541	
N	443		443	