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Embeddedness and path dependence of organizational capabilities for mass customization and green management: A longitudinal case study in the machinery industry

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ABSTRACT

A growing number of firms today have to cope with the twofold challenge of mass customization (i.e., combining high performance in product customization with high performance in cost, delivery and quality) and green management (i.e., integrating environmental-sustainability principles into businesses). Research on this joint challenge, however, is still limited in the literature. To narrow this gap, we empirically investigate the interconnectedness of mass customization and green management on the level of their enabling capabilities. Through a single longitudinal case study in a machinery manufacturing organization that, during the period of observation, succeeded in developing both mass-customization capabilities and green-management capabilities, we find overlaps and path dependences between such capabilities. Pragmatically, these findings indicate synergies that firms pursuing a green mass customization strategy may leverage in order to alleviate the difficulty of implementing that strategy. From an academic standpoint, these findings contribute to the debate on the relationship between the environmental pillar of sustainability and its economic pillar and, at the same time, add both to the body of the literature on mass customization and to the one on green management. Limitations of the present study and the related opportunities for future research are, finally, discussed.

1. Introduction

As global competition intensifies and customers become more sophisticated, a growing number of firms face the challenge of fulfilling each customer's idiosyncratic needs without substantial trade-offs in cost, delivery and quality (Squire et al., 2006; Huang et al., 2008). The ability to do this has been called in literature mass customization (MC) (e.g., Pine, 1993; McCarthy, 2004; Liu et al., 2006). At the same time, more and more companies nowadays, due to increasing regulatory pressure and stakeholders' environmental consciousness, are challenged by the need for integrating environmental-sustainability principles into their businesses (Kleindorfer et al., 2005). This integration has been named in literature green/environmental management (GM) (e.g., Gupta, 1995; Angell and Klassen, 1999; Wiengarten and Pagell, 2012; Wiengarten et al., 2013). As a result of these two concomitant trends, a growing number of firms today have to cope with the joint challenge of MC and GM.

Studies that focus on this combined challenge, however, are still scarce in the literature. Academe has promptly reacted to the growing importance of both MC and GM for the business community by multiplying the studies on GM in a variety of areas, such as supply chain management (Sarkis et al., 2011) or human resource management (Renwick et al., 2013), as well as the studies on MC (Fogliatto et al., 2012). Previous research, however, has typically focused on either MC or GM, without addressing their possible interrelations. The only exceptions are a few mostly conceptual studies which suggest that some well-known MC enablers, such as product modularity or form postponement, may have positive effects (Nielsen et al., 2011; Pedrazzoli et al., 2011; Petersen et al., 2011), but also negative effects (Petersen et al., 2011), on a firm's environmental performance. None of these few works, however, explore the relationships between MC and GM with a focus on organizational capabilities, even though organizational capabilities play a fundamental role both in MC (e.g., Salvador et al., 2009) and in GM (e.g., Hart, 1995).

The present paper aims to narrow this research gap by empirically investigating the interconnectedness of MC and GM on the level of their enabling capabilities. To that purpose, we conducted a single longitudinal case study in a machinery manufacturing organization that, during the period of observation, succeeded in developing both MC capabilities (MCCs) and GM capabilities (GMCs). As a result of this study, we find overlaps and path dependences between individual MCCs and individual GMCs. Pragmatically, our findings indicate synergies that companies faced with the twofold challenge of MC and GM may leverage in order to alleviate the difficulty of that challenge. From an academic standpoint, our results contribute to the debate (e.g., Montabon et al., 2007; Gimenez et al., 2012; Seuring, 2013) on the relationship between the environmental pillar of sustainability, which requires GMCs, and its

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economic pillar, which requires MCCs if a firm faces both highly heterogeneous demand and intense competition (Pine, 1993; Bardakci and Whitelock, 2003; Huang et al., 2008). Moreover, our results add to the body of the literature on MC as well as to the one on GM.

2. Literature review

2.1. Organizational capabilities

Organizational capabilities are often depicted in the literature as combinations of routines characterized by a recognizable organization-level purpose, such as the development of new products or services (Parmigiani and Howard-Grenville, 2011; Salvato and Rerup, 2011). In turn, organizational routines are commonly defined in the literature as repetitive patterns of interdependent organizational actions (Feldman and Pentland, 2003; Parmigiani and Howard-Grenville, 2011; Felin et al., 2012). Such recurrent patterns have both ostensive (cognitive) and performative (behavioral) aspects (Feldman and Pentland, 2003; Salvato and Rerup, 2011). The former aspect captures "the abstract idea of the routine" (Feldman and Pentland, 2003: 95) and includes, for instance, standard operating procedures for new product development (NPD) or an NPD team's collective interpretation of how new products are or should be developed (Salvato and Rerup, 2011). Instead, the performative aspect captures the enactment of a routine in specific places and at specific times (Felin et al., 2012). As such, it includes behavioral regularities, rather than abstract patterns or understandings shaping and guiding organizational behavior (Salvato and Rerup, 2011). Organizational routines are described as having a context-dependent nature, where the context "is seen as a kind of 'external memory' and as a source of inputs to actions" (Dosi et al., 2008:1166). A customer database, for instance, might be a contextual requisite of some of the organizational routines supporting a marketing capability (Dosi et al., 2008). As emphasized by Winter (2000), routines, and capabilities even more so, require not only information flows and information processing, which are their nervous system, but also key inputs from their bones and muscles. In line with this view, we define organizational capabilities as the organizational knowledge of how to repeatedly organize a number of inputs in order for the organization to obtain a desired output (Grant, 1996; Dosi et al., 2008). It is worthwhile noting that this conceptualization of organizational capabilities, which is typical of the strategic-management literature, differs from the conceptualization that is common in the operations strategy research. In the latter body of the literature, capabilities are generally seen as "business unit's intended or realized competitive performance or operational strengths" (Peng et al., 2008: 730) and, accordingly, are measured through indicators such as delivery time, conformance quality or costs (e.g. Ferdows and De Meyer, 1990; Flynn and Flynn, 2004). The operations strategy view of capabilities, in other terms, focuses on the outcome a capability is supposed to enable, rather than on the "means" or pathways to achieve that outcome (Swink and Hegarty, 1998; Peng et al., 2008).

2.2. Green-management capabilities

Green management (GM) is a concept that emerged in the last decade of the twentieth century, when the term "eco-efficiency" was coined and organizations started to look for innovative ways to reduce materials use, to utilize renewable energy, etc. (Pane Haden et al., 2009). Since then, management scholars have become particularly interested in the organizational capabilities that support GM. Hart (1995) introduced this theme in the strategic-management literature by proposing three GMCs: namely, "pollution prevention", "product stewardship" and "sustainable development". The first is the capacity to abate the emissions, effluents and waste caused by an organization's manufacturing processes by eliminating the sources of pollution in those processes, rather than by controlling pollution with end-of-pipe technologies. "Product stewardship" is the capacity to design new products with minimal life-cycle environmental impact. Finally, "sustainable development" can be defined, using Judge and Douglas' (1998) words, as the capacity of an organization to integrate environmental issues into its strategic-planning process and decisions, thus minimizing the environmental burden of the firm's growth and development. A few subsequent studies in the same body of literature have drawn upon Hart's (1995) capabilities to understand their antecedents and/or their consequences on a firm's performance and competitive advantage (e.g., Russo and Fouts, 1997; Judge and Douglas, 1998; Marcus and Geffen, 1998; De Bakker and Nijhof, 2002). Other studies in the same strand of research have proposed additional capabilities a firm should deploy for GM, such as Aragón-Correa and Sharma's (2003) "proactive environmental strategy" capability.

The notion of GMC has more recently been adopted in the operations and supply chain management field as well (e.g., Bowen et al., 2001; Miemczyk, 2008; Bremmers et al., 2009; Wong et al., 2012; Ji et al., 2014; Lai et al., 2015). While some studies in this research stream have focused on upstream or downstream supply chain operations, others have taken a more comprehensive perspective. In particular, Lee and Klassen (2008), adopting a holistic view of supply chain operations, propose the following five GMCs: "product environmental management" (i.e., the capacity to provide green products to the customer through environmental practices in the NPD process), "process environmental management" (i.e., the capacity to sustain manufacturing processes that meet or exceed environmental regulations), "organization environmental management" (i.e., the capacity to integrate environmental issues into an organization's daily business routines by building an environmental–management system that clearly assigns environmental responsibilities within the organization and provides environmental training and education to employees), "supply chain environmental management" (i.e., the capacity to motivate suppliers to be environmentally responsible and to reduce the environmental burdens caused by logistics) and "relationship environmental management" (i.e., the capacity to sustain environmentally sound relationships with external stakeholders through various communication methods, such as environmental reporting or participation in environmental-conservation programs).

2.3. Mass-customization capabilities

As compared to the research stream on GMCs, the one on MCCs is more recent and relatively underdeveloped. The first authors to use the term "capability" in conjunction with the term "mass customization" were Tu et al. (2001), who define MCC as the organization's ability to produce differentiated products without sacrificing manufacturing costs and delivery lead-times. Similar to the manufacturing capabilities studied in the operations management literature (Peng et al., 2008), Tu et al.'s (2001) MCC is conceptualized as a competitive performance, rather than as a combination of routines and related inputs that enable such a performance.

Conversely, Zipkin (2001) identifies three MCCs that are more in line with the "capabilities as routine bundles" view which is typical of the strategic-management literature: "elicitation", "process flexibility" and "logistics". These capabilities can be thought as the means that a company needs to employ to achieve Tu et al.'s (2001) MCC. "Elicitation" is the capacity to identify exactly what the customer wants, which can be hard since customers themselves "often have trouble deciding what they want and then communicating or acting on their decisions" (Zipkin, 2001: 82). "Process flexibility" is the capacity to innovate production technology to increase its flexibility. "Logistics", finally, is the capacity to make sure that the right product ultimately reaches each customer.

By elaborating on Zipkin's (2001) MCCs, Salvador et al. (2009) propose another three capabilities that support the organizational movement toward MC: "solution space development", "choice navigation" and "robust process design". "Solution space development" is the capacity to identify the product attributes along which customers' needs diverge in order for a firm to clearly delineate what it will offer within its solution space and what it will not. “Choice navigation” is the capacity to support customers in identifying their own solutions while minimizing complexity and the burden of choice. Finally, “robust process design” is the capacity to reuse or recombine existing organizational and value-chain resources to fulfill a stream of differentiated customer needs, for example by reusing the same product components or manufacturing processes for different product variants.

2.4. *Linkages between mass customization and green management*

In literature, the few studies that explore the links between MC and GM typically consider some well-known enablers of MC, such as product modularity or form postponement, and conceptually examine their effects on a firm's environmental performance. On the one hand, Nielsen et al. (2011) argue that product modularity reduces the life-cycle environmental impact of customized goods and Badurdeen and Liyanage (2011) point to the environmental benefits of postponing product differentiation until customer order receipt. On the other hand, Petersen et al. (2011) argue that MC enablers may have both positive and negative effects on a firm's environmental performance, depending on the specific type of product. In this vein, Pedrazzoli et al. (2011) examine the specific case of footwear and find that, in that context, MC enablers such as direct delivery reduce overall consumption of energy and resources.

None of the above mentioned works, however, address the relationship between MC and GM with a focus on organizational capabilities, which would imply examining the possible links between MCCs and GMCs. To narrow this research gap, the present study investigates the interconnectedness of MC and GM on the level of their enabling capabilities. Based on Hart's (1995) seminal work on the interconnectedness of three different GMCs, interconnectedness is characterized here as comprising two concepts: namely, embeddedness, or overlap, and path dependence. Embeddedness, or overlap, means that the development of one capability facilitates and accelerates the development of another capability and vice versa, as the two capabilities share something–for example the same routine of cross-functional coordination (Hart, 1995)–which is beneficial for both. Instead, path dependence means that prior development of one capability mitigates the costs (Hart, 1995), or increases the benefits (Barney, 1991), of building another capability, but not vice versa. Development and exploitation of one capability, in other terms, depends upon having already built another capability first.

3. Methodology

To investigate possible overlaps and path dependences of GMCs and MCCs, we designed an exploratory case study, consistent with the early stage of the academic inquiry on the topic (Edmondson and McManus, 2007), with the objective of understanding also the “whys” behind relationships (Yin, 2009) and with the focus on organizational routines (Cohen et al., 1996), which are considered in this study as the “building blocks” of capabilities (cf. Section 2.1). Specifically, we opted for a longitudinal case study, which has the potential for increasing the internal validity of results and alleviates the risk that participants do not recall relevant events or that their recollection is subject to bias (Leonard-Barton, 1990; Voss et al., 2002). While offering these important advantages, longitudinal case studies are also very time- and resource-consuming (Åhlström and Karlsson, 2009) and, consequently, we opted for a single case study.

In line with previous research on organizational capabilities (Lockett et al., 2009), we chose the business unit as our level of analysis, since different business units of the same company may have different capabilities. We selected our case according to Pettigrew's (1990) “extreme situation” decision rule (p. 275). To limit the shortcomings of having only one case, Pettigrew (1990) recommends choosing a situation where the phenomena of interest are more likely to be clearly observable. The business unit we chose for this study did provide such an opportunity because, at the time of selection, it was far from having high MCCs and GMCs but was strongly committed to developing both MCCs and GMCs, thus making any overlaps or path dependences of such capabilities more likely to be clearly observable.

3.1. *Setting*

The study was conducted over a period of three years, from mid-2008 to mid-2011, in a large firm manufacturing wash equipment for every type of vehicle: cars, buses, tankers, trains, streetcars, underground trains and military vehicles. Competition in the vehicle-wash equipment industry was high, as at least six multinational companies, besides a number of regional producers, competed in the market with similar products at that time.

We focused our inquiry on the car-wash business unit, which offered a high degree of product customization (8 product families; 55 product-differentiating attributes for the high-end product family, with a total of 528 pre-engineered attribute levels which could be combined in millions of different configurations and with the possibility of ad-hoc engineering). Since a few years before, the business unit had suffered from worsening operational performance and decreasing profitability. In May 2008, a progressive turnover of top managers had begun, following the company take-over by new owners. The new managers, in accord with the new ownership, were convinced of the need for developing MCCs which allowed the business unit to improve its operational performance while preserving its ability to fulfill customers' idiosyncratic needs. Additionally, to differentiate the company's offer from the competitors' ones, the new managers, supported by the new owners, decided to invest in the development of GMCs.

3.2. *Data collection*

Consistent with Peng et al. (2008), we consider routines as the operationalizations of organizational capabilities. In accord with this view and the terminology used in longitudinal studies, we refer to the variations in the capabilities of interest as events and to the variations in their underlying routines as incidents. Incidents are the empirical indicators that an event has happened, while events are conceptual constructs explaining the pattern of incidents that are empirically observed (Van de Ven and Poole, 1990).

To ensure reliability in our case study (Yin, 2009), we established a research protocol and, to augment construct validity (Yin, 2009), we included multiple sources of evidence in the protocol: semi-structured interviews, unstructured interviews, direct observation and documents. During the semi-structured interviews, we gathered information on the activities, if any, performed by the business unit to achieve a number of organization-level purposes characterizing as many organizational capabilities. The first round of semi-structured interviews covered a subset of the MCCs and GMCs defined in the available literature at the time the research was designed (see Appendix A).[1] In the subsequent rounds, we revised the initial list of capabilities by adding new GMCs/MCCs based on the data collected from other sources and the results of preliminary data

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[1] Distilling a set of mutually exclusive and collectively exhaustive GMCs or MCCs from the available literature was beyond the scope of the present study. As regards the numerous GMCs discussed in literature, we selected the three proposed by Hart (1995) in his seminal paper, with “sustainable development” capability being interpreted and renamed according to Judge and Douglas (1998). In addition, we chose four of the five GMCs defined by Lee and Klassen (2008) with a holistic view of supply chain operations. We excluded “product environmental management” capability, as we considered it as fully captured by Hart's (1995) “product stewardship” capability. As regards the few MCCs discussed in literature, we selected the three proposed by Salvador et al. (2009) and we added Zipkin's (2001) “logistics” capability, which is not captured, in our view, by the three proposed by Salvador et al. (2009).

analysis. In particular, new capabilities were suggested by the unstructured interviews, which were made in alternation with the semi-structured ones to the same key informants. During the unstructured interviews, we presented the notions of MC and GM and asked the interviewees to tell any actions taken by the business unit in order to move toward MC and/or GM. While the unstructured interviews allowed us to add new capabilities to the ones initially considered in our research protocol, the semi-structured interviews enabled us to gather information in a more systematic and comprehensive manner, thus controlling and completing the understanding gained from the unstructured interviews. Furthermore, as lower-level routines can sometimes be less visible to managers than to lower-level employees (Winter, 2000), we complemented managers' viewpoints–captured through the unstructured and semi-structured interviews–with data gathered through informal conversations with lower-level personnel participating in observed actions[2]. In addition to interviews and informal conversations, there were also numerous opportunities to gather information through personal observation at various meetings, such as strategic discussions on the top management level and meetings in NPD projects or in projects of business process improvement. Yet, "the purest form of a longitudinal field study, namely daily participant observation, was not feasible" (Leonard-Barton, 1990: 254) and the research site could be visited only once or twice a month, with the same key informant being interviewed approximately every five months. As retrospective interviews concerned relatively recent facts, however, we could reliably anchor our data in time on a relatively fine-grained scale, that is on a monthly basis. To alleviate the influence of subjectivity (Voss et al., 2002) and simultaneously enhance the creative potential of the study (Eisenhardt, 1989), all the interviews were conducted by at least two investigators and 70% of the meetings personally observed during this research were attended by more than one investigator.

Predictably, we found a number of incongruities between responses from different informants. Whenever possible, such disagreements were resolved using relevant documents or data collected through direct observation. On one occasion, for example, we collected conflicting answers regarding the extent to which sales agents were actually making use of the sales configurator that the business unit had adopted in June 2010. This incongruity was resolved by examining a document reporting the updated number of tenders prepared by sales agents using the sales configurator since its introduction. Similarly, at the beginning of our observation, we gathered conflicting answers as to the organization's capacity to understand its target customers' needs and this incongruity was resolved based on data recorded by one of the authors during one strategic-planning meeting. When neither documents nor direct observation could help, we went back to the informants and asked for clarification until agreement was reached. For instance, when we heard from one informant that the substitution of solvent-based paints with water-based paints had not been decided yet, as opposed to what another informant had previously told us, we went back to the latter, who eventually confirmed that water-based paints were still under evaluation.

3.3. Data analysis

Before performing the more detailed analysis, we wrote a case narrative, as suggested by Åhlström and Karlsson (2009), with the twofold purpose of gaining familiarity with all the collected material and distilling a story that narrates the sequence of the events occurred at the case study organization in the domains of MC and GM during the period of observation. For each event mentioned in the narrative, references to the relevant sources of evidence (i.e., interview transcripts, field notes and documents) were included to permit fast retrieval of all the raw data pertaining to that occurrence. The narrative was progressively extended by one of the researchers as additional data were collected and was periodically checked by the other investigators.

Subsequently, the more detailed analysis started with the identification of the basic elements of information, that is bracketed strings of words describing discrete incidents (Åhlström and Karlsson, 2009). Consistent with the aim and focus of our study, we defined an incident as the establishment of a new organizational routine, or a change in an existing one, which supported MC and/or GM. Therefore, when deciding whether an occurrence mentioned in the case narrative was to be considered an incident, we asked ourselves the following two questions: "did the occurrence represent a change in the organizational routines of the company?" "Did it support MC and/or GM at the company?" Only in the case of a positive answer to both questions, the occurrence was considered an incident. Take the following piece of narrative as an example: "The idea of the top management team was to also apply for ISO 14000 certification. In May 2010, the operations manager and the health and safety officer, with the assistance of an external audit team, assessed the organization's processes to identify problems of non-compliance with ISO 14000 prescriptions. The identified non-compliances guided a few improvements […] However, the idea of applying for ISO 14000 certification was abandoned a few months later". Undeniably, the audit mentioned in this excerpt supported GM by prompting a number of improvement actions that enhanced the environmental sustainability of the organization's processes. However, this audit was performed on one occasion only. It did not become part in the organization's recurring action patterns for identification of environmental improvement opportunities and, therefore, was not considered an incident. Conversely, one example of change in the organization's routines is mentioned in the following piece of narrative: "In early 2009, the new operations manager completed the creation of an assembly manual describing all the possible activities that final-assembly operators may have to perform, as well as the tools that they have to use for each activity. Following the adoption of the manual, the supervisor of the assembly department started to […] correct the behaviors of those employees who did not follow the standard procedures. Previously, the operators used to perform their tasks mostly by memory and, over time, had developed their own work procedures, which could vary from one operator to another […] thereby causing problems in the subsequent stages of product testing and installation". Furthermore, this change in the company's manufacturing routines supported MC by improving operational performance without sacrificing product customization. Therefore, the raw data pertaining to this change were transformed into a qualitative datum describing an incident.

To enhance the reliability and validity of the incidents entered into the qualitative data file, we resorted to the procedures recommended by Van de Ven and Poole (1990) for that purpose. First, incidents were identified by two researchers. For 81% of the incidents initially identified, there was consensus between the two investigators on the interpretation of the decision rule. Subsequently, all the incidents initially identified, both those on which the two researchers disagreed and those on which there was consensus, were reviewed by key informants. The informants involved at this stage were explained the rule used by the investigators to identify incidents and were asked to judge whether the incidents initially identified by at least one researcher satisfied that rule. Additionally, they were asked to indicate whether any incidents were missing or incorrectly described. Based on key informants' feedback, three incidents were removed because one-time behaviors had been mistakenly interpreted as recurring action patterns (e.g., one meeting for the communication of the company's strategic goals to its main suppliers), six incidents were eliminated because changes that had been planned, but had failed to reach implementation, had been incorrectly interpreted as actually

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[2] Based on the existing literature (Zelditch, 1962; Åhlström and Karlsson, 2009), the recording of informal conversations with lower-level employees participating in observed actions is considered part of the process of direct observation.

implemented (e.g., the integration of sales configurator and technical product configurator), one incident was added, and 21 incidents were revised (e.g., the description of the restructuring of the existing manufacturing bills of materials and assembly sequences was revised to clarify that such a restructuring had been accompanied with the redefinition of the coding scheme for parts and products and with the modeling of the restructured product data in the existing technical product configurator).

The subsequent stage of the analysis consisted in coding the identified incidents into event constructs. Each incident was assigned one or more codes according to the MCC(s) and/or GMC(s) that the incident had helped improve at the case company. With reference to the continuum from theory-driven codes to data-driven codes discussed by Åhlström and Karlsson (2009), we opted for an intermediate approach, using a combination of data and theory to create our codes. The initial coding scheme comprised 11 coding rules based on the definitions of the 11 GMCs and MCCs included in the initial research protocol. However, we also drew upon our data to create a number of sub-codes capturing specific aspects of some of those capabilities. In the case of "robust process design" capability, for example, we generated three sub-codes to capture different ways in which the focal organization had improved its capacity to reuse existing organizational and value-chain resources to fulfill a stream of differentiated customer needs. Furthermore, whenever an incident could not be coded into any of the 11 initial GMCs and MCCs, we generated a new code, along with a tentative definition of the corresponding capability and coding rule. Subsequently, both the conceptual definition and the coding rule were refined based on relevant literature and further analysis of data.

At a later stage of the analysis, we came to realize that the aspects captured by our sub-codes cannot be considered as necessarily co-varying dimensions of the higher-order constructs that we had coded them into.[3] For example, the capacity to stay abreast of relevant environmental regulations, the capacity to stay abreast of relevant environmental technologies and the capacity to acquire customer information that is relevant to integrating environmental-sustainability principles into an organization's business are all specific aspects of a higher-order capability of environmental scanning for GM, but these aspects do not necessarily co-vary. Having realized that, we critically reviewed our coding scheme and defined a number of lower-level capabilities capturing specific aspects of the higher-order capabilities initially included in the coding scheme. Our final coding scheme is presented in Appendix B, while the conceptual definitions of the final set of GMCs and MCCs are provided in Appendix C, along with the complete list of the incidents coded into each capability. To help the reader see the connections between incidents and event constructs, Appendix C not only contains a short description of each incident, but also illustrates its consequences during the period of observation.

As recommended by Van de Ven and Poole (1990), we assessed the reliability and validity of the coding scheme. To alleviate the influence of subjectivity in the coding process, two researchers independently performed the coding of incidents into event constructs based on the final coding scheme. Disagreements concerned 16% of the incidents and were resolved through research group discussions based on construct definitions and, sometimes, additional information collected from key informants. Consider, for example, the introduction of a photocell system in the paint booth where plastic components were varnished using polluting solvent-based liquid paints (cf. PEC_OC08 in Appendix C). This incident had been coded into "pollution prevention" capability by one investigator and into "process environmental control" capability by the other. Reconsidering the definitions of the two capabilities, we eventually decided to code the incident into "process environmental control" capability. We did so because the source of pollution, that is solvent-based liquid paints, had not been eliminated with that change in the organization's routines and, consequently, an end-of-pipe technology for sucking and washing paint-laden air in the paint booth had continued to be utilized to control pollution.

To display the events indicated by the coded incidents in a clear chronological sequence, we created a time-ordered matrix (Miles and Huberman, 1994). The columns of this matrix were the 36 months of the observation period, the rows were the GMCs and MCCs of our final coding scheme and the entries were the incidents coded into each capability. Subsequently, we highlighted all the incidents that were common to different rows of the matrix. Drawing upon Hart (1995), we took a common incident as an indication of embeddedness, or overlap, between the corresponding capabilities, as the fact that two capabilities share a certain routine implies that the development of one of them facilitates the development of the other and vice versa. Consistent with the aim of our study, we systematically searched for common incidents among pairs of one GMC and one MCC, while the overlaps suggested by common incidents among two MCCs and the overlaps suggested by common incidents among two GMCs were not investigated further.[4]

Subsequently, for each pair of one GMC and one MCC, we asked ourselves if any prior incident coded into one capability had alleviated the costs, or had amplified the benefits, of any subsequent incident coded into the other capability. Answering this question required continuously weaving back and forth between the time-ordered matrix and the raw data pertaining to each pair of incidents in search of evidence that the routine involved in the prior incident had reduced the costs, or had increased the benefits, of the routine involved in the subsequent one. Whenever we found evidence of such a case, we considered such evidence as an indication of path dependence of the corresponding capabilities (cf. Hart, 1995; Barney, 1991). In an attempt to strengthen the sequence analysis, we also considered using autoregressive models to examine whether the values of one event construct at a certain time period influence the values of another event construct at a later time period. To that purpose, we transformed our qualitative codes into quantitative dichotomous indicators of event constructs, using "1" for presence and "0" for absence of a certain code of a qualitative incident, as recommended by Van de Ven and Poole (1990). However, we soon came to realize three main problems of our data: namely, (i) the ordered categorical nature of the event variables to be modeled, (ii) the large sparsity of the values that are different from zero and (iii) the shortness of the time series. These problems forced us to consider using nonparametric autoregressive models for ordered outcomes. In the end, however, we discarded this possibility, as in any case, in our situation, these models would produce possibly biased estimates of the model parameters and/or with large variability and comparative testing procedures with very low power (e.g., Fan and Yao, 2003; Lutkepohl, 2005; Hamilton, 1994).

All the relationships emerged from the sequence analysis were subsequently submitted to the criticism of key informants in order to check the credibility of interpretations and findings (cf. Dubé and Paré, 2003). Finally, we derived generalizations pertaining to the overlaps and path dependences that had emerged at the case company. Consistent with case study research methodology (cf. Glaser and Strauss, 1967; Yin, 2009), such generalizations relied on analytical/conceptual arguments.

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[3] We thank one anonymous reviewer for raising this point.

[4] For instance, this is the case of "parts commonalization" and "process standardization" capabilities, which share two incidents, and that of "pollution prevention" and "process environmental control" capabilities, which share three incidents.

4. Results

4.1. Embeddedness

4.1.1. "Solution space development" and "customers scanning for GM"

4.1.1.1. Empirical observation. At the case company, two changes in the organization's routines helped to improve both "solution space development" capability and "customers scanning for GM" capability. The first was the revision of the NPD process to include the routine of visiting customers of pre-series products and observing their behaviors in using the product (cf. CSG_JA10 and SSD_JA10 in Appendix C). During some of these visits, customers were seen modifying the settings of their products to enable the drying of hand-washed cars. The observation of this unexpected behavior improved the firm's understanding of market demand heterogeneity by making the organization understand that some of its customers needed a "drying-only" option which was not required by the rest of its target market. The observation of customers' spontaneous behaviors during product use also allowed the company to acquire customer information relevant to GM. Specifically, the firm uncovered that its customers typically overlooked the periodical maintenance activities required by the water purification system, even though they claimed water purification to be one of their main concerns. This observation made the company realize that its target customers were unwilling to put much effort into the maintenance of the water treatment system and, therefore, needed a very simple one.

The second change in the organization's routines that enhanced both "solution space development" capability and "customers scanning for GM" capability was the creation of a marketing department and the hiring of an experienced marketing manager (cf. CSG_NO10 and SSD_NO10). The new organizational unit took on responsibilities for such activities as market segmentation and competitive analysis, which were previously assigned to the sales department, and was endowed with competences in customer data collection and analysis that the sales department was lacking. This led to a finer segmentation of the company's target market. For example, by analyzing already available customer data and by collecting additional data through personal visits to key customers, the marketing manager understood that the segment comprising oil companies' car-service stations, which accounted for most of the firm's turnover in foreign markets, could be further divided in three sub-segments. Devoting specialized resources to market analysis was also a means of improving the firm's understanding of its customers' needs and priorities in the environmental domain. In early 2011, for example, a large-scale customer survey was designed under the supervision of the marketing manager to identify environmental problems encountered by customers. The results of that survey made the company realize, among other things, the opportunity to develop complementary services to help customers comply with environmental regulations.

4.1.1.2. Analytical generalization. The capacity to acquire customer information relevant to GM and the capacity to identify the product attributes along which customers' needs diverge are different dimensions of a higher-order capability of market sensing, that is the ability of a firm to learn about markets (Day, 1994). Market sensing is enhanced as marketing and sales are separate organizational units. Part of the reason for that is task specialization, which grows in importance as new technologies demand more analysis in both marketing and sales tasks (Cespedes, 1996): marketing and sales should not be the same unit because the functions they perform are different (Piercy, 2006; Le Meunier-FitzHugh and Piercy, 2009). Another part of the reason is that differences between marketing and sales may provide a much-needed breadth of perspective and richness of market understanding (Piercy, 2006). When marketing and sales are separate units, there are likely to be fundamental differences between them in perspective and priorities (Lorge, 1999; Rouziès et al., 2005; Piercy, 2006). The synthesis emerging from conflict over the diverse standpoints may be superior to the individual perspectives themselves (Homburg and Jensen, 2007), thus eventually enhancing business performance (Piercy, 2006). For example, Homburg and Jensen (2007) find that the different goal orientations and the different time orientations of separate marketing and sales units have a positive effect on a business unit's market performance. By enriching market understanding, separation of marketing and sales units enhances both "customers scanning for GM" and "solution space development" capabilities.

In addition, both "customers scanning for GM" and "solution space development" capabilities are improved by the employment of observational marketing techniques. These methods range from personal observation, carried out by an organization's staff, to recording customers' behaviors by means of technological instruments, such as digital video recording technology or the Internet (Lee and Broderick, 2007). Gathering self-report information about customers' actual behaviors in the environmental domain is difficult, as people asked about such ethical topics are unlikely to report any unsustainable behaviors (Roxas and Lindsay, 2012). Conversely, observation-based marketing research methods allow for collecting such sensitive information (Malhotra, 2002). This advantage is more appealing as the life-cycle environmental impact of a product depends more heavily on product usage, the product is more complex to use and customers are less concerned for environmental protection. Under these circumstances, there is a higher risk that customers do not use the product properly, thus worsening its life-cycle environmental impact. Such unsustainable behaviors, however, could be difficult to uncover using survey questionnaires or customer interviews, owing to social desirability bias.

The recording of customers' behaviors in either real or simulated experiences of product purchase and use also helps develop "solution space development" capability (Salvador et al., 2009). This is a complex and costly capability to build (Salvador et al., 2009), as it requires collecting and analyzing a great deal of information about individuals (Pine, 1993). The possibility to gather data about a wide variety of aspects without having to ask too many questions to the respondents is a distinctive advantage of observation-based marketing research routines, especially of those based on personal observation (Malhotra, 2002). This advantage is more appealing as a product is more complex and the number of product attributes along which customers' needs can diverge is higher. Based on the above arguments, we propose that:

> P1. *"Solution space development" capability and "customers scanning for GM" capability are embedded within one another. That is, the development of "solution space development" capability facilitates and accelerates the development of "customers scanning for GM" capability and vice versa.*

4.1.2. "Product stewardship" and "parts commonalization"

4.1.2.1. Empirical observation. At the case company, two changes in the organization's routines helped improve both "product stewardship" capability and "parts commonalization" capability. The first was the adoption of a new approach for product design review activities (cf. PST_NO09 and PAC_NO09 in Appendix C). This approach relied on a number of matrices where the considered design solutions were to be assessed in terms of their effects on both customer satisfaction and a number of cost items and where environmental-impact problems due to the considered design solutions were to be pointed out, if any. During the development of a new product family in 2010, for example, this approach revealed an environmental problem of the solution proposed by the R&D department to meet the sales department's request that the new products looked like greenery to reduce their esthetic impact in the urban landscape. The operations manager pointed out that the plastic careening that the R&D department was contemplating would have required a highly polluting painting process. The consideration of this environmental impact led to the adoption of an alternative design solution necessitating a less polluting painting process while still allowing the achievement of the desired product esthetics. The new approach for product design review activities also enhanced the organization's capacity to reuse the same component parts to fulfill a stream of differentiated customer needs. During the development of the product family mentioned above, for example, this approach brought to light that the traditional solution of painting a number of structural components in different colors would have caused high logistics costs–because of the high unit value of those components and the need for painting them based on sales forecasts–without improving customer satisfaction, as those parts were hardly visible to customers. The simultaneous consideration of such pieces of information led to the decision of standardizing the color of those components among all the products of the new product family.

The second change in the organization's routines that was beneficial for both "product stewardship" and "parts commonalization" capabilities was the involvement of the company's main suppliers in its NPD process (cf. PST_MR10 and PAC_MR10). This helped reduce the variety of the purchase materials employed in the three new product families developed between 2010 and mid-2011. For example, one supplier redesigned an electric component in such a way that its customization could be deferred to the phase of product assembly. This redesign enabled the company to purchase one generic component, instead of multiple component variants, and thus to enjoy a reduction in both purchase costs and inventory-holding costs that largely outweighed the increase in processing costs in the stage of product assembly. Supplier involvement in NPD also helped the firm design new products with minimal life-cycle impact. At the beginning of 2011, for example, one supplier suggested the adoption of electric motors that exceeded the efficiency requirements in force at that time and that the supplier was already supplying to other customers. Using such motors, the company succeeded in substantially reducing power consumption during product use.

4.1.2.2. Analytical generalization. Cross-functional integration is a process of interaction and collaboration in which an organization's functional departments exchange information and work together in a cooperative manner to arrive at mutually acceptable outcomes (Kahn, 1996; Kahn and McDonough, 1997; Pagell, 2004). Cross-functional integration enhances the capacity of a discrete-manufacturing company to reuse the same component parts to fulfill a stream of differentiated customer needs. Higher levels of component commonality are enabled by a modular product architecture (Ulrich, 1995) and by a platform approach to NPD (Robertson and Ulrich, 1998), both of which are facilitated by cross-functional integration. Platform-based product development consists in designing a family of products that address a related set of market needs and that share both product and process technologies (Meyer and Utterback, 1993; Jao et al., 2007). Platform-based product development requires making complex trade-offs in different business areas (Robertson and Ulrich, 1998). Common components, for example, can lower manufacturing costs but can also hinder the ability to extract price premiums through product differentiation (Desai et al., 2001). Close coordination among a firm's marketing, design and manufacturing departments helps make such trade-offs, thus facilitating platform-based product development (Robertson and Ulrich, 1998). Likewise, cross-functional integration helps design modular products (Lau et al., 2010; Zhang et al., 2014), that is products which are made up of separable modules that can be mixed and matched to create a variety of product configurations (Salvador, 2007). Cross-functional integration facilitates the transfer of the commonalities among customer demands into design characteristics and, ultimately, manufacturing instructions (Zhang et al., 2014). Furthermore, cross-functional integration is needed to specify product module interfaces in the early stages of development of a modular product and to solve unidentified design problems which may appear downstream in the NPD process (Lau et al., 2009; Lau et al., 2010). For the same reason, whenever product modules are outsourced to external partners, product modularity is also facilitated by supplier integration in NPD (Lau et al., 2010), which may range from simple consultation with suppliers on design ideas to making suppliers fully responsible for the modules they will supply (Petersen et al., 2005).

Both cross-functional integration and supplier involvement in NPD also help build "product stewardship" capability. To develop new products with minimal life-cycle environmental impact, every step of the value chain must be taken into account, from raw material procurement up to product disposal, as every step contributes to build up the environmental impact of a product (Hart, 1995; Higgins, 1995). Considering all these aspects requires information sharing among the organizational members involved at different stages of product life-cycle and necessitates engineers' willingness to value and accept information from all the organization's departments, including those with relatively low internal "status" (Lenox and Ehrenfeld, 1997). In addition, as companies are not directly involved in all stages of product life-cycle (Albino et al., 2012), they need to complement their experience and competencies by drawing on outside expertise (Geffen and Rothenberg, 2000). In particular, supplier involvement in NPD is of help, as suppliers can assist in understanding the environmental impacts of the product components they supply as well as in identifying ways of reducing such impacts (Lamming and Hampson, 1996). Based on the above arguments, we propose that:

> P2. *In a discrete-manufacturing company with product variety/customization, "product stewardship" capability and "parts commonalization" capability are embedded within one another. That is, the development of "product stewardship" capability facilitates and accelerates the development of "parts commonalization" capability and vice versa.*

4.1.3. *"Continuous improvement for MC" and "pollution prevention"*

4.1.3.1. Empirical observation. At the case company, three changes in the organization's routines helped improve both "continuous improvement for MC" capability and "pollution prevention" capability. The first was the beginning of the periodic analysis, by the R&D department, of the document where the production department had been reporting, since 2007, the product data errors detected during manufacturing operations, such as wrong dimensions in technical drawings or missing items in bills of materials (cf. PPR_MY09 and CMC_MY09 in Appendix C). Due to the traditionally high number of customer orders requiring ad-hoc engineering and the time constraints in the fulfillment of such orders, the technical product data of around 10% of the products of the car-wash business unit contained errors at the beginning of the observation period, and many of those errors remained unfixed even after being detected during manufacturing operations. The progressive correction of those errors, since May 2009, contributed to preventing such waste of resources as rework during final assembly, thereby improving both operational performance and environmental performance.

Another change that was beneficial for both "continuous improvement for MC" and "pollution prevention" capabilities was the establishment of a procedure for assembly operators' involvement in improvement actions (cf. PPR_JL10 and CMC_JL10). To that purpose, a box containing forms for workers to signal problems or make suggestions was positioned on the shop floor, close to product assembly stations. According to the procedure, workers' notifications and suggestions were to be analyzed by the operations manager, together with the production manager, on a weekly basis and, where relevant, would have been discussed with the R&D manager every two weeks. In addition, workers were to be informed of the implementation of any suggestions or would have been given explanation for their rejection. The systematic application of this procedure made assembly operators feel the importance of their contributions. As a result, the number of suggestions and problem notifications increased rapidly, leading to a total of almost 400 improvement actions implemented from the establishment of the procedure to mid-2011. Many of these actions consisted in the correction of technical drawings or bills of materials and the improvement of assembly sequences and product architecture. For example, assembly line operators signaled that a few structural components that were employed only in certain low-volume product variants did not fit with each other and, therefore, needed rework during final assembly, thus lowering the efficiency of the manufacturing process. The procedure of employees involvement also proved beneficial for pollution prevention. Specifically, assembly operators signaled that, because of the zinc-coating process performed by a subcontractor on some exterior and structural product components, the holes and threads of those components ended up with being covered. Consequently, those components needed rework during final assembly and small quantities of zinc powder were produced, which were hard to collect for disposal. The notification of this problem prompted the project for shifting such finishing activities down to the subcontractor's plant, which had specific equipment for the proper disposal of zinc powders.

Finally, both “continuous improvement for MC” and “pollution prevention” capabilities enhanced because of the adoption of a visual management tool to check the progresses of the projects approved by the R&D manager (cf. PPR_JL10 and CMC_JL10). The main benefit of this change in the organization's routines was to keep R&D employees focused on all the projects they had been formally assigned and to substantially reduce the amount of time they spent in supporting sales and post-sales personnel without the R&D manager's approval. Previously, because of this “hidden workload”, R&D employees were overloaded by more than 50% of their work capacity. As a result, they ended up with paying insufficient attention to the projects of improvement of existing products and processes and focused mainly on NPD projects. Many improvement projects were therefore completed with a delay of six months or more and 10% of them even failed to reach completion. Moreover, the insufficient attention given to that kind of projects sometimes impaired the quality of their results. By keeping R&D employees focused also on improvement projects, the adoption of the visual management tool increased the organization's capacity to incrementally enhance both operational performance and environmental performance.

4.1.3.2. Analytical generalization. A key resource underlying a firm's capacity to eliminate the sources of pollution in its manufacturing processes is continuous improvement (Hart, 1995), that is an organization-wide process of focused and sustained incremental innovation (Bessant and Francis, 1999). In a manufacturing company with product variety/customization, continuous improvement also underlies the capacity to sustain a stream of incremental innovations that reduce the adverse operational-performance implications of product variety/customization. A fundamental aspect of continuous improvement is a high level of involvement of all the employees of an organization in sustained incremental problem-solving (Bessant and Caffyn, 1997; Wu and Chen, 2006). Consequently, employees involvement plays an important role in improving the organizational capability of “pollution prevention” (Hart, 1995; Hanna et al., 2000). Identifying organizational areas where pollution prevention is viable is a complex task, which requires considering even ancillary operations, such as storage or materials handling, which can be sizable sources of waste and resource consumption (Higgins, 1995). Considering all the potential areas for pollution prevention would be impossible without the involvement of an organization's employees, who possess tacit knowledge of the operational processes, gained through their day-to-day working experience (Boiral, 2002; Renwick et al., 2013).

Similarly, employees involvement enhances the organizational capability of “continuous improvement for MC”. This is because, in many practical cases, products and processes are not perfectly modular (Schilling, 2000), as companies try to balance between the gains and the costs of decomposing a system into re-combinable modules (Mikkola, 2007). With non-perfectly modular architectures, the variety of parts and processes tends to increase (Ulrich, 1995) and, due to constraints on time and costs in product development, a company may choose to focus its engineering resources on those parts and processes that are employed in the most requested products of a family. Consequently, there is a risk that interface problems between parts or activities that are specific to low-volume product configurations are not detected until the production phase of those configurations. The risk of interface problems and, more generally, of errors in technical product data tends to further increase if the customization strategy of a company includes the possibility that a new product variant is ad-hoc engineered to meet the idiosyncratic needs of an individual customer, according to a pure customization strategy (Lampel and Mintzberg, 1996). In this case, engineering activities become part of the order fulfillment process and, consequently, tend to be subject to tighter constraints on time and costs. To resolve interface problems that may remain unidentified during NPD and, more generally, to correct errors in technical product data, it is essential that the employees involved in the manufacturing process voluntarily make suggestions and signal problems whenever they occur.

While employees involvement plays an important role in the continual discovery of ideas to enhance operational and environmental performance, continuous improvement also requires mechanisms for the selection and prioritization of improvement projects as well as for their effective implementation (Anand et al., 2009). In particular, mechanisms to maintain focus on established improvement goals must be put in place (Anand et al., 2009). This may be even more important when a company's customization strategy includes pure customization, as striking a balance between process improvement projects and NPD projects in the engineering department may become harder in that case. Practices gearing implementations of improvement projects toward purpose are, therefore, advantageous for both “pollution prevention” and “continuous improvement for MC” capabilities. Based on the above arguments, we posit that:

> P3. *In a manufacturing company with product variety/customization, “continuous improvement for MC” capability and “pollution prevention” capability are embedded within one another. That is, the development of “continuous improvement for MC” capability facilitates and accelerates the development of “pollution prevention” capability and vice versa.*

4.2. Path dependence

4.2.1. “Parts commonalization” and “environmental-performance reporting”

4.2.1.1. Empirical observation. At the case company, product life-cycle environmental impact was first assessed for the three new product families launched in 2011 and this assessment required determining raw materials, energy, water and detergents consumptions for those products (cf. EPR_AP10 in Appendix C). The costs incurred by the company to collect such consumption data were alleviated by the high degree of parts commonality that characterized those products. Those three product families were developed after the company's R&D personnel had been made aware of the negative implications of component proliferation to operational performance and after a new approach had been adopted to systematically evaluate possible design solutions in terms of their effects on operational performance (cf. PAC_NO09). By virtue of such changes in the organization's NPD routines, the three product families launched in 2011 ended up with sharing approximately 80% of their components. Consequently, many of the consumption data collected for the product family that was developed first were reused for the other two.

4.2.1.2. Analytical generalization. The capacity to inform external stakeholders about an organization's environmental performance goes beyond the obligatory reporting to the government and encompasses the voluntary disclosure of more comprehensive environmental information relevant to the general public (Lee and Klassen, 2008). Such a disclosure requires systematically collecting, analyzing and reporting a large amount of information about the consumptions of inputs (energy, iron,.) and the levels of pollution (carbon dioxide, waste water,.) caused by a firm's internal processes and products (Bremmers et al., 2009). The broader the variety of the components used by a discrete-manufacturing company to make a certain variety of products, the more the resources (instruments, labor hours,…) which are needed to assess the life-cycle environmental impacts of those products, as input consumptions and pollution levels need to be computed for a greater variety of elements. Conversely, prior development of the capacity to reuse the same component parts to fulfill heterogeneous customer needs reduces the variety of elements to assess and, therefore, the cost of developing "environmental-performance reporting" capability. Based on these considerations, we propose that:

> P4. *In a discrete-manufacturing company with product variety/customization, the cost of developing "environmental-performance reporting" capability decreases as "parts commonalization" capability increases.*

4.2.2. "Parts commonalization" and "greening the customers"

4.2.2.1. Empirical observation. During the development of the three new product families launched in 2011, the case company created a "green manual" providing customers with suggestions on how to use those products in an environmentally sound manner (cf. GCU_NO10 in Appendix C). To create such manuals, the company carried out a series of product tests to understand which wash cycles minimize the consumptions of energy, water and detergents under different usage conditions (e.g., different water characteristics, different outside temperatures,…) while preserving wash quality. The costs incurred by the case company to conduct such analyses and to create such manuals were alleviated by the fact that, by virtue of prior changes in the organization's NPD routines (cf. PAC_NO09), the three product families shared approximately 80% of their components. Consequently, many of the user guidelines created for the first product family were reused for the two developed subsequently and the respective "green manuals" ended up with being largely the same.

4.2.2.2. Analytical generalization. The capability of "greening the customers" requires that a company understands how its customers should behave to reduce the environmental impact of using, transporting, storing and disposing any of its products depending on the specific conditions of usage, transportation, etc. The amount of resources that a discrete-manufacturing company needs to invest to get such an understanding increases as the variety of the component parts used by the company to make a certain variety of products increases, because a greater variety of elements must be considered and different design solutions may require specific analyses. Conversely, prior development of the capacity to reuse the same component parts to fulfill heterogeneous customer needs reduces the variety of elements to consider and the amount of analyses to perform. Based on the above, we propose that:

> P5. *In a discrete-manufacturing company with product variety/customization, the cost of developing "greening the customers" capability decreases as "parts commonalization" capability increases.*

4.2.3. "Parts commonalization" and "product stewardship"

4.2.3.1. Empirical observation. The collaboration with a research institution (cf. PST_AP10) helped the case company redesign the air-drying module of the first of the three new product families launched in 2011 in such a manner that energy consumption during product use was reduced for that family. By virtue of prior changes in the organization's NPD routines (cf. PAC_NO09), the same module was then carried over the other two families. Consequently, that module ended up with being employed on a larger scale and the environmental benefits of its "green" redesign were amplified.

A similar amplification effect was also brought about by two changes in the firm's routines of customer order acquisition and customer order fulfillment, respectively. On the one hand, the automated generation of technical product data by a technical product configurator during the order fulfillment process (cf. PAC_SE09) reduced the risk of unduly proliferation of design solutions. Previously, the difficulty to retrieve bill of materials, technical drawings, etc. of an existing product variant sometimes led to manually recreating its product data from scratch when a new customer order for that product variant came in and, on that occasion, unnecessary variations in product design were sometimes introduced. The risk of unduly proliferation of design solutions was also reduced through the adoption of a sales configurator to support customer order acquisition (cf. PAC_JN10 and PAC_SE10). Previously, because of their insufficient training on the characteristics of the company's newly developed products, sales agents sometimes sold product variants requiring ad-hoc engineering even when fully pre-engineered solutions capable of fulfilling the same customer needs already existed within the firm's offer. Engineered-to-order products, in turn, sometimes ended up with having poorer environmental performance than the ones already included in the company's solution space, owing to time and cost constraints in customer order fulfillment. For example, this was the case of a product variant developed at the beginning of 2009 on a to-order basis to satisfy a customer's request for a product that could wash under a car body. The company's solution space already included a product variant with the requested feature and both energy and water consumptions resulted higher for the ad-hoc engineered solution than for the existing one.

4.2.3.2. Analytical generalization. In a discrete-manufacturing company, the development of "product stewardship" capability leads to designing products whose components have reduced environmental impact, such as components with more recyclable materials (Maxwell and van der Vorst, 2003). Clearly, the environmental benefits of investing resources in the "green" design of a certain component are greater if that component is utilized in higher volumes, given the same variety of products. This is what happens if the company has previously developed the capacity to reuse the same component parts to fulfill heterogeneous customer needs. Therefore, we posit that:

> P6. *In a discrete-manufacturing company with product variety/customization, the positive effect of "product stewardship" capability on environmental performance increases as "parts commonalization" capability increases.*

5. Discussion

The findings of this research contribute to the debate on the relationships between the different dimensions of sustainability (e.g., Russo and Fouts, 1997; Rao and Holt, 2005; Surroca et al., 2010; Seuring, 2013). More specifically, this study provides insight into the linkage between, on the one hand, the economic sustainability of a firm facing both highly heterogeneous demand and intense competition and, on the other hand, the firm's environmental sustainability. For such a company, economic sustainability requires fulfilling each customer's idiosyncratic needs without substantial trade-offs in cost, delivery and quality (Pine, 1993; Bardakci and Whitelock, 2003; Huang et al., 2008), which in turn necessitates the development of a number of MCCs (e.g., Salvador et al., 2009). Likewise, environmental sustainability requires that the firm develops a number of GMCs, including "customers scanning for GM", as suggested by Anderson and Bateman (2000), "pollution prevention" (Hart, 1995) and "product stewardship" (Hart, 1995). The embeddedness relationships posited in our paper indicate that the development of these three GMCs facilitates and accelerates the development of the three MCCs of "solution space development", "continuous improvement for MC" and "parts commonalization", thus ultimately reinforcing the economic pillar of sustainability as well. This finding echoes, in the specific context of a discrete-manufacturing firm offering product variety/customization and facing intense competition, the results of previous studies which find that a number of GM actions, such as implementation of pollution prevention technologies, improvement of the environmental impact of products through appropriate design solutions and surveillance of the market for environmental issues, are positively associated with economic performance dimensions (e.g., Klassen and Whybark, 1999; Montabon et al., 2007; Schoenherr, 2012; Gimenez et al., 2012).

In addition, the path dependences posited in our paper indicate that a discrete-manufacturing firm offering product variety/customization and facing intense competition is better positioned to implement GM and, therefore, to build the environmental pillar of sustainability, if it has previously taken at least one step in the direction of reinforcing also the economic pillar of sustainability–that is, if it has previously developed the MCC of "parts commonalization". This is because product variety/customization increases the costs of developing the GMCs of "environmental-performance reporting" and "greening the customers" as well as decreases the environmental benefits of building the GMC of "product stewardship", but these negative effects of product variety/customization are mitigated if the MCC of "parts commonalization" has been developed in advance. This result echoes those of prior studies, which find that the successful implementation of GM requires that assets such as total quality management processes (e.g., Darnall and Edwards, 2006), which reinforce the economic pillar of sustainability (e.g., Nair, 2006), have been built beforehand.

By investigating the interconnectedness of MCCs and GMCs, the present paper also adds to the individual strands of research on MC and GM, respectively. Our study indicates that "product stewardship" and "parts commonalization" capabilities are embedded within one another because they share routines of internal and external integration in NPD. This finding echoes those of previous studies, in the two streams of research, which point to the importance of high levels of internal and external integration for achieving MC (e.g., Salvador et al., 2004; Liu et al., 2012; Lai et al., 2012; Trentin et al., 2012; Zhang et al., 2014) and GM (e.g., Hart, 1995; Albino et al., 2012), respectively. Likewise, our paper indicates that "pollution prevention" and "continuous improvement for MC" capabilities are embedded within one another because they share routines of employees involvement in sustained incremental problem-solving as well as routines for the selection and prioritization of improvement projects and for their effective implementation. This result is consistent with those of previous studies that point to the enabling role played by continuous improvement in the pursuit of MC (e.g., Liu et al., 2006; Kristal et al., 2010) and GM (e.g., Hart, 1995; De Ron, 1998; Yang et al., 2010), respectively.

6. Conclusions, limitations and future research opportunities

This paper has empirically investigated the interconnectedness of MC and GM on the level of their enabling capabilities. Our results support the existence of overlaps and path dependences between individual GMCs and individual MCCs. Overlaps, or embeddedness relationships, capture the fact that the GMC and the MCC involved in the relationship share some organizational routines that form a strong foundation for both capabilities. As a result, the development of one capability facilitates and accelerates the development of the other and vice versa. Instead, path dependences capture the fact that prior development of a certain MCC alleviates the costs, or increases the benefits, of building a certain GMC, but not vice versa. Collectively, these results indicate synergies that firms facing the joint challenge of MC and GM may leverage in order to alleviate the difficulty of that challenge. In particular, these results provide some insights into what sequences of improvement of MCCs and GMCs increase the chances of successfully coping with the challenge of implementing a green MC strategy in a discrete-manufacturing context.

The present study is not without limitations, which might be addressed in future research. A first set of limitations derives from the choice of conducting a single case study with no embedded units of analysis and from the characteristics of the organization selected for the study. Our research design precluded the possibility of taking advantage of replication logic to strengthen the validity of our findings (Yin, 2009), for example using Van de Ven and Poole's (1990) phase analysis to identify and compare developmental patterns of GMCs and MCCs across different units of analysis. Furthermore, a few characteristics of the selected organization, that is its being a discrete manufacturer with product variety/customization, limit the validity of several of our propositions. Other characteristics of the selected organization, such as its making complex products whose life-cycle environmental impact heavily depends on how customers use them or its providing a high degree of product customization, could be circumstances under which some of the synergies posited in our paper are stronger. As the degree of product customization decreases, for example, the positive effects of "parts commonalization" capability on the costs of developing "environmental-performance reporting" and "greening the customers" capabilities could become weaker. Our research, however, involved only one unit of analysis and, therefore, these remain conjectures which should be examined in future studies. Although we have done our best to consider possible boundaries of validity of our propositions, we are aware that it is difficult to foresee all the contextual limits on a theory's applicability before the initial theoretical statement is tested in a broad variety of settings (Whetten, 1989). Additional limits of generalizability, as well as relevant contingencies, could therefore be unveiled by future qualitative and quantitative studies which seek to replicate, confirm or augment the results of our study in a different research setting, across multiple settings simultaneously, or within larger statistical samples. Future quantitative studies, for example, could test the path dependences posited in our paper using the approach employed by Darnall and Edwards (2006) to test their hypothesis that an organization's prior expertise with quality-based and inventory-control management systems alleviates the cost of adopting an environmental-management system. As for the embeddedness relationships proposed in our paper, future quantitative studies could test them by testing the hypotheses that the organizational capabilities embedded within one another are positively associated.

A final set of limitations of the present study derives from the characteristics of our data and from the focus of our research. As explained in Section 3.3, our data precluded the possibility of using more sophisticated and powerful methods for sequence analysis, which could have helped us to go beyond "subjective eye-balling" (Van de Ven and Poole, 1990: 327) and "to find regularities or patterns that might be hidden in the material" (Åhlström and Karlsson, 2009: 223). In addition, our focus on the interconnectedness of GMCs and MCCs led us to neglecting possible overlaps and path dependences among MCCs or among GMCs, as well as possible trade-offs between these two sets of capabilities. Future studies should seek to overcome these limitations in order to provide managers with richer indications on what developmental paths may lead to success and failure when coping with the joint challenge of MC and GM. Finally, the social pillar of sustainability remained out of the scope of this study and additional research could be devoted to including social sustainability in the debate.

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Appendix A. Initial semi-structured interview protocol[a]

Organizational capability[b]	Key informants[c]	Questions
Green management		
Product stewardship (Hart, 1995)	R&D, MD	What does the business unit (BU) do to design products with minimal life-cycle environmental impact?
Pollution prevention (Hart, 1995)	OM, R&D	What does the BU do to abate the pollution caused by its manufacturing processes at the source?
GM integration into strategic planning (Hart, 1995; Judge and Douglas, 1998)	MD, R&D, OM, SM	What does the BU do to explicitly consider environmental issues within its strategic-planning process?
Process environmental management (Lee and Klassen, 2008)	OM, R&D	What does the BU do to sustain manufacturing processes that meet or exceed environmental regulations?
Organization environmental management (Lee and Klassen, 2008)	MD, I&QS	Are environmental responsibilities clearly assigned within the BU and how? Is environmental training provided to employees and how?
Supply chain environmental management (Lee and Klassen, 2008)	OM, MD	What does the BU do to ensure that its supplier base is “green”? What does the BU do to reduce the environmental burdens caused by its logistics activities?
Relationship environmental management (Lee and Klassen, 2008)	MD, SM	What does the BU do to sustain sound relationships with its external stakeholders as regards environmental issues (e.g., environmental reporting, active management of environmental claims,…)?
Mass customization		
Solution space development (Salvador et al., 2009)	SM, R&D, MD	What does the BU do to understand the product characteristics along which its customers' needs diverge?
Choice navigation (Salvador et al., 2009)	SM, I&QS, MD	What does the BU do to reduce the effort put by its customers into identifying their own solutions within its offer?
Robust process design (Salvador et al., 2009)	OM, R&D, MD	What does the BU do to reuse or recombine existing organizational and value-chain resources (product parts, manufacturing tools and equipment, human resources, suppliers' resources,…) in the fulfillment of differentiated customers needs?
Logistics (Zipkin, 2001)	OM, I&QS	What does the BU do to make sure that the product solution ordered by each customer ultimately reaches the customer?

[a] In the subsequent rounds of semi-structured interviews, the questions were slightly modified to understand what had changed since the previous interview round.

[b] See Sections 2.3 and 2.4 for the definition of each organizational capability.

[c] I&QS: information and quality systems manager; MD: managing director; OM: operations manager; R&D: research and development manager; SM: sales manager and, since November 2010, marketing manager.

Appendix B. Final coding scheme

Organizational capability	Incident code	Coding rule: an incident is coded into the corresponding capability if it represents the establishment of a new organizational routine, or a change in an existing one, which improved the ability of the BU to:
Green management		
Product stewardship[a]	PST_MMYY[g]	Design new products with minimal life-cycle environmental impact.
Pollution prevention[a]	PPR_MMYY	Eliminate the emissions, effluents and waste caused by its own manufacturing processes at the source, rather than simply reducing the incidence or severity of pollution.
GM integration into strategic planning[a]	GMS_MMYY	Explicitly consider and proactively tackle environmental issues within its own strategic-planning processes.
Organization environmental management[a]	OEM_MMYY	Integrate environmental issues into daily business routines by clearly assigning environmental responsibilities within the organization and by providing environmental training to employees.

Process environmental control[b]	PEC_MMYY	Reduce the incidence or severity of the pollution caused by its own manufacturing processes while not eliminating the sources of pollution in such processes.
Greening the supply process[c]	GSP_MMYY	Incorporate environmental considerations in the selection of its own suppliers.
Logistics environmental management[c]	LEM_MMYY	Reduce the environmental impact of its own logistics activities.
Environmental-performance reporting[d]	EPR_MMYY	Collect environmental-performance data and report them to external stakeholders.
Greening the customers	GCU_MMYY	Advise and, where relevant, educate and support its own customers in the environmentally sound use, transportation, storage and disposal of its own products.
Customers scanning for GM	CSG_MMYY	Acquire information about customers' needs, priorities and behaviors that is relevant to integrating environmental-sustainability principles into its own business.
Regulations scanning for GM	RSG_MMYY	Stay abreast of environmental regulations that are relevant to its own products and processes.
Technological scanning for GM	TSG_MMYY	Stay abreast of technological solutions developed outside the firm that have the potential for reducing the life-cycle environmental impact of its own products.
Mass customization		
Solution space development[a]	SSD_MMYY	Identify the product attributes along which its own customers' needs diverge.
Choice navigation[a]	CHN_MMYY	Reduce the effort put by its own customers into identifying the product solutions that best meet their needs within its own solution space.
Parts commonalization[e]	PAC_MMYY	Reuse the same component parts (including purchased materials) to fulfill differentiated customer needs.
Process standardization[e]	PRS_MMYY	Reuse the same manufacturing processes (i.e., transformation activities and the physical and human resources needed for such activities) to fulfill differentiated customer needs.
Suppliers flexibilization[e]	SUF_MMYY	Reuse the same supplier processes (i.e., supplier's transformation and logistics activities as well as the physical and human resources needed for such activities) to fulfill differentiated customer needs.
Logistics for MC[f]	LMC_MMYY	Deliver the right product solution to the right customer, in the right quantity and condition, at the right time and place, in an efficient manner.
MC integration into strategic planning	MCS_MMYY	Explicitly consider and proactively tackle, within its own strategic-planning processes, the potential trade-off between satisfaction of customers' idiosyncratic needs and operational performance.
Continuous improvement for MC	CMC_MMYY	Continuously improve existing products and processes in such a way that the adverse operational-performance implications of product variety/customization are reduced.

[a] Included in the initial research protocol.

[b] It captures a particular dimension of the “process environmental management” capability initially included in the research protocol.

[c] It captures a specific dimension of the “supply chain environmental management” capability initially included in the research protocol.

[d] It captures a particular dimension of the “relationship environmental management” capability initially included in the research protocol.

[e] It captures a specific dimension of the “robust process design” capability initially included in the research protocol.

[f] Based on the “logistics” capability initially included in the research protocol.

[g] “MMYY” is the part of the incident code that indicates the month and year of occurrence of the incident (e.g., JN10 indicates June 2010).

Appendix C. Final list of organizational capabilities and corresponding incidents

Organizational capability	Organizational capability definition	Incidents (incident code: summary of the incident and evidence supporting the coding of the incident into the organizational capability)
Product stewardship	Capacity to design new products with minimal life-cycle environmental impact (Hart, 1995).	PST_JA09: The company began a long-term collaboration with a design firm which would have been systematically involved in NPD projects to help the R&D department develop new products with more recyclable materials. For example, this partnership led to the use of aluminum for many structural components of the new products developed afterward; PST_NO09: Design review activities (included in the NPD process) started to take advantage of a new approach (based

		on the "house of quality" technique) intended to help a cross-functional team (comprising operations manager, R&D manager and sales manager, or marketing manager since November 2010) to systematically evaluate possible design solutions in terms of their effects on several performance dimensions, including environmental performance (initially considered in a qualitative manner and subsequently assessed in a more quantitative way–cf. PST_MR10). For example, in May 2010, a design solution for the careening of a new product family was discarded because of its environmental impact and a different more environmentally sound solution was chosen; PST_MR10: Following the positive results of a few collaborations with suppliers (cf. TSG_FE09), the company decided to systematically involve its main suppliers in its NPD projects. One supplier of electric motors, for example, helped the company substantially reduce power consumption during product use; PST_AP10: The company began a long-term collaboration with a consultancy company which would have been systematically involved in NPD projects to assess product life-cycle environmental impact. The collaboration started with the assessment of three new product families planned to be launched in 2011. The results of that life-cycle assessment (LCA) project helped the R&D department identify a number of aspects that it would have had to focus on (e.g., product disposal) to reduce the life-cycle environmental impact of future product generations; PST_AP10: The company began a long-term collaboration with two research institutions which would have supported the R&D department in developing new products with minimal life-cycle environmental impact by providing knowledge base and laboratory testing in the areas of fluid dynamics, renewable energies, materials science, architecture and acoustics. For example, one of these partners helped perform complex fluid dynamics analyses that enabled the R&D department design an air-drying module that reduced energy consumption during product use.
Pollution prevention	Capacity to abate the emissions, effluents and waste caused by an organization's manufacturing processes by eliminating the sources of pollution in those processes, rather than by controlling pollution with end-of-pipe technologies (Hart, 1995).	PPR_JA09: To prevent the waste of water, the company introduced a monitoring system inside the paint booth, where water was employed to wash paint-laden air. The system would have issued an alarm in case of abnormal water consumption, for example because of pipe breakages. In addition, a rule was established to empty water pipes in case of very low temperatures in order to prevent pipe breakages such as the one happened during the previous end-of-year closure of the plant; PPR_MY09: The R&D department started to systematically analyze, on a monthly basis, the document (called "defects file") where the production department had been reporting, since 2007, the product data errors detected during manufacturing operations. As a result, around 83% of the errors listed in the "defects file" were fixed by the end of 2010, for a total of over 800 improvement actions carried out up to that date; PPR_JA10: The company adopted a new, nanotechnology-based process for the pre-treatment of metal components before powder-coating. This pre-treatment process did not require zinc phosphates and, therefore, prevented the creation of special waste; PPR_FE10: The company started to periodically analyze power consumption data to identify drivers of power consumption on the shop floor. As a result of this analysis, for example, summer work shifts were modified in the painting department so as to schedule its activities on the most favorable part of the day and thus reduce power consumption (10% less with respect to the previous year); PPR_JN10: Establishment of a new procedure to abate the environmental impact of internal processes: every six months, the health and safety officer would have analyzed environmental-impact data

		(cf. OEM_JN10) and would have created a document reporting the identified problems of poor environmental performance of internal processes. Subsequently, the managers in charge of those processes would have developed improvement plans to eliminate the identified sources of pollution or at least to reduce their incidence or severity. For example, to eliminate a source of waste, a system for water recycling was introduced in the paint booth in early 2011; PPR_JL10: Establishment of a procedure for collecting, analyzing and giving feedback on assembly operators' suggestions and notifications of problems. As a result of this procedure, the rework of purchase zinc-coated components during final assembly was eliminated. Such rework activities were a source of polluting zinc powders which were very difficult to collect for disposal; PPR_JL10: Following a training program on kaizen principles, the R&D department started to use a visual-management tool to weekly check the progresses of both NPD projects and product/process improvement projects. As a result, R&D employees cut their “hidden workload” (due to assistance requests from sales and post-sales personnel) by 30%, thus increasing their capacity to carry out improvement projects according to the original schedule and with satisfactory results.
GM integration into strategic planning	Capacity to integrate environmental issues into an organization's strategic-planning process and decisions (Hart, 1995; Judge and Douglas, 1998).	GMS_JL08: As a result of the managers' turnover begun in May 2008, the new top management team was made up of people who regarded a proactive environmental strategy as an effective means of differentiating the company's offer from the competitors' ones. Conversely, the company had not gone beyond compliance with environmental regulations in the previous years. The new attitude of the top management team drove its strategic decision to launch a project (supported by a consultancy company) for the revision of the corporate vision and mission to reflect the firm's commitment to environmental sustainability. In addition, environmental sustainability became a key issue in the subsequent top-management-team meetings for the definition of the product strategy of the BU, even though the team did not comprise an environmental manager (only occasionally, these meetings were joined by the health and safety officer, a lower-level manager with a number of environmental responsibilities–cf. PPR_JN10). The centrality of environmental issues during such meetings is witnessed, for example, by the strategic decision to apply for an environmental product declaration (EPD®) for three new product families to be launched in 2011; GMS_FE09: The review of the corporate vision and mission to reflect the firm's commitment to environmental sustainability, the subsequent redesign of the corporate logo in accord with the new vision/mission and the meetings held to disseminate the new mission/vision within the company increased the attention to environmental issues on all management levels of the company.
Organization environmental management	The capacity to integrate environmental issues into daily business routines by building an environmental-management system that clearly assigns environmental responsibilities and provides environmental training to employees (Lee and Klassen, 2008).	OEM_MR10: Revision of the company's safety manual to include environmental issues. The new “environment and safety” manual identified, for example, the employees in charge of managing environmental emergencies; OEM_JN10: Following an external audit (contracted by the company when application for ISO14000 was being considered), the “environment and safety” manual was updated by adding a section devoted to environmental-performance improvement. That section indicated the health and safety officer as the responsible for periodically collecting and analyzing environmental-impact data (e.g., consumptions of water, energy,…) with the aim of identifying improvement opportunities (cf. PPR_JN10); OEM_SE10: The health and safety officer increased the frequency of the meetings devoted to training warehouse personnel on environmental issues

		(e.g., handling of chemicals, chemical safety data sheets, management of forklift batteries, etc.).
Process environmental control	Capacity to abate the emissions, effluents and waste caused by an organization's manufacturing processes by controlling pollution rather than by eliminating it at the source.	PEC_OC08: Introduction of a photocell system in the paint booth where plastic components were varnished using polluting solvent-based liquid paints. After one component was completely varnished, the photocell system stopped paint-spraying until the subsequent piece along the chain conveyor reached the right position in the paint booth. In this manner, the consumption of polluting paints decreased. Yet, that source of pollution was not eliminated and an end-of-pipe technology for sucking and washing paint-laden air in the paint booth was still necessary to reduce the severity of the pollution caused by painting operations; PEC_AP10: The company introduced a system for the recovery and reuse of waste powder paints; PEC_JN10: Establishment of a new procedure to abate the environmental-impact of internal processes (cf. PPR_JN10): every six months, the health and safety officer would have analyzed environmental-impact data and would have created a document reporting the identified problems of poor environmental performance of internal processes. Subsequently, the managers in charge of those processes would have developed improvement plans to eliminate the identified sources of pollution or at least to reduce their incidence or severity. For example, insulating panels were installed to control noise pollution in the outdoor area of the plant where product test activities were carried out; PEC_JL10: Establishment of a procedure for collecting, analyzing and giving feedback on assembly operators' suggestions and notifications of problems (cf. PPR_JL10). A few suggestions (e,g., placing a basket for separate collection of rubbish close to each assembly station or moving a shelf to reduce air current from the plant warehouse to the shop floor) helped control pollution, for example by reducing unsorted waste and heating emissions; PEC_JL10: Following a training program on kaizen principles, the R&D department started to use a visual-management tool to weekly check the progresses of both NPD projects and product/process improvement projects (cf. PPR_JL10). As a result, R&D employees cut their "hidden workload" (due to assistance requests from sales and post-sales personnel) by 30%, thus increasing their capacity to carry out improvement projects according to the original schedule and with satisfactory results.
Greening the supply process	Capacity to incorporate environmental considerations in an organization's purchasing activities.	GSP_NO10: Following the purchasing manager's deep involvement in the LCA project for three new product families (cf. PST_AP10), buyers were instructed to preferably select suppliers capable of providing evidence of good environmental performance. In case none of the company's existing suppliers met this requirement, the purchasing manager would have probed their willingness to improve on that aspect or else would have considered new suppliers. For example, one supplier of plastic components was replaced with another who was capable of supplying fully recyclable parts.
Logistics environmental management	Capacity to reduce the environmental burdens caused by an organization's logistics activities.	LEM_AP09: Creation of a procedure for the disposal of polluting chemicals (used in the pre-treatment of metal pieces before varnishing) at their expiry dates. Previously, it was not uncommon that cans of expired chemicals remained in the plant warehouse for a long time, thus increasing the risk of environmental accidents; LEM_JL10: Within the context of a broader reorganization of the plant warehouse, dangerous materials were re-slotted on the lowest shelves of the warehouse to reduce the risk of environmental accidents. In addition, fastest-moving materials and slowest-moving materials were re-slotted so as to reduce the emissions due to internal transportation activities with forklifts.

Environmental-performance reporting	Capacity to report information to external stakeholders about an organization's environmental performance.	EPR_AP10: The company began a long-term collaboration with a consultancy firm which would have been systematically involved in NPD projects to assess product life-cycle environmental impact (cf. PST_AP10). Within the context of this partnership, the company would have collected data (e.g., energy, water and raw materials consumptions for its products) which the consultants would have used for LCA calculations; EPR_NO10: The NPD process was revised to include the creation of a “green manual”. Among other things, such a manual would have reported information about the environmental impact of product use (e.g., energy and water consumptions per wash cycle, noise level,…) In accord with the revised procedure, the R&D department created the “green manuals” of all the new products launched starting from 2011; EPR_FE11: After the obtainment of an EPD® for three new product families, the marketing department started to disseminate EPD® documents reporting third-party certified data on the life-cycle environmental impact of such products on the company's website as well as among its customers. Previously, the reporting of environmental-impact information to external stakeholders had not gone beyond fulfillment of legal obligations.
Greening the customers	Capacity to advise and, where relevant, to educate and support customers in the environmentally sound use, transportation, storage, and disposal of products.	GCU_DE09: The company started to systematically promote the use of a low-polluting detergent–developed by one of its suppliers (cf. TSG_FE09)–among its customers by (i) providing a sample of that detergent together with every car-wash equipment sold to a customer and (ii) giving customers the supplier's contact details for future supplies of the same detergent. The adoption of that detergent by several customers contributed to reducing the environmental impact of product use; GCU_AP10: Following a series of tests performed by the R&D department to find out the optimal dosage of detergents under different climate conditions, both the employees in charge of product installations and post-sales personnel were instructed to suggest that customers dose detergents differently in summer and in winter (tests had shown that, with higher outside temperatures, the dosage of detergents could be reduced by 20% without deteriorating wash quality); GCU_NO10: The NPD process was revised to include the creation of a “green manual”. Among other things, such a manual would have provided customers with guidelines for the environmentally sound use of the new product being developed (beyond mere compliance with environmental regulations). In accord with the revised procedure, the R&D department created the “green manuals” of all the new products launched starting from 2011.
Customers scanning for GM	Capacity to acquire customer information that is relevant to integrating environmental-sustainability principles into an organization's business.	CSG_JA10: In light of the positive results of a number of customer visits made at the end of 2009, the company revised its NPD process to include regular visits (by a multifunctional team comprising sales, post-sales and R&D personnel) to customers who had bought pre-series products and had used them for at least three months. By virtue of such regular visits, the company understood that its customers needed a simpler system for water purification. Otherwise, they would have continued overlooking periodical maintenance activities of that system, such as regeneration of exhausted chemicals, which were important to alleviating the environmental impact of product use; CSG_SE10: Following their involvement in the LCA project for three new product families (cf. PST_AP10), post-sales personnel became more effective at recognizing (e,g., during their regular visits to customers with pre-series products) customers' behaviors that could worsen product life-cycle environmental impact. For instance, post-sales personnel noticed that customers typically wasted

		energy, water and detergents because of their inability to choose the optimal settings of their car-wash equipments according to the varying usage conditions. These pieces of information highlighted customers' unfulfilled needs for a simpler regulation system and for better advice on the environmentally sound use of the company's products (cf. GCU_NO10); CSG_NO10: In light of the valuable customer information acquired through a campaign of customer interviews conducted in the previous months, the company created a marketing department headed by an experienced marketing manager. This enabled the company to understand, for example, the opportunity to develop complementary services to help customers comply with environmental regulations.
Regulations scanning for GM	Capacity to stay abreast of relevant environmental regulations.	RSG_SE08: The company began to regularly take advantage of the services provided by a government agency for environmental protection and prevention. In this manner, the firm increased its capacity to stay abreast of developments of relevant regulations concerning waste water effluents and, more generally, industrial-waste management. Instead, relevant environmental regulations concerning products and product components continued to be monitored by the R&D department.
Technological scanning for GM	Capacity to stay abreast of relevant environmental technologies.	TSG_FE09: Through regular visits to key suppliers (3–4 times a year) and suppliers' fairs (1–2 times a year) as well as by regularly scanning industry periodicals, the new R&D manager started to systematically collect information on suppliers' technological innovations that could help the company reduce product life-cycle environmental impact (instead, the former R&D manager had focused technological scanning almost exclusively on cost reduction). This broader scope of technological scanning enabled the company, for example, to find out a chemicals supplier who was highly proactive from an environmental standpoint and had a lot of green products for a variety of applications. By virtue of its specialized environmental expertise, that supplier was able to develop a green detergent for car-wash applications, which was systematically promoted by the company among its customers (cf. CGU_DE09). The scanning of green technological developments also led to the adoption of a greener process for the pre-treatment of metal components before powder-coating (cf. PPR_JA10); TSG_JL09: The R&D department, with the support of the sales department, started to systematically analyze competitors' products in terms of environmental performance and environmental solutions adopted. In this manner, the company found out, for example, that one of its competitors was using high-efficiency reduction gearboxes, which were subsequently adopted by the company as well.
Solution space development	Capacity to identify the product attributes along which customers' needs diverge (Salvador et al., 2009).	SSD_SE09: As a result of a project involving R&D and sales departments, some of the 16 functions and performance dimensions traditionally used by the sales department to describe customers' needs were further specified. For example, the traditional notion of "high wash quality" was specified by distinguishing 12 dimensions of that concept and such a specification allowed the firm to understand that, for car-service stations (but not for car dealers or car rent service providers), "high wash quality" also means producing a lot of vapor during car wash (the so-called "scenic effect", which influences the car owner's perception of car-wash quality); SSD_JA10: The company revised the NPD process to include regular visits to customers who had bought pre-series products (cf. CSG_JA10). By virtue of such regular visits, the company understood that some of its customers needed equipment giving them the possibility of drying hand-washed cars; SSD_NO10: Creation of a marketing department

		(cf. CSG_NO10). This enabled the company to understand, for example, that the so-called “scenic effect” (cf. SSD_SE09) was more important to car-service stations in Eastern Europe and less important to the same type of customers in Germany. Conversely, the wheel wash option was of lower value to car-service stations in Eastern Europe than elsewhere in Europe.
Choice navigation	Capacity to support customers in identifying their own solutions while minimizing complexity and the burden of choice (Salvador et al., 2009).	CHN_FE09: Establishment of a new procedure for customer order entry, which prescribed that all the orders submitted by sales agents would have been checked for configuration errors by sales back-office personnel. Furthermore, any corrected orders would have been resubmitted to the respective agents for final customer validation before entering the order into the company's information system. As a result of this new procedure, sales agents started to pay a greater attention to what they offered to customers, and sales configuration errors almost halved. Consequently, recycles between salespersons and customers decreased and so did the effort put by customers, on average, into identifying their own solutions; CHN_DE09: The company started to use sales agents' training meetings to disseminate market segmentation knowledge (codified into a document periodically revised by the sales department–cf. MCS_NO09) among sales agents and to train these latter on how to exploit such knowledge to support customers in their purchase decisions (e.g., by suggesting options typically chosen by the “average” customer in the respective market segment); CHN_JN10: The sales agents operating in the domestic market started to use a sales configurator. This reduced the risk that customers were not asked about their preferences on certain product features just because agents did not recall such features, as well as the risk that inexpert agents proposed “typical” configurations even when better-fitting configurations were available within the company's solution space (as often happened before). Furthermore, the sales configurator provided images and detailed textual explanations that helped sales agents better explain the benefits of the available product options; CHN_SE10: Following translation of the configuration dialog modeled in the sales configurator into a number of foreign languages, the company extended the use of the sales configurator to foreign sales channels; CHN_MR11: The process of new product launch was revised to include a more in-depth training of sales agents on the characteristics of newly developed products. Such a training, along with the use of the sales configurator, enabled sales agents to more effectively present newly developed products to potential customers and to better support customers' choices on such products. That contributed to the positive sales trend of the new products launched in 2011, which was stronger than the trend typically observed after the launch of a new product in the previous years.
Parts commonalization	Capacity to reuse the same component parts to fulfill a stream of differentiated customer needs.	PAC_SE09: Start of the restructuring of the existing manufacturing bills of materials (with the definition of an appropriate part/product coding scheme) and of the existing assembly sequences. While the existing manufacturing bills had only two levels (i.e., end products and purchase materials), the restructured bills (as well as any new manufacturing bill) would have included intermediate levels, whose items would have been associated with only one work center and with only one product function. In addition, the company began to model the revised/new manufacturing bills and assembly sequences in the existing technical product configurator to automatically generate such product data during order fulfillment. Previously, the manual generation of technical product data and the difficulty to retrieve them had contributed to the unduly proliferation of product components (e.g., there were numerous variants of dosing pumps

		which were not necessary); PAC_NO09: End of a training program of R&D employees through both seminars on component carry-over/standardization and visits to the shop floor to better understand the negative implications of component proliferation to operational performance. As a result of that training, more R&D employees systematically considered component carry-over/standardization in their engineering decisions during NPD projects, as witnessed by the increase in the percentage of common components among the BU products (the percentage raised approximately from 40% in 2008 to 80% in 2011) and by the reduction of NPD lead-times (the development of the three product families launched in 2011 required the same time span that the development of one single family had typically required before); PAC_NO09: Product design review activities started to take advantage of a new approach intended to help a cross-functional team systematically evaluate possible design solutions in terms of their effects on several performance dimensions, including a number of cost items and customer satisfaction (cf. PST_NO09). This favored, for example, the standardization of the color of a number of structural components of the three new product families developed between 2010 and mid-2011; PAC_MR10: Establishment of a procedure for the involvement of main suppliers in the NPD process (cf. PST_MR10). For example, one supplier redesigned a family of electric components in such a way that the same component could be easily customized by the company during product assembly according to the product variant on which the component was to be mounted; PAC_JN10: The sales agents operating in the domestic market started to use a sales configurator (cf. CHN_JN10). The use of this software application prevented the risk that salespeople unduly sold product solutions requiring ad-hoc engineering and the ensuing risk of parts proliferation; PAC_SE10: The company extended the use of the sales configurator to foreign sales channels (cf. CHN_SE10); PAC_SE10: One senior product engineer, who had always opposed component carry-over/standardization, was moved from the product development office to the research office. This helped increase the percentage of common components among newly developed products; PAC_OC10: Establishment of a new procedure for the acceptance of customer orders requiring ad-hoc engineering. According to this new procedure, any request falling outside the company's pre-engineered solution space would have been accepted only with the permission of the managing director after careful examination of the following aspects: consistency with the BU product strategy, estimated development lead-time, availability of manufacturing resources, and expected contribution margin. This procedure further reduced the number of engineered-to-order products (cf. PAC_SE10), which decreased by 90% from 2009 to 2011.
Process standardization	Capacity to reuse the same manufacturing processes to fulfill a stream of differentiated customer needs.	PRS_JA09: Creation of written work instructions for final-assembly operators in order to standardize product assembly operations. Previously, such operators used to perform their tasks mostly by memory and, over time, had developed their own work procedures, which could vary from one operator to another. As a result, it was not uncommon that products supposed to be identical were actually assembled in different ways (e.g., with different types of wiring or with the same component mounted in different positions), thereby causing problems in the subsequent stages of product testing and installation. Besides preventing such problems, standardization of assembly operations allowed for redesigning production layout so as to increase productivity (e.g., 10% less direct-labor hours per product unit) by creating mix-model assembly lines; PRS_SE09: Start of the restructuring of the existing manufacturing bills and assembly sequences and progressive modeling of the revised/

		new technical product models in the existing technical product configurator (cf. PAC_SE09). The automated generation of technical product data prevented the risk that an ad-hoc assembly sequence were designed even when an adequate sequence already existed, just because it was too laborious to retrieve the related product data; PRS_NO09: Product design review activities started to take advantage of a new approach intended to help a cross-functional team systematically evaluate possible design solutions in terms of their effects on several performance dimensions, including operational performance (cf. PST_NO09). That approach favored the choice of design solutions that could be produced using available manufacturing resources, as happened for example with the module moving the vertical brushes of the three new product families developed between 2010 and 2011; PRS_FE11: Establishment of a new procedure which prescribed that, whenever possible, the generic assembly sequence of a new product family (to be modeled in the technical product configurator) would have been created only by combining standard sub-sequences approved by the operations manager. Otherwise, the operations manager (with the support of the production manager) would have estimated the lead-times and costs associated with a new sub-sequence and would have decided whether to include the new sub-sequence among the approved ones or to require engineering changes to the R&D department.
Suppliers flexibilization	Capacity to reuse the same supplier processes to fulfill a stream of differentiated customer needs.	SUF_MY10: Creation of a procedure for supplier evaluation and development. According to this procedure, critical suppliers (e.g., suppliers of costly components) would have been rated along a number of operational-performance dimensions and supplier risk factors (e.g., delivery dependability, value of goods returned, company size and ownership, breadth of the supplier's customer base, etc.). As a step in this procedure, an inter-functional team (comprising purchasing, quality and production personnel) would have visited the supplier's plant(s) on a yearly basis to assess aspects such as machine set-up times and production-planning routines, which influence supplier flexibility. Furthermore, in case of poor supplier performance, an inter-organizational team would have been created to address the problem. In late 2010, for example, the collaboration with one supplier of plastic components led to improving its mix flexibility: the supplier's molds were re-designed in such a way that 10 different components could be produced with just three molds instead of the 10 previously needed, thereby reducing set-up times and alleviating minimum lot size constraints; SUF_SE10: Beginning of a supplier base restructuring program supported by a consultancy company. While historically the supplier base of the BU had been highly fragmented, one of the goals of this program was to reduce the number of suppliers of non-critical purchase items, thus increasing the company's capacity to reuse the same supplier resources to fulfill heterogeneous customer needs. For example, the firm switched from multiple sourcing to single sourcing for a number of metal components, and this enabled the creation of an open-order system with call-offs and no minimum lot size constraints for such components.
Logistics for MC	Capacity to plan, implement and control an efficient flow of materials and products that fulfills a stream of differentiated customers demands (adapted from Zipkin, 2001).	LMC_DE10: As a result of a project launched a few months before, a new procedure for sales forecasting and master production scheduling was adopted. The company continued to purchase the majority of its materials (especially the most expensive ones, such as the structural components of the product) based on sales forecasts, as purchasing and production stacked lead-time largely exceeded customer-expected delivery lead-time. In the past, however, materials gross requirements had been forecasted using a planning bill

		whose coefficients was based only on historical sales data, with no input from the sales department (a few months earlier, for example, the sales department had launched a promotion without informing the operations department and that lack of communication had caused many problems of inventory stock-out and delivery delay). To take advantage of the latest demand-mix information available to the sales/marketing (since November 2010) departments, the new procedure prescribed that materials would have been purchased based on judgmental forecasts concerning market demands for the various options of a number of critical product-differentiating attributes. Furthermore, such attribute-based forecasts would have been progressively revised as new demand-mix information became available and would not have been frozen until purchase orders for the corresponding components had to be released (with different frozen intervals according to the component sourcing lead-times). As a result of this new procedure, the accuracy of demand-mix forecasts increased by 60%.
MC integration into strategic planning	Capacity to integrate the issue of the potential trade-off between fulfillment of customers' idiosyncratic needs and operational performance into an organization's strategic-planning processes and decisions.	MCS_JL08: As a result of the managers' turnover begun in May 2008, the top management team included a managing director, an operations manager and an R&D manager who had already faced the challenge of MC and who, therefore, brought a much greater attention to the issue of improving operational performance while preserving product customization. Conversely, operational performance (particularly, quality and costs) had significantly worsened during the previous years for the very reason that the degree of product customization offered by the BU had progressively increased. Such a greater attention to MC is witnessed by the launch of a number of projects for MC, such as the “product configurator” project, which was rated by the managing director as the most important improvement project of 2009; MCS_NO09: Following the restructuring of manufacturing bills of materials and assembly sequences (cf. PAC_SE09), the management control office became able to more accurately estimate the cost of a product that was under consideration for development, based on the functionalities that the sales department was contemplating to include in that product. At the same time, in order to support strategic planning, the sales department started to codify its market segmentation knowledge in a document (to be periodically revised) reporting information on desired product functions, desired performance levels, target price as well as competitors' offerings for each market segment. During the product-planning meeting of November 2009, for example, this document made it clear to the top management team that the BU was weak in the car dealers segment (which needed car-wash equipment less performing but with a relatively low price). At the same time, the more accurate cost estimates that the management control office was able to generate made it clear that the costs for better fulfilling the specific needs of that market segment would have been too high unless the BU had succeeded in significantly increasing the degree of component commonality among its products.
Continuous improvement for mass customization	Capacity to continuously generate a stream of incremental innovations that reduce the negative operational-performance implications of product variety/customization.	CMC_NO08: The R&D department started to collaborate with the post-sales department to more regularly get information on the quality problems dealt with by post-sales personnel, as well as on the costs incurred to fix such problems. In addition, the R&D department adopted a more systematic approach for the analysis of those pieces of information (e.g., analysis of problem occurrences by product family and problem class), which improved its capacity to identify common sources of problems across the high variety of engineered-to-order product variants and components that characterized the company's offer at that time. For example, brush-moving carriage wheels were identified as the common source of a

series of problems frequently reported by post-sales personnel. Additionally, the R&D department adopted a more systematic approach for the development of improvement solutions (clear definition of improvement objectives and systematic consideration of the implications of the contemplated design solutions to manufacturing through direct contacts between individual product engineers and production supervisor); CMC_MY09: The R&D department started to systematically analyze and fix the product data errors detected during manufacturing operations (cf. PPR_MY09); CMC_NO09: End of a training program of R&D employees (cf. PAC_NO09). As a result, more R&D employees systematically considered the operational-performance implications of their engineering decisions during improvement projects; CMC_JA10: Re-engineering of the product test phase. Previously, the R&D department had sometimes failed to give precise product test instructions, owing to its heavy workload for the fulfillment of customer orders falling outside the company's predefined solution space. In addition, product test at the end of the assembly process had sometimes been skipped in an attempt to minimize product delivery delays whenever the fulfillment of a production order was very late. The new procedure prescribed that (i) no NPD project would have been closed without the creation of product test instructions, (ii) no products would have been delivered to customers before testing and (iii) any quality problems detected at that stage would have been systematically reported to, and analyzed by the R&D department. For example, a reliability problem affecting the rim wash system of certain product variants was identified and resolved as a result of this procedure in the second half of 2010; CMC_JL10: Establishment of a procedure for collecting, analyzing and giving feedback on assembly operators' suggestions and notifications of problems (cf. PPR_JL10). As a result, many problems of product architecture and errors in technical product data were uncovered and corrected; CMC_JL10: Following a training program on kaizen principles, the R&D department started to use a visual-management tool to weekly check the progress of both NPD projects and product/process improvement projects (cf. PPR_JL10). As a result, R&D employees cut their “hidden workload” (due to assistance requests from sales and post-sales personnel) by 30%, thus increasing their capacity to carry out improvement projects according to the original schedule and with satisfactory results.

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