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The contribution of IT-leveraging capability for collaborative product development with suppliers

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ABSTRACT

This paper investigates how Information Technology (IT) leveraging capability supports buyer-supplier collaboration in New Product Development (NPD). IT-leveraging capability is defined as the ability to effectively use IT functionalities to support IT-enabled NPD activities. We consider three dimensions of this capability: effective use of Project and Resource Management Systems (PRMS), effective use of Knowledge Management Systems (KMS) and effective use of Cooperative Work Systems (CWS). We consider the dynamics between these three dimensions, which have usually been treated as equal. Using an in-depth case study approach, we show that effective use of KMS and CWS are key dimensions to support collaboration, creating a unique source of competitive advantage. On the other hand, while effective use of PRMS does not help to create differentiation it is important to support the coordination of KMS and CWS. Furthermore, the three dimensions have different intensities of contribution depending on the NPD stage and supplier involvement configuration.

Introduction

Suppliers play an important role in New Product Development (NPD) as a source of innovation and knowledge for product firms (Le Dain and Merminod, 2014). Although the literature highlights collaborative NPD with suppliers as an important activity (Sambamurthy et al., 2003; Ylimäki, 2014), firms may face challenges when involving suppliers. The main reasons reported in previous works are problems in managing external knowledge and the increase of project complexity that requires more coordination of the cooperative tasks and resources between partners (Banker et al., 2006; Lau, 2011; Loebbecke et al., 2016). Information technology (IT) tools are proposed to support such activities and reduce the challenges of suppliers' involvement (Bell et al., 2012; Boonstra and de Vries, 2008; Enrique et al., 2018; Frank and Echeveste, 2012); these are especially important when buyer and supplier are geographically distant (Chen and Tsou, 2012). For instance, commercial IT tools for remote project management (i.e., with cloud access) allow partners to jointly plan and schedule projects with resource assignments, team member task management, and real-time analytics (Frank et al., 2015). Other commercial IT tools are proposed for managing information and knowledge from dispersed NPD teams, such as product-related documents, lessons learned and content (Frank et al., 2015). Moreover, some IT tools allow real-time virtual joint design between remote NPD teams (Frank et al., 2015). These are some of the many options supported by

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IT tools for collaboration with suppliers in NPD.

However, companies need to do more than simply adopting IT tools to support NPD, since this narrow vision frequently leads to limited value in return for the high levels of investment made (Fichman and Nambisan, 2009; Teo and Ranganathan, 2003; Bharadwaj 2000). Firms need to combine IT tools with other internal resources (e.g., people, physical goods, information) to create IT capability, i.e., the ability to use IT tools correctly to create value for the company (Bharadwaj, 2000; Stoel and Muhanna, 2009). Moreover, when buyer and supplier work in a collaborative NPD, IT capability depends on the effective use of the combination of IT tools and resources from both firms, i.e., it is an interfirm IT capability (Rai et al., 2012; Nambisan, 2003). Pavlou and El Sawy (2010, 2006) have conceptualized 'IT leveraging capability' in the context of NPD as a three-dimensional construct that capture how the functionalities of three IT systems – *Project and Resource Management System (PRMS), Knowledge Management System* (KMS) and *Cooperative Work System* (CWS) – are leveraged.

NPD is usually represented as a stage-gate process consisting in five main stages (Cooper, 2008): Scoping, Business Case, Development, Testing & Validating and Launch. In the case of interfirm collaborative NPD, the development of IT-leveraging capability requires an understanding of how teams interact throughout the NPD process (Banker et al., 2006; Nambisan, 2003). This is because the use of the different IT functionalities in the IT tools influences each NPD stage differently (Durmuşoğlu and Barczak, 2011). Durmuşoğlu and Barczak (2011) demonstrated that the positive effect of the use of specific IT tools on NPD performance varies according to each stage of the NPD process. This is also the reason why different forms of supplier involvement may require different resources to support them (Ayala et al., 2017; Le Dain and Merminod, 2014). The dynamics of the interactions between the project teams (customer and supplier) depend on which of three types of supplier involvement is in play (Petersen et al., 2005): black box (design is supplier driven), grey box (joint design) and white box (design is customer driven).

However, little is known about how supplier involvement can affect the IT capability needed during the NPD process. While some prior works have considered certain combinations of these variables (Marion et al., 2016; Reid et al., 2016), there is a research gap regarding the combination of supplier involvement types and the required IT-leveraging capabilities at different stages of the NPD process. This creates practical difficulties, when managers have to define specific IT tools that provide specific functionalities to support NPD activities in this collaborative context. Thus, we propose the following research question: *how do the IT-leveraging capability dimensions (*i.e. *effective use of PMRS, KMS and CWS) contribute to collaborative NPD with suppliers when the different NPD stages and supplier involvement types are considered?*

To answer this question, we investigate the specific IT-leveraging capability dimensions needed in each of the NPD stages (Scoping, Business Case, Development, Testing & Validating and Launch) when three different types of supplier involvement are adopted (white, grey and black box). We combine these elements in a conceptual framework that is used for a case study analysis of a multinational firm in the agriculture machinery sector. We investigate the intensity of the IT-leveraging capability dimensions required in the different NPD stages and for different forms of supplier involvement, providing a clearer spectrum of requisites that should be supported by the functionalities of IT tools. As a result, the main contribution of this paper is that we provide a detailed description of how the combination of IT-leveraging capability, NPD stages and collaboration types work together. This creates a new base for future research on specificities of IT tools and systems for collaborative NPD. It also provides support for IT practitioners who need to understand what functionalities should be considered when implementing IT tools in collaborative NPD with suppliers.

Theoretical background

Supplier involvement in the new product development process

NPD has been considered as a process with several stages of activities that start with the product scoping and end with the product launch. One of the most widespread NPD models is the 'stage-gate model' proposed by Cooper (2008). It consists of five main stages representing activities that the firm should address during the NPD process. The first stage, 'Scoping', is dedicated to a preliminary investigation of the project with the objective of determining market size and market potential. The second stage, 'Build a Business Case', includes product and project definition, project justification and project plan. The third stage, 'Development', involves the detailed design and development of the new product as well as of the production process. The fourth stage aims at 'Testing and Validating' the new product and its manufacturing process. Finally, 'Launch' is the fifth stage, focused on product commercialization activities, production ramp-up and training of the sales force.

Digital transformation has allowed companies to integrate NPD activities with third-party stakeholders, including suppliers and customers as active parties in product value creation (Dalenogare et al., 2018; Frank et al., 2019a). Customer involvement has been seen as one of the most important sources for creating new market value (Frank et al., 2019b; Marodin et al., 2018; Paslauski et al., 2016) and as a source of innovation ideas (Sambamurthy et al., 2003); while supplier involvement has been considered one of the most important sources for technological innovation in NPD (Chung and Kim, 2003; Johnsen, 2009). Assuming that these two stakeholders play different innovation roles in the NPD process and require different approaches for their involvement in NPD activities, in this study we choose to focus specifically on one of them, the supplier. The supplier is usually considered as a key external partner in product innovation, especially when firms face technological challenges (Ayala et al., 2017; Johnsen, 2009). Suppliers play an important role as they may possess specific knowledge and technology relating to product components or systems (Ragatz et al., 2002; Wang et al., 2008). NPD with suppliers can also help reduce product design flaws as well as time-to-market and costs, which also means better customer satisfaction levels (Ragatz et al., 2002; Sjoerdsma and van Weele, 2015; Ylimäki, 2014).

Depending on project complexity and risk, firms (buyers) can take different decisions as to how they involve suppliers in the NPD process (Langner and Seidel, 2009; Le Dain et al., 2010; Peng et al., 2014). Petersen et al. (2005) distinguish three basic types of collaboration: black box, white box and grey box. In *Black Box* the supplier is responsible for both design and manufacturing activities, based on product requirements provided by the buyer (Petersen et al., 2005). In *White Box* the buyer is mainly responsible for design decisions and specifications, while the supplier is responsible for processing and manufacturing activities based on buyer specifications (Petersen et al., 2005). Finally, the *Grey Box* configuration is characterized by closely integrated co-creation activity (Le Dain and Merminod, 2014; Petersen et al., 2005). In this case, neither the buyer nor the supplier has the knowledge or the capacity to fully execute the development activities (Koufteros et al., 2007).

Prior research has shown that these three types of involvement have different implications for the dynamic of interaction between the buyer and supplier, influencing the way information and knowledge is exchanged and products are developed (Ayala et al., 2017; Le Dain and Merminod, 2014). We extend this prior research by considering that these three types of supplier involvement will have differing intensity of interaction with the product firm during the NPD stages. IT tools may provide different support in different types of collaboration.

IT capability to support supplier involvement in NPD

IT capability is rooted in the dynamic capability concept, which is defined as the ability of a firm to integrate, build and reconfigure internal and external competences to better adapt to changing environments (Teece et al., 1997). In the IT context, Sambamurthy and Zmud (2000) define IT capability as the combination of IT-based assets and routines to support a firm's value-adding activities. Additionally, Bharadwaj (2000) defines IT capability as the ability to mobilize and deploy IT resources in combination with a firm's existing resources and capabilities. IT assets and functionalities can be generic and imitable; however, IT capability is dependent on how these IT assets and functionalities are used, implemented and combined with other resources, thus making it a unique source of competitive advantage (Rai et al., 2012).

While IT capability is usually seen as something internal to each firm (Bharadwaj, 2000), in an interfirm collaborative NPD process, IT capability should be treated from a relational viewpoint (Dyer and Singh, 1998). As stated by Rai et al. (2012), in this context, IT capability should be developed as an 'interfirm capability' which is built on sets of IT functionalities combined with other resources from both firms (e.g., people, physical goods, information) in order to manage the interdependencies of interfirm business processes. Thus, interfirm IT capability is developed jointly between partners who need to use common IT tools to obtain collaborative advantage (Banker et al., 2006; Rai et al., 2012). As Nambisan (2003) points out, NPD partners may differ in their IT capability, so information systems need to be flexible to take such differences into account. In the context of value co-creation, previous studies have shown that an IT-enabled coordination of interfirm processes allows firms to obtain better performance from collaboration (Rai et al., 2012; Sambamurthy et al., 2003), and in particular for NPD performance (Fichman and Nambisan, 2009; Nambisan, 2003; Reid et al., 2016).

Following the argument of Ray et al. (2005) that IT capability should be examined at the process level and not at the firm level, Pavlou and El Sawy (2006, 2010) conceptualized the concept of IT leveraging capability in the context of NPD. They define IT-leveraging capability in NPD as '*the ability to effectively use IT functionalities to support IT-related NDP activities'*. They propose three main dimensions that represent this construct. The first dimension, effective use of *Project and Resource Management Systems (PRMS)*, includes the functionalities of planning meetings, time management, and resource management for each NPD stage. This category includes the use of IT to determine the true availability of people, skills, and resources to enable appropriate task assignment. Evaluation of the project progress is also included in this category. The second dimension, effective use of *Knowledge Management Systems (KMS)*, includes the functionalities of knowledge sharing between members of the NPD project team by means of virtual interaction, knowledge storage and recovery, identification of knowledge experts, and other functionalities that support knowledge flows among teams. The third dimension, effective use of *Cooperative Work Systems (CWS)*, refers to the effective use of technologies that enable collaborative work. CWS functions include the definition of structures, configurations and routines of the teams; the manipulation of the contributions of the teams; and the coordination of team interaction routines. CWS aim to support activities that NPD teams perform jointly, allowing communication in real time, collaborative product design, brainstorming, and the convergence of ideas to reach group consensus and find new solutions (Carlile, 2004).

The three IT-leveraging capability dimensions for IT-enabled NPD activities proposed by Pavlou and El Sawy (2006) have been broadly acknowledged and used in both information system and innovation management literature. In Table 1, we extend the analysis made by Peng et al. (2014) by summarizing prior research on these dimensions. As seen in this table, some authors have considered more detailed dimensions, but these are still encompassed by the three main dimensions proposed by Pavlou and El Sawy (2006). For instance, Peng et al. (2014) presented a fourth dimension related to product design IT tools, such as CAD software, but this type of IT tool could be included in Pavlou and El Sawy's (2006) more generic dimension CWS as it supports cooperative work. Pavlou and El Sawy (2006, 2010) developed the IT-leveraging capability concept and its dimensions without distinguishing between intra and interfirm NPD. The fact that IT capability should be observed at the NPD process level (Ray et al., 2005) makes this concept generalizable for both intra and interfirm NPD collaborative processes.

Conceptual framework for the research

In the light of the theoretical background presented, we developed an analytical framework to guide our case study analysis, as presented in Fig. 1. The framework relates the different types of supplier involvement according to the Petersen et al. (2005) taxonomy (i.e., Black, Grey and White Box configuration) to the main NPD stages proposed by Cooper (2008) (i.e., Scoping, Business Case, Development and Testing). For each of the possible combinations of these two variables, we consider the relevance of Pavlou

Table 1
Studies related to the IT-leveraging capabilities dimensions for IT-Enabled NPD activities.

Author	Intra or interfirm	Groups of IT-Enabled NPD activities		
(Pavlou and El Sawy, 2006)	No differentiation	**Project and resource management**	**Knowledge management**	**Cooperative work**
(Rangaswamy and Lilien, 1997)	No differentiation	Project management Team management		Decision making
(Nambisan, 2003)	Intra and Interfirm	Project management Process management	Information and knowledge management	Collaboration and Communication
(Sambamurthy et al., 2003)	Intra and Interfirm	Process management	Knowledge management	Communication
(Gordon and Tarafdar, 2007)	Intrafirm	Project management	Information and knowledge management	Collaboration and Communication
(Barczak et al., 2008)	Intra and Interfirm	Project management	Information and knowledge management	Communication and collaboration Product development
(Chen and Li, 2010)	Intra and Interfirm	Project and process management	Knowledge management	Collaboration management
(Song and Song, 2010)	Intrafirm		Decision -aiding	Communication
(Pavlou and El Sawy, 2010)	No differentiation	Project and resource management	Organizational memory	Cooperative work
(Peng et al., 2014)	Intra and Interfirm	Project management	Product data and knowledge management	Communication Product Design
(Mauerhoefer et al., 2017)	Intrafirm	Project and resource management	Information and knowledge management	Collaboration Product development
(Kroh et al., 2018)	Intra and Interfirm	Project and process management	Information and knowledge management	Collaboration Product development

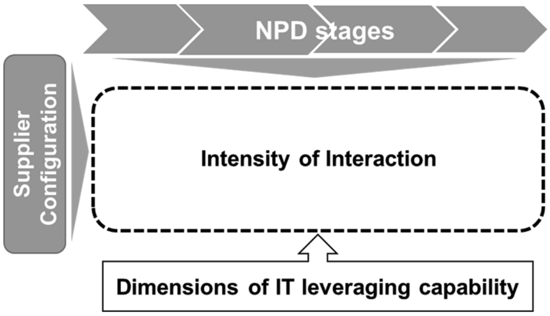

Fig. 1. Conceptual Framework.

and El Sawy's (2006) IT-leverage capability dimensions (i.e., PRMS, KMS and CWS). This allows us to understand in detail the IT-leveraging capability requirements related to each NPD stage and each type of supplier involvement. Our main assumption is that the importance of effective use of PRMS, KMS and CWS may differ during the NPD stages and for different supplier involvement types.

Research method

We adopted an empirical case study research approach based on qualitative data collection and analysis (Yin, 2009). As stated by Tsang (2014), case studies are an important method for theory building in Strategic Information System research, providing an in-depth understanding of different phenomena. We also used the proposed conceptual framework (Fig. 1) to underpin our research and to guide our empirical data collection. Research design was based on the Voss et al. (2002) guidelines for case studies in management, which are described next.

Case study selection

The case was selected by means of theoretical sampling. According to Eisenhardt and Graebner (2007), theoretical sampling means that cases are selected because of their suitability for shedding light on particular constructs. For this study we were specifically seeking a manufacturing firm that met certain criteria. First, the firm should have developed new products with suppliers in the three types of configurations described by Petersen et al. (2005). Second, we took into account the risk related to the development of the product delegated to supplier since the higher the risk, the greater the need for collaboration between buyer and supplier (Le Dain et al., 2010) and, thus, the higher the need for IT-leveraging capability. For this reason, the firm studied should have at least one risky NPD project for each supplier involvement configuration. Following these criteria, the firm chosen was a multinational manufacturer of tractors and harvesters in the agricultural sector, hereinafter named AGRO. Our unit of analysis was a collaborative NPD project with suppliers. Three main co-development projects were selected, one for each of the supplier configurations (i.e., black, grey and white box). To identify a black box project, we asked the NPD managers to select the most representative project of this configuration, i.e., a project in which they judge that AGRO's supplier was clearly responsible for both the design activity and the industrialization activity, based on AGRO's requirement specifications (Le Dain and Merminod, 2014). To identify a white box project, we asked the same managers to identify the most representative case in which AGRO was in charge of design and specification decisions about the product, but industrialization and manufacturing activities were delegated to a supplier (Le Dain and Merminod, 2014). Finally, to identify a grey box project, we asked them to select the most representative case in which the design activity required close collaboration between AGRO and its supplier and for which neither AGRO nor the supplier possessed the knowledge and ability to execute the design activity entirely by themselves. Once a list of projects was identified, the NPD managers discussed the suitability of each and we asked them to select only one for each collaboration type, which should also be the most high-

Table 2
Interviewee descriptions.

Interviewee's position in the firm	Abbreviation	Years of experience in the firm
Project Manager 1	PM1	2.5
Project Manager 2	PM2	7
Project Manager 3	PM3	5
Engineering Manager 1	EM1	3.5
Engineering Manager 2	EM2	12
Engineering Manager 3	EM3	3.5
Purchaser 1	Purchaser 1	18
Purchaser 2	Purchaser 2	4
Purchaser 3	Purchaser 3	10

risk for each category. In the AGRO case, the project risk is defined by a board composed by four top managers: the vice-president (VP) of supply chain, the VP of operations, the VP of continuous improvement and the VP of finances. They defined the risk of a project based on factors such as technical complexity, probability of return of investments, business impacts, among others.

Research instruments

We employed semi-structured interviews as a primary source of data collection. The interview questions were developed based on information from the literature and following the conceptual framework (Fig. 1). We evaluated the level to which each of the three specific IT-leveraging capabilities (i.e., PRMS, KMS and CWS) are needed at each NPD stage and for each of the supplier involvement types. For this purpose, we used an interaction intensity scale, asking the interviewees to self-assess according to the following five-point scale: 0 = very low interaction; 1 = less than once a week; 2 = once a week; 3 = at least twice a week; 4 = almost everyday interaction. The questions were structured using the following generic sentence: *Considering the collaborative project 'X' [*i.e.*, one of the three: black, grey or white box], what was the intensity of interaction with the supplier for PRMS, KMS and CWS activities [*i.e.*, the three IT-leveraging capability dimensions] during each of the stages of the NPD process?*) We also provided descriptions of what is understood by PRMS, KMS and CWS activities and assisted the interviewees with explanations if they had any doubts regarding this in their practice. We also asked them to provide arguments and examples for each assessment of the intensity, in order to ensure that they understood clearly what they were describing. In addition, interviewees were asked to describe in detail which and how IT tools were used to support their interactions with suppliers during the NPD process, if the IT tools were used jointly by both buyer and supplier, and if there were any problems (particularly problems due to a non-effective use of IT functionalities or lack of tools to support collaborative NPD activities).

When discrepancies were identified between interviewees or other sources, we used a second and third round of interviews to clarify these differences until consolidated and convergent agreement about collaboration intensity was achieved.

The conceptual framework was developed around four of the five NPD stages proposed by Cooper (2008). The research focuses on the effective use of IT capability to support collaborative NPD activities with suppliers. In this respect, the contribution of the supplier in the development activities of the buyer is mainly effective during the upstream phases of the NPD process. For this reason, we did not consider the final stage – product launch, which essentially refers to product commercialization activities. We considered each stage with regard to the three dimensions of IT-leveraging capability. Moreover, the NPD stages and dimensions of IT-leveraging capability were examined for the three configurations of buyer–supplier collaboration. This resulted in 36 potential combinations of the framework that could be analyzed in terms of the intensity of collaboration with suppliers.

Data collection

For data collection, we used different sources of information to improve the reliability of our analysis (Yin, 2009). Therefore, we interviewed nine persons from different departments of the firm. These persons participated directly in the NPD projects (see Table 2 for details). All interviewees were from the main firm (buyer), and the firm provided us with information about the suppliers. We did not collect data from suppliers since access to them was restricted by the firm because of the strategic and sensitive nature of the information required. Due to the complexity of the information requested, we sent an outline of the research protocol to the interviewees a few days before the interviews, so that they could prepare and collect the documentation to support their statements, as suggested by Voss et al. (2002).

Interviews were conducted face-to-face on the firm's premises. On average, each meeting took around one hour and a half. We used an audio recorder and written notes to record the impressions and comments from participants during the interviews. Notes were taken by four researchers: this approach helped us contrast and compare impressions from each researcher during the interviews, thus allowing us to obtain a more complete view of each case and reduce observer bias, as suggested by Yin (2009). After analyzing the interview transcriptions, we conducted a fresh round of interviews with the same respondents (each lasting from 1 to 1.5 h) to clarify and hone details or questions that remained from the first round. To assure data triangulation, we reviewed company documents relating to the project, such as contracts, stage-gate deliverables, internal procedures and process descriptions. The entire data collection process was conducted from May 2016 to March 2017, and it comprised almost 25 h of recorded conversations (18 interviews) and 91 pages of transcriptions.

Data analysis

As a first step in data analysis, the recorded interviews were transcribed. Once all the interviews from a particular project had been transcribed, several meetings were conducted between the four researchers involved in the data collection process to extract all the information from the notes, transcriptions and collected documents. The collected data was analyzed to seek evidence confirming the stated (Petersen et al., 2005) buyer–supplier configuration and the intensity of collaboration associated with each of Pavlou and El Sawy's (2006) key dimensions. The results were structured and organized into a draft case study report for each project. The third round of interviews was used to show this draft to the interviewees and aimed at collecting feedback on our interpretation as well as new information for cases where convergence had not been reached. Finally, we contrasted the results of the case analysis with the literature and developed a final theoretical framework.

In this research, we adopted the three approaches suggested by Yin (2009). To increase construct validity, we triangulated multiple sources of evidence; we maintained a chain of evidence; and we organized the exchanges with practitioners and other

Table 3
Black Box Project – Tractor Engine – Interaction Analysis.

NPD Stage	Intensity of Key dimension activities		Description of case study	Observed Problems
1. Scoping	PRMS	Very low	*"The budget and planning data defined by us were far removed from the real ones"* (PM2)	
	KMS	Low	"*At this stage, consultations with suppliers were practically zero, we [AGRO] contacted them [by e-mail or phone] just for small queries that we had about legislation*" (Purchaser 2).	
	CWS	Very low		
2. Business Case	PRMS	High	*"Operational resources were mostly from the supplier. However, we [AGRO] actively participated in the validation of the development plan"* (EM1). *"We regularly asked by e-mail for updates of product definition progress"* (Purchaser 2).	
	KMS	High	"*We [AGRO and supplier] had weekly meetings by voice call and everyday communication by e-mail" (EM3). "[At the end,] the supplier sends us a concept version in 3D CAD of the engine just to see how it fits inside the tractor […] and to analyze the cost of the parts*" (EM3).	
	CWS	Low	"*The supplier's engineering team has to develop the product according to the layout and specification that we [AGRO] developed*" (Purchaser 1). *"The supplier sometimes disagreed with the solutions we proposed, and we [AGRO] and [supplier] need to talk by videoconference in order to reach a solution that meets the needs of the project"* (EM2).	
3. Development	PRMS	Low	"*Only if the supplier was behind schedule with the prototype did we call them*" (Purchaser 1)	*"The red tape involved for the purchaser to access the software in order to communicate with the supplier sometimes made them stop waiting for an answer from us"* (EM3). *"When the supplier introduced the prototype, there were some things we would have liked to change; we wished we had discussed this with them earlier"* (EM2)
	KMS	Low	"*We do not need to approve the technical solutions that they [supplier] found during product development […], our interaction at this stage was virtually limited to approval of the final prototype*" (EM1)	
	CWS	Very low		
4. Testing	PRMS	Low	"*This phase is more about asking the supplier: will you solve the problem in that part that we detected in the field test or in the lab test?*" (EM3).	*"The interaction was: 'we [AGRO] test it here and we send you [supplier] the results so you can improve'; it would have been faster and more efficient if we had conducted the tests together to solve the problems at that time"* (PM2)
	KMS	Low	*"The results of the test were collected and sent to the supplier, so they could take action to improve engine performance […]; the responsibility was theirs."* (EM1).	
	CWS	Very low		

● Very high ◕ High ◑ Medium ◔ Low ○ Very low evidence in a case study database. We also used a case study protocol and a rigorous process for data analysis to increase reliability. Finally, we used the conceptual framework as a template for comparing the empirical results of the case study to ensure transferability to other configurations and enhance the study's external validity (Voss et al., 2002; Yin, 2009).

Results

AGRO chose the buyer–supplier configuration type to develop a new product mainly based on the level of technology, time to market, cost of internal development, product strategic level, and project complexity and risk. In particular, the risk level of each project was measured using an internal procedure called "initial risk evaluation", which categorizes risks on a scale varying from 1 (very low) to 5 (very high). If the project is high-risk, it must be evaluated by the firm's board to decide in which kind of buyer–-supplier configuration it should be developed. According to this internal standard, the three projects considered in this study were considered highly risky. We present below the findings of each co-development project, i.e., Black Box, White Box and Grey Box, performed by AGRO to develop a new tractor.

Black box Project: Tractor engine

Interviewees chose a tractor engine project as the most complex and risky black box case, as it represents a very important part of the tractor that has a high impact on customer satisfaction. Since the firm was unable to develop it internally, this project was delegated to a supplier. In line with Petersen's et al. (2005) definition, the statement of interviewee EM2 clearly reflects the project's black box characteristics: "*we basically say to our supplier: we need an engine with this power, this level of torque and this level of pollution; you develop the engine and we will test it*". The buyer–supplier interaction analysis is presented in Table 3.

At the Scoping NPD stage (Stage 1), interaction with the supplier was very low. AGRO defines product ideas internally based on its own knowledge. PRMS activities at this stage, such as price and time estimations, were conducted by comparing with similar projects developed previously by AGRO, i.e., without CWS activities with the supplier. This activity was supported by Product Lifecycle Management software (PLM) used by AGRO to store and classify past projects. However, the interviewees confirmed that the lack of participation by any supplier in these activities resulted in a wide gap between the estimated schedule and the time the project finally took. Only when the team needed very specific technical information in order to continue with the project did they ask a supplier. Such communication was ad hoc and took place by e-mail or over the phone.

At the start of Stage 2 (Business Case), the supplier was selected, and close interaction was initiated with them. *"This is the most important stage because we decide with the supplier whether or not it is feasible to produce the engine with them"* (EM3). Here, AGRO was concerned with whether or not the supplier could meet the initial overall specification. Therefore, a high intensity of KMS activities occurs at this stage, mainly to allow the supplier to understand the product definitions correctly. The knowledge sharing was supported by IT such as e-mail and videoconferences using specific software employed by AGRO, and CAD designs shared by File Transfer Protocol (FTP). These designs were storage by AGRO in their PLM system. Since the supplier used a different CAD software package, some issues arose with sharing 3D designs, such as there being no possibility of exploding components of the object in view. Some problems arose because the supplier could not understand some of the definitions produced by AGRO in Stage 1, so CWS activities were required and achieved through videoconferencing. Several PRMS activities were carried out to define and validate the plan for the tractor engine. During all the stages AGRO regularly monitored the progress of product definitions by using workflow software and project management software; however, since none of the software for PRMS was shared with the supplier, the information to be declared in the internal software was obtained mainly by e-mail. At the end of this stage, a 3D design of the engine, a cost breakdown, and the definition of items such as service warranty features and production capacity, among other deliverables, were presented and stored by AGRO in the PLM software.

Interaction at Stage 3 (Development) was low, since the supplier developed the engine prototype almost exclusively based on the definitions jointly agreed in Stage 2. Buyer-supplier interaction was restricted to the meeting of deadlines and the approval of the final prototype. The PRMS NPD activities were supported by AGRO's own workflow software and project management software but the information from the supplier was obtained mainly by e-mail and telephone because no IT for PRMS was shared between actors. Interviewees stated that this lack of shared PRMS IT tools resulted in problems: "*we [AGRO] only took note of supplier delay when the prototype deadline had passed […], then we had to call them*" (Purchaser 2). Regarding the IT to support interfirm KMS activities, any time that changes were made in Stage 3 (with AGRO's consent), new documentation had to be uploaded by the supplier to a web portal developed exclusively by AGRO to formalize technical documents and drawing delivery. Since in black box projects the interaction with suppliers is mainly through the purchasing department, only purchasers access the web portal because they are responsible for supervising the contract. The red tape involved in the KMS activities with the supplier caused some delays in the information flow, resulting in a delay in decision making. And the lack of CWS activities led to a suboptimal result, as stated by EM2: *"When the supplier introduced the prototype, there were some things we would have liked to change; we wished we had discussed this with them earlier"*.

At Stage 4 (Testing and Validating), interaction was mainly about controlling schedules for testing and validating the tractor engine. Indeed, in this case of black box involvement, the supplier was in charge of testing conformance of the tractor engine. AGRO then tested this sub-system integrated in the global tractor to finalize its validation. AGRO's NPD team monitored the deadlines internally with the use of PRMS IT tools, mainly project management software, and questioned the supplier when the date was reached. Since the field tests were conducted by AGRO, some knowledge sharing occurred, mainly in the form of explicit knowledge in performance reports shared by File Transfer Protocol (FTP). After this stage, communication between actors was restricted to

Table 4
White Box Project – Tractor Hood – Interaction Analysis.

NPD Stage	Intensity of Key dimension activities		Description of case study	Observed Problems
1. Scoping	PRMS	○	There was no interaction with potential suppliers during this stage. “*The supplier has not yet been chosen at this stage*” (PM1).	“*As we did not consult any suppliers, we only knew afterwards that there was a better and cheaper material for developing the tools; it cheapened our project*” (Purchaser 2). “*We were surprised by the deadline requested by the supplier to develop the stamping tool; because of this we had to increase the deadline for delivery of prototypes*” (PM1).
	KMS	○		
	CWS	○		
2. Business Case	PRMS	○	“*We did not discuss plans with the supplier; discussions were restricted to being sure that they had the technical competence to carry out the project*” (PM1).	
	KMS	◔	“*We [AGRO] develop the 3D design and send them to our supplier […], then they have to estimate their costs based on investments in the manufacturing tools*” (EM3).	
	CWS	○	*“The supplier will usually know that they have something to develop only after we [AGRO] have finished the designs” (PM1). “We design it, we deliver it to the supplier, and we want them to deliver according to the drawing*” (EM3).	
NPD Stage	Intensity of Key dimension activities		Description of case study	Observed Problems
3. Development	PRMS	○	*“We designed this product and the plan alone because we have the knowledge […], then we chose this supplier because we knew that they would be able to correctly develop the product” (EM3).*	“*We lacked further information from the supplier about the progress of project development. We often received inquiries about steps that we thought were already finalized*” (PM1).
	KMS	◕	“*In this phase we have a high interaction with our supplier because we develop the detailed product [on 3D CAD software] […]; we have several meetings [through videoconference with screen sharing] to define whether they agree with the final design or whether they need some modifications*” (EM3). “*Frequently, the supplier suggested changing the product material to improve price and manufacturability”* (EM2).	
	CWS	◔	“*The focus of our discussions was Design for Manufacturing”* (EM3). *“We held several [videoconference] meetings at this phase to be sure that the supplier really understood our product and was not just telling us what we wanted to hear in order to be awarded the contract*” (EM1).	
4. Testing	PRMS	◑	“*We [AGRO] closely monitored [through a project management software] the aspect of the final manufacturing tools to check whether they were produced on time and quality. Also, we monitored the delivery of the first parts for pilot production”* (EP3).	
	KMS	◔	“*We [AGRO] only contacted the supplier if we detected some problems in our field test” (EM3)*.	
	CWS	○	*“We [AGRO] did not have anything more to discuss with our supplier at this stage; we just validated each part developed by them”* (PM3).	

● Very high ◕ High ◑ Medium ◔ Low ○ Very low

AGRO's purchasing department and the supplier's commercial department.

White box Project: Tractor hood

The interviewees chose a tractor hood project because it is one of the most complex, risky and expensive NPD projects developed by AGRO in a white box configuration with the supplier. The buyer–supplier interaction analysis is presented in Table 4. To be able to produce the hood for AGRO, the supplier needs to develop specific manufacturing tools that have a high financial impact on the project. In this project, the buyer developed the entire hood design. As the interviewee EM3 stated: "*We designed this product alone because we have the knowledge […], then we chose this supplier because we knew that they would be able to manufacture the product correctly*".

At Stage 1 (Scoping), the final supplier had not yet been selected. Estimates of preliminary costs and technical assessments were developed internally, based only on the knowledge already possessed by AGRO's NPD team, and designs stored in the PLM software database. The lack of involvement of any supplier here caused some problems concerning the supposition of tools and materials that would be used in manufacturing. This reflects a lack of KMS to create a common understanding of the needs and a lack of CWS for the actors to consider together this relevant aspect of design for manufacturing. Fortunately for AGRO, this deviation was positive for the budget.

During Stage 2 (Business Case) the potential supplier must be chosen. "*In this kind of project, we cannot make a mistake when choosing the supplier […], we cannot develop two parallel suppliers because the cost of the manufacturing tools is too high*" (EM1). AGRO developed the 3D designs of the hood using their own CAD design software and then shared it with the supplier through FTP; the supplier was using a different 3D CAD software package. Both programs were only compatible to a certain degree (as CAD viewer), making it impossible to share certain parameters, which had to be described in accompanying text. The discussions at the business case stage, which were conducted face-to-face and through videoconference, focused on being sure that the supplier selected had the technical competence to carry out the project. Knowledge sharing was restricted to cost definitions of specific manufacturing tools that would be used in the stamping process for the hood. However, interaction with the supplier was still low and resulted in negative consequences, especially in defining the schedule for development of the manufacturing tools.

At the Development stage (Stage 3), there was a high level of interaction with the supplier. "*We know that any misunderstanding from the supplier at this stage would mean delays for the project and probably a cost increase*" (EM1). During this stage, all product specifications in digital technical documents and CAD drawings stored in the PLM software were transferred from the buyer to the supplier using File Transfer Protocol (FTP). This is the last stage before the supplier makes an expensive investment in the definitive manufacturing tools that will consolidate the relationship between the partners for the rest of the product lifecycle. IT tools such as telephone, conference call, e-mail and FTP for sending the 3D drawings developed by AGRO supported the high intensity level of KMS activities. "*We frequently sent the 3D and 2D drawings of the product to our supplier and asked them if any of the modifications made had an impact on manufacturability cost or if they had any suggestions for improving the product*" (PM2). Sometimes these modifications were discussed in videoconference with screen sharing with the supplier to reach a better solution with less impact on the project (CWS activities). However, once AGRO delegated the manufacturing process development and manufacturing to the supplier, the lack of PRMS activities was problematic for the NPD team because they could not see the progress in development. AGRO and the supplier used their own IT to support NPD activities, e.g. workflow software, project management software and PLM software; however, since these IT tools were not shared, the link between them was only made periodically by e-mail, telephone or videoconference, making it difficult to collaborate or track the details of the product development process.

After the PRMS problems observed during Stage 3, at Stage 4 (Testing and Validation) AGRO decided to monitor more closely some critical aspects that could have a high impact on the project in terms of cost and time. Since there was no shared PRMS IT tool, AGRO monitored these aspects in its own project management software and asked the supplier for reports by telephone to determine the real situation. At Stage 4, the supplier is in charge of the pilot run of the hood and AGRO monitored the compliance of the first manufacturing prototype and the ramp-up. Interaction was then virtually restricted to contract agreements monitored by the purchasing and quality departments.

Grey box Project: Tractor cabin

Interviewees selected a tractor cabin case as the most critical product developed in a grey box configuration by AGRO. Although it was strategic, the firm decided to develop this project with a supplier due to its own lack of knowledge, capabilities and capacity, which could affect the quality of the final product and the time-to-market necessary to increase market share. A grey box configuration was established because neither the buyer, AGRO, nor the supplier had all the knowledge required to develop the product alone. The high level of collaboration for this project was also reflected in the way that AGRO referred to this project: "a *four hands project*" (PM1). Intensities of interaction between buyer and supplier for each NPD stage are stated in Table 5.

In this project, AGRO had already chosen the supplier at the Scoping stage. For grey box projects, it was mandatory at the firm to start with face-to-face meetings. "*We spent an entire day discussing with them [the supplier] to be sure that they understood exactly what we wanted for the project*" (EM1). Strategic definitions were made at this stage, such as the main characteristics of the product, the schedule, task allocation, and an estimate of investments. These parameters were stored by AGRO in two parallel PRMS applications: one enterprise level project management application for storing general information and one workflow application for tracking the activities of the AGRO members of the NPD team. The supplier was contacted again at the end of Stage 1 to approve the scope of the project. The presentation finalizing the scope was made through a videoconference with the participation of NPD teams from both

Table 5
Grey Box Project – Tractor Cabin – Interaction Analysis.

NPD Stage	Intensity of Key dimension activities		Description of case study	Observed Problems
1. Scoping	PRMS	Low	*"First, our [AGRO] team designed alone a draft of the product and project steps […]; normally, even if we share a NPD with a supplier, the project is ours, they will carry out the manufacturing engineering part"* (Purchaser 1).	*"At the outset, we thought we had enough knowledge to develop stage 1 entirely alone, but when we called the supplier they pointed out several issues and we had to perform several reworkings before we could jointly approve the deliverables from stage 1"* (EM1).
	KMS	Medium	*"Several rounds of discussions with the supplier take place to align expectations about the objectives of the NPD project"* (EM3).	
	CWS	Low		
2. Business Case	PRMS	Very high	Since one firm depends on the other for task progression, *"we call or send e-mails every day asking for information about the progress of their part of the project"* (EM3)	
	KMS	Very high	*"Both firms work together to define whether it would be feasible to continue with the NPD project"* (EP3).	
	CWS	Very high	*"In-depth analysis of costs, technologies and other aspects does not come merely from us [the buyer], but also from the supplier who is working with us all the time"* (EM3).	
3. Development	PRMS	Very high	*"We phoned them daily to ask about the progress of the different deliverables"* (EM3).	
	KMS	Very high	*"We each have half of the knowledge […] we need to interact all the time"* (EM1).	
	CWS	Very high	*"While developing the product, we were online practically every day, communicating by sharing our screens and by web conferences"* (EM3).	
4. Testing	PRMS	Medium	*"Here [at stage 4] we were monitoring product delivery for pilot production in the manufacturing plant"* (PM1).	
	KMS	Medium	*"We still have problem-solving interaction about manufacturing and assembly of the product"* (EM3).	
	CWS	Low	*"The supplier's engineering manager spent two weeks during pilot production rapidly solving with us any problems that might arise"* (EM3)	

Very high · High · Medium · Low · Very low

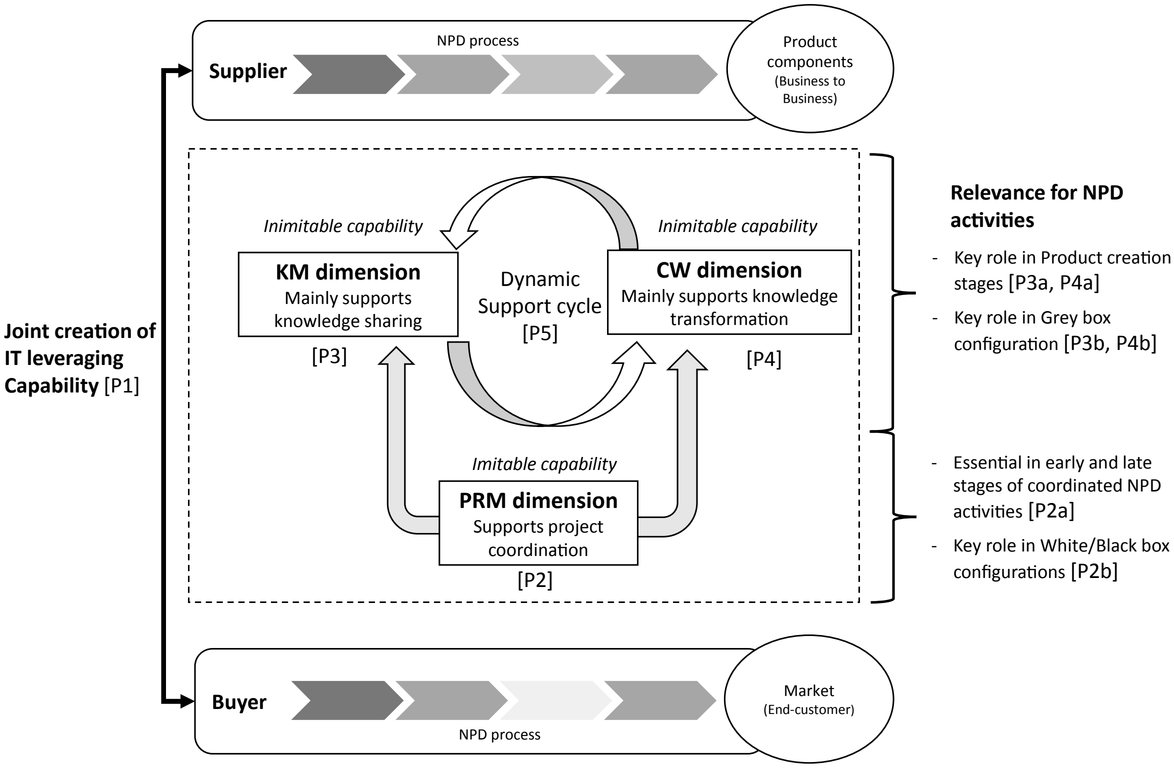

Fig. 2. Dynamics among the three dimensions of IT-leveraging capability in NPD to support NPD collaborative activities with suppliers.

buyer and supplier. Since most of the definitions were already made by AGRO, few PRMS and CWS activities were performed as interfirm activities; the interviewees indicated that as a result several definitions needed reworking.

During Stages 2 and 3 (Business Case and Development), the interviewees stressed a high level of interaction with the supplier. "*We [AGRO] had full daily interaction […], we were practically inside their firm*" (EM2). This interaction was mainly made by *e-mails, instant messenger, telephone and videoconferences*. Since the collaboration between AGRO and the supplier was specific for this project, the firms made no effort to make their IT compatible in order to support the NPD activities. Each company continued with their own IT and this aspect was not considered in the contract. Utilization of IT tools for collaboration between both NPD teams was very frequent but restricted to basic IT tools because their systems were not integrated. For instance, engineers from each NPD team worked on their own computers and software to develop 2D and 3D drawings. Coincidentally, both firms used the same 3D CAD software, allowing the interchange of designs. Periodically, using screen sharing, phone calls and videoconferences, the engineer from one firm showed their counterpart how something was done, while also asking for assistance or approval.

The lack of integration between information systems led to problems that resulted in a more time-consuming process: engineers were working separately using CAD software on some parts of the project and only realized there was conflict between these parts when they tried to link them together. This difficulty is reflected in the EM3 statement: "*it is far easier being next to the engineer and showing him or her what are you referring to [on the CAD software] on their computer, than trying over and over to explain it remotely*". The lack of appropriate IT tools for support interaction led AGRO's NPD team to ask the supplier to send at least one of their product engineers to spend some time in their offices, and vice versa.

The NPD teams from each firm used their own PRMS, i.e. project management software and workflow software, to track progress and responsibilities. Thus, PRMS IT-enabled NPD activities were highly affected by the lack of appropriate integration between information systems: "*we used weekly web conference meetings to update on the progress of parallel developments […] frequently, they promised a certain date and then waited until the meeting to inform us that they had not kept to the deadline*" (PM3). After this situation had been repeated several times, AGRO's team developed a routine of calling or sending e-mails almost daily asking for information about the progress of deliverables to update their own project management software. However, this behavior also made the relationship more tense: "*there are two engineers in the supplier's team that do not want to see me anymore*" (EM3). Still, while high levels of KM are needed during Stages 2 and 3, management of the knowledge generated during this process was extremely limited by the lack of proper interfirm IT tools. EM1 reported: "*I used annotation software to record the lessons learned […] I keep these in a folder shared within my department [within a PLM software] if one of the suppliers needs it, they can ask me*". Even when both firms had IT to support their own NPD activities, project managers did not consider implementing shared IT tools or integrating existing ones.

The level of interaction between buyer and supplier decreased at the Testing Stage. Project management software was used by the buyer to monitor the right time for product delivery for pilot production of the tractor itself in the manufacturing plant. Regarding

KMS and CWS, the CAD software was used to share 3D drawings of the product, and videoconferences to discuss aspects of the manufacturing and assembly of the product, however, yet again the limitations of the shared IT tools forced "*the supplier's engineering manager to spend two weeks during pilot production*" (EM3) working on solving problems presented in the assembly process on the buyers' line. After this, interaction was limited to a commercial relationship.

Discussion and theoretical consolidation

Our study was framed on Pavlou and El Sawy's (2006, 2010) IT-leveraging capability conception which, according to them, should be considered at the process level rather than at the company level. We demonstrated empirically the importance of this view, since we found that the functionalities of three IT systems are leveraged for NPD (i.e., PRMS, KMS and CWS); these have different roles depending on the NPD stage and the type of collaboration adopted for supplier involvement. Our findings reinforce the view that the analysis of IT-leveraging capability only at firm level can be risky, since it provides a static view – instead of a dynamic one – of the role that IT capability plays in NPD; as a result IT capability may be misaligned with the specific needs of the NPD process. Moreover, our results reveal that IT-leveraging capability should also consider external relationships in addition to the leveraging of IT for internal NPD activities. IT-leveraging capability cannot be treated generically and should reflect the dynamic behavior of the NPD process (Banker et al., 2006; Durmuşoğlu and Barczak, 2011). This view opens up several avenues of discussion, which are represented in Fig. 2 and described next.

The fact that IT-leveraging capability depends on collaboration with external suppliers has important implications for the way companies manage IT tools and related resources. Our results show that in the context of collaborative NPD, IT-leveraging capability is an interfirm capability rather than an individual one. That's why in Fig. 2, the three dimensions of IT-leveraging capability is represented at the center of both buyer and supplier NPD processes. Both parties need to integrate tools, resources and capabilities if they want to be successful in the use of IT to support NPD performance (Rai et al., 2012). Companies must focus on IT interdependencies with their suppliers instead of being concerned only with their individual IT implementation (Fawcett et al., 2011). Developing team capacity to work with external parties is essential and complementary to the use of IT tools for this purpose (Frank et al., 2015; Marion et al., 2016). IT serves as a communication forum to make explicit and manageable implicit areas of the relationship (Makkonen and Vuori, 2014). Both buyer and supplier should develop the capabilities needed to manage IT utilization together. Our results show some of the difficulties faced by the NPD firm when the company tried to develop its own IT capability without the participation of the external suppliers. Thus, we introduce the following proposition, which is also represented in Fig. 2:

Proposition 1 (*[P1]:***).** *In the context of interfirm collaborative NPD, IT-leveraging capability should be created jointly by buyer and supplier to enhance the chance of NPD success.*

According to Pavlou and El Sawy (2006, 2010), IT-leveraging capability can provide competitive advantage, since it is a rare, valuable, inimitable and non-substitutable capability. However, the extant literature does not define *how* each dimension of the IT-leveraging capability contributes to this competitive advantage in the collaborative NPD relationship. Our findings shed light on this.

Our findings demonstrate that the effective use of PRMS functionality is crucial at the start of the project in order to organize the NPD process and plan activities. For this reason, this dimension is considered an elementary capability. Effective use of the coordination functionalities of PRMS is considered the most imitable dimension of the IT-leveraging capabilities. Effective use of KMS and CWS are dependent on the culture and the complexity of the project and are less imitable. PRMS allow buyer and supplier teams to properly apply their expertise at the right moment during the NPD process, since PRM supports the coordination of activities and resources (Reid et al., 2016). As observed, lack of interfirm PRMS and lack of coordination jeopardize KM and CW at several points in the three configurations: at the start of interaction, when project activities have to be defined; at the stage during which the new product is developed; and at final stage when project outcomes from both partners are required. Our findings reveal that effective use of PRMS establishes the basis for effective use of KMS and CWS. Before sharing knowledge (KM) and cooperative problem solving, (CW) a common definition of the NPD project process and organization (PRM) is required to coordinate the planning of NPD activities and key millstones. Additionally, the effective use of PRMS involves different coordination modes depending on the type of collaboration. Grey box design is characterized by joint cooperation and a mutual need for close interaction between buyer and supplier and so can be qualified as a tightly coupled coordination (Petersen et al., 2005; Ragatz et al., 2002). In this case, the PRMS helps to organize and synchronize activities between partners. On the other hand, black and white box designs have more loosely coupled coordination (Petersen et al., 2005; Ragatz et al., 2002); both teams apply their own expertise and work independently. In both the black and white box cases, the PRMS was mostly used for tracking the execution of tasks and deliverables. Although in all cases PRMS has an important role in supporting NPD activities our findings showed that black and white box configurations were more affected by the lack of a PRMS. Indeed, these configurations depend on distant activities and coordination was not compensated for by the regular interactions that were necessary in grey box. Thus, we introduce the following propositions, also represented in Fig. 2:

Proposition 2 [P2]:. *The PRMS dimension of IT-leveraging capability supports the coordination activities between buyer and supplier; it is required to support the KMS and CWS dimensions. PRMS has a key role at the start of the interaction and at the final stages of NPD [P2a] and is more essential in loosely coupled coordination such as black and white box configurations [P2b].*

KMS support the processing and sharing of information. They include a common knowledge base shared with suppliers, which is naturally hard to imitate because it involves thetransfer and translation of knowledge. In collaborative NPD both partners have to reduce equivocality, due to the existence of multiple and conflicting interpretations of knowledge (Koufteros et al., 2005). Knowledge sharing difficulties can result from differences in language, skills and understanding of product expectations. The semantic vocabulary relating to a collaborative NPD project needs to be explicit for inter-organizational communication (le Dain and Merminod, 2014). We observed that effective use of KMS was ‘a necessary condition’ for interfirm NPD, for all NPD stages and configuration types; a minimum set of shared explicit knowledge (e.g., rules of design and standards) is always necessary in collaborative NPD activities (van Echtelt et al., 2008).

The CWS dimension of IT-leveraging capability supports the interactions and communication of project actors across time and space (Shen et al., 2008). It notably supports remote collaborative work (Mauerhoefer et al., 2017), and complements face-to-face interactions (Addas and Pinsonneault, 2016). As a result, this dimension facilitates the generation of creative ideas and the debating of ideas, and helps to reduce ambiguity around information (Peng et al., 2014). Problem solving involves transforming existing knowledge (Carlile, 2004); CWS also make it possible to solve development problems in real time, especially when actors are distant. Our findings show that both KMS and CWS are very necessary during the business case stage (when the product is defined) and development stage (when the product is created). In both these stages knowledge flow is intensive. Our results also evidence that the effective use of KMS and CWS are key dimensions in grey box configurations; in situations where the actors need to have close interaction and knowledge sharing CWS and KMS are necessary tools to support knowledge flow between the partners (Ayala et al., 2017). Thus, we introduce the following propositions also represented in Fig. 2:

Proposition 3 [P3]:. *The KMS dimension of IT-leveraging capability is a necessary condition for building and sharing a common understanding of the needs and risks of the project between the two teams. It is an inimitable capability, since it combines specific knowledge coming from different companies. Effective use of KMS is a key dimension in the business case and development stages [P3a] and for grey box configurations [P3b].*

Proposition 4 [P4]:. *The CWS dimension of IT-leveraging capability is a real-time capability that supports the exchange of knowledge between the two teams. It is an inimitable capability because it enables joint problem-solving activities. CWS plays a key role at the product creation stage [P4a] and for grey box configurations [P4b].*

Moreover, KMS and CWS reinforce each other, creating a synergistic effect. CWS needs to be supported by KMS, which provide a structured base of knowledge. The knowledge transformation performed by the buyer and supplier (supported by CWS) requires the transfer and translation of knowledge supported by KMS. Subsequently, the new knowledge created during this transformation can be shared through KMS (Carlile, 2004; le Dain and Merminod, 2014; Alaya et al., 2017). This creates the foundation for the subsequent articulation and combination into the explicit base of knowledge for the project (Alavi and Leidner, 2001; Nonaka, 1994). Meanwhile, PRMS act as a mechanism for the coordination of activities which supports this dynamic between CWS and KMS. This is represented in Fig. 2 as a dynamic cycle between KMS and CWS [P5], with the PRMS at the base, creating a support framework for the operation of both the KMS and CWS. We summarize this in our last proposition:

Proposition 5 [5]:. *The KMS and CWS dimensions of IT-leveraging capability are mutually sustained in a cycle in which the CWS supports buyer–supplier knowledge transformation, fed by the creation of a common knowledge-base through the KMS dimension.*

Implications, limitations and future research

Theoretical contributions

This paper contributes to both the IT and innovation literature by focusing on IT as an enabler of interfirm innovation (Nambisan, 2013).

These results contribute to understanding the role IT tools and associated resources play in NPD collaborations with suppliers. Our empirical study found evidence to support propositions that extend theoretical understanding of this context.

While prior studies of collaborative NPD have focused on the contribution of people and processes to interfirm activities (Banker et al., 2006; van Echtelt et al., 2008), our study highlights the importance of creating joint IT capabilities. We have demonstrated that the NPD stage and collaboration type influence the dynamics and intensity of the IT-leveraging capability needed. Our study complements the literature on IT capability applied to innovation and new product development (Pavlou and El Sawy, 2010; Rai et al., 2012) by shedding light on the dynamics between the three IT-leveraging capability dimensions; these have usually been treated as equal. We have shown that the effective use of PRMS plays an important role in supporting the other dimensions, but it is an imitable aspect of IT capability. The effective use of KMS and CWS are the inimitable dimensions of IT capability and, therefore, firms that develop new products should focus on building shared capabilities in these dimensions with their suppliers.

Finally, we extend the prior literature on the role of IT in the NPD process such as the study by Reid et al. (2016). The Reid et al. study divides IT tools for supporting NPD into two main groups: (i) general purpose (e.g., e-mail, desktop tools, and shared files and drives) and (ii) collaborative (e.g., PLM applications, compatible CAD software, virtual simulation applications, cloud-based file sharing, and project management tools with common access). Our study shows that, in an interfirm context, the demand for these tools will be different for different buyer–supplier configurations. For a *White Box configuration*, general-purpose IT tools combined with ad hoc collaborative IT tools, especially tools for facilitating DFM (Design for Manufacturing) decision-making, may be sufficient, since the buyer has more expertise about the product being developed, and the supplier about the process to manufacture the product. For a *Black Box configuration*, collaborative IT tools are slightly more important because the buyer does not have the necessary technical expertise. Indeed, the two teams in our black box case interacted using a 3D digital mock-up (CAD viewer) to discuss whether the solution proposed by the supplier would achieve the expected end use and performance. On the other hand, the

Grey Box configuration requires a larger convergence of buyer and supplier IT capabilities. Utilization of IT tools that are not well integrated could lead to difficulties in communication, delays and other problems such as those observed in our case study. Consequently, in the grey box configuration it is vital that actors broadly implement both general-purpose and collaborative IT tools and use them continuously throughout the NPD project. All these findings extend understanding of IT in NPD, resulting also in managerial implications and new opportunities for future research, as we explain next.

Managerial contributions

In previous studies, IT leveraging capability in NPD is explored without considering the different stages of this process and the contribution of suppliers to the design activities of the buyer (white, grey and black box). From a managerial point of view, our analysis allows firms to have a deeper understanding of which dimensions of IT capability they should focus on at each stage to obtain better results in collaborative NPD activities. This analysis can help IT managers to improve their strategic decision making with regard to the required information system to support the appropriate set of activities at each NPD stage. Indeed, our study helps to guide firms in the assessment of the IT tools and capabilities needed to support NPD activities. The propositions in this paper form part of the recommendations for IT managers. In our case study we demonstrated that, in general, in an inter-organizational NPD project, the challenge is more than just deciding which IT tool should be used. As partners may differ in their IT capabilities, the IT-based collaboration and communication systems used must be flexible. Our findings help clarify which IT capability dimensions need to be leveraged at each NPD stage; this will influence the subsequent design of the IT infrastructure needed to support interfirm NPD activities (Broadbent et al., 1999). This study also shows the importance of developing each of the three IT-leveraging capability dimensions, since they are highly interdependent and a lack of development of one of them could jeopardize the entire interfirm NPD activity.

Limitations and future research

This study has some limitations that open up new opportunities for future research. Firstly, the case studies were conducted with the project teams of AGRO, thus, the supplier's point of view was only partially taken into consideration. A deeper analysis of the supplier's perspective would enhance the propositions. Secondly, our study focuses on supplier involvement during NPD; customer involvement in NPD was not within our scope. Since the involvement of all stakeholders is crucial for the success of the developed product (Peng et al., 2014), future research may study how IT-leveraging capability dimensions contribute to customer participation in the NPD process. Finally, the context of our study was a single multinational firm; future studies could investigate the influence of other variables such as company size and industry sector to improve the generalizability of the findings. In addition to future research that overcomes the limitations of this study, more granularity could be applied to future studies. For instance, the KMS dimension could be analyzed by using Loebbeckés et al. (2016) divisions of inter-firm knowledge sharing, i.e., type (explicit or tacit) and mode (unilateral or bilateral) and dynamics of knowledge sharing (intended and actual).

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