Unpacking Product Modularity Innovation in R&D Teams

by

Daniel Martinez Martin

Supervisors:
Stefan Haefliger and Tim de Leeuw

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Cass Business School

Faculty of Management

City, University of London

106 Bunhill Row

London

EC1Y 8TZ United Kingdom

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Declaration

I, Daniel Martinez, declare that this thesis entitled "Unpacking Product Modularity. Innovation in R&D Teams" together with the work presented in it are my own. This material is the result of the PhD work carried out in the joint venture program of both CASS business School and Tilburg University from 2014 to 2018. In order to receive this degree, this thesis has been published in both institutions: at Tilburg University, with ISBN no. 978 90 5668 585 0, as well as, at City university, with the present work.

Aknowledgements

To my Family

Per a la meva Família

This dissertation is the result of my PhD project at both City university of London (CASS business school) and Tilburg University (TIAS business school) during the years 2014-2018. Although my name alone is printed at the front cover of this book, I couldn’t have accomplished this life milestone without the essential collaboration and encouragement of many people. I would like therefore to take this opportunity to express my thanks to a number of people that contributed to this effort.

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Daniel

Shanghai, 2018

ABSTRACT

Does modularity stimulate innovation or, on the other side, are these modules and standards limiting engineers and hindering innovative activities? Innovation is a crucial factor for the long-term survival of any organization. In order to reduce complexity, organizations introduce product modularity as one essential strategy for R&D. Modularity is extensively applied in the research of technology and organizations. However, collaboration in R&D teams working with product modularity is somewhat paradoxical, as it requires autonomy, on one hand, working and keeping modules separate in design, and yet interdependent on the other hand, as teams need to be participative in the integrative process of bringing different modules together. Building on the insight that product modularity can have contradictory effects on innovation, this dissertation is centered on the influences of product modularity on innovation under the specific R&D team context. Essentially, this study unpacks the understanding of the concept of product modularity by establishing the two essential dimensions of product modularity (i.e., module standardization and reconfiguration) and studying the effects on innovation. In addition, this work enhances the understanding of the concept of alignment between task and organizational structure and provides evidence of the impact of this alignment on innovation. Moreover, this study aims to resolve the prevailing poor fit between innovation practice and theory by adopting, empirically, effectiveness and efficiency views of innovation. A sample from 140 R&D teams from a large organization in the automotive industry was analyzed and multiple additional data triangulations and robustness checks were conducted. The findings reveal that organizations must carefully consider the different, even opposite effects of standardization and reconfiguration on innovation and find an optimum balance. In particular, it is crucial to understand what areas of the product and organization, managers need to pay particular attention to cope with the impact of misalignments, identifying critical design interfaces, ensure the most effective team setting and promote innovation.

CHAPTER 1

INTRODUCTION TO THE STUDIES

1.1. Background and Context

The fundamental topic of this dissertation focuses on the role of product modularity in innovation in the research and development (R&D) team context. Distributed organizations are becoming ubiquitous in an increasingly complex and competitive business environment. In this context, innovation is crucial for the strength and survival of the organization. Innovation refers to the development and execution of new ideas to solve problems (Van de Ven 1986, Dosi 1988), which predominantly derives either from combining knowledge and technologies in a novel manner (Schumpeter 1934, Nelson and Winter 1982, Fleming and Sorenson 2001, Carnabuci and Bruggeman 2009), or from recombining existing technologies so that they can acquire new functions (Henderson and Clark, 1990, Yayavaram and Ahuja 2008).

In this competitive setting, organizations form R&D teams to innovate. Indeed, this has become an established practice (Ahuja et al. 2003, Hinds and Mortensen 2005). These R&D teams are formed by members commonly from very diverse disciplines and levels of understanding, and members commonly come from different areas and apply ICT in different ways. (Robbins 2001, Emmitt and Gorse 2007). A possible graphical representation of the R&D team is shown in Figure 1.

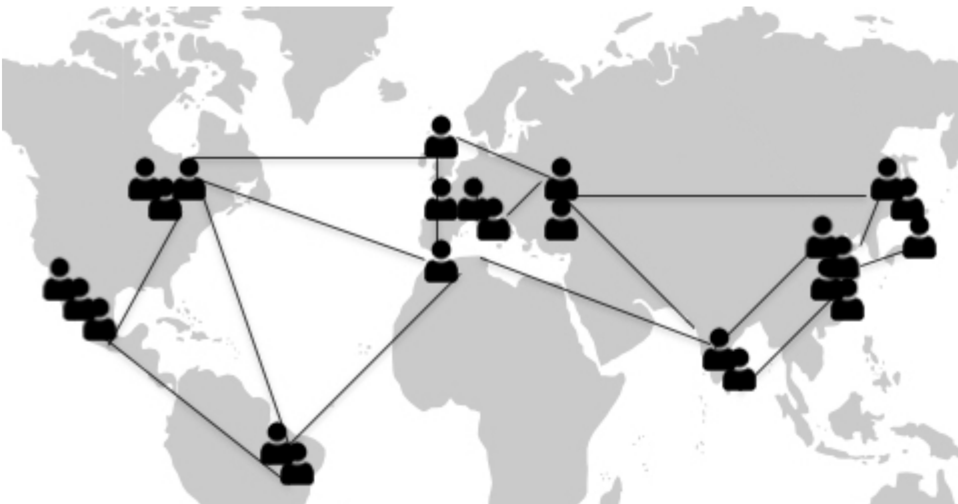

Figure 1 – Representation of R&D Teams (source: Knowledge_brief.com)

Many global organizations struggle with how to manage their R&D. Managers responsible for R&D must leverage a body of knowledge effectively and efficiently (Szulanski 1996, Gassmann and Von Zedtwitz 1999). New product development is influenced by customer demand, increased globalization, and advances in product technology and complexity (Kotler

2003, Tidd and Bessant 2009). In addition, shorter product development cycles and the need to continuously introduce new technologies have an important impact on the overall R&D team setting. This situation drives organizations to adopt different approaches to develop new products (Rycroft and Kash 1999), with scholars proposing the use of product modularity to manage and reduce the complexity of the development (Starr 1965, Sanchez and Mahoney 1996, Ulrich and Eppinger 2000, Baldwin and Clark 2000, Garud et al. 2003).

Product modularity has received increasing attention in the academic literature (Gershenson et al. 2003, Salvador 2007, Ro et al. 2007, Furlan et al. 2014, Sorkun and Furlan 2016, Cabigiosu and Camuffo 2017). Many companies across industries are somehow applying product modularity in their daily activities (Spencer 1998, Suzik 1999, Macduffie 2013). In the most varied domains, such as design engineering (Ulrich and Tung 1991, Schilling 2000), software design (Spencer 1998), or home construction (Civil Engineering Research Foundation 1996), we can perceive the systematic use of modularity. Actually, it is modularity, more than other technologies responsible for the increasing changes that different industries are confronted with (Baldwing and Clark 1997). Modularity strategies are a common approach to cope with this situation, visible in very diverse industries such a computer, tourism, software development, or even finance. A significant number of studies suggest that many products are becoming more modular over time and that this development is often associated with a change in industry structure towards higher degrees of specialization. These advances can have substantial consequences for the industry's overall competition landscape, such as the computer industry has experienced (Baldwin and Clark 1997).

Overall, product modularity has become an important strategic approach for firms to innovate and cope with an increasingly complex business environment. (Baldwin and Clark 1997, Gershenson et al. 2003). Product modularity provides a significant number of benefits (Baldwin and Clark 1997, Ro et al. 2007). For instance, in a life-cycle approach, product modularity reduces maintenance costs and increases the degree of recycling and re-use, as modularity allows modules to be detached and regrouped. (Sosale et al. 1997). In robotics, for example, modularity reduces design and replacement time and increases flexibility (Scheidt and Zong 1994, Tosunoglu 1994). Furthermore, through module sharing across product families, product variety and changeability is increased (Huang and Kusiak 1998).

The general concept of modularity refers to the degree to which a system or product can be separated and recombined (Schilling 2000). This concept is visualized in the form of different module components with diverse shapes (i.e., round. triangle, square) that share common interfaces (Salvador et al. 2002). These modules, combined, create various further variations. A representation to visualize the concept of modularity is shown in Figure 2. The three displayed "products" are composed of three types of standardized modules (semi-circle, triangular and square shapes). With these modules, several product configurations and variations can be generated. The three figures represent an example of these possible configurations.

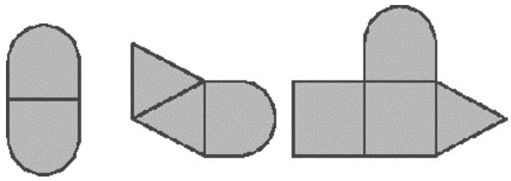

Figure 2 – Representation of Modular Products and their Configurations (Salvador et al. 2002)

Within the widespread and increasing range of applications, there are many definitions related to modularity. In sum, this situation leads probably to the lack of a consolidated consensus in its definition. (Ulrich and Tung 1991, Huang and Kusiak 1998, Gershenson et al. 2003, Ro et al. 2007). Simon (1962) was the first to propose the concept of modularity within the academic literature, bringing in the topic of nearly decomposable systems. Sanchez and Mahoney (1996) state that systems become modules when they possess a high degree of independence.

Further, Baldwin and Clark (1999) consider modularity to be a design strategy that avoids creating strong interdependencies among specific modules within the product. Allen and Carlson-Skalak (1998) define "module" as a group of components that can be removed from the product as a unit, without "destroying" the whole product. This definition is in line with Schilling (2000), who affirms that modularity refers to the degree of recombination and separation that the components of a product can achieve, in order to create new configurations. In sum, the common understanding is that product modularity includes building blocks that can be combined to offer a large number of configurations (Sanchez 1995, Baldwin and Clark 1999, Schilling 2000).

Modularity is extensively applied in the research of technology and organizations. In particular, this dissertation is centered on the influences of product modularity under the specific R&D team context. Within this setting, product modularity is considered one of the most substantial techniques for R&D. Firms such as Bosch, Continental, or Lear have integrated it into their R&D processes and systems in automotive, and numerous examples can be found in the computer and software design (Spencer 1998), bicycle (Fixson and Park 2008), tourism (Avlonitis and Hsuan 2018) and automotive industries (Teece 1986, Baldwin and Clark 1997, Suzik 1999). Example of modules could be the bricks in building construction or the pieces of the Lego game. A further example of a modular product in the automotive industry would be the product shown in Figure 3. This explosion view represents a transmission system. Some of the elements that compose this product are standardized and reused again in other similar applications. (i.e., axis, gears, etc.)

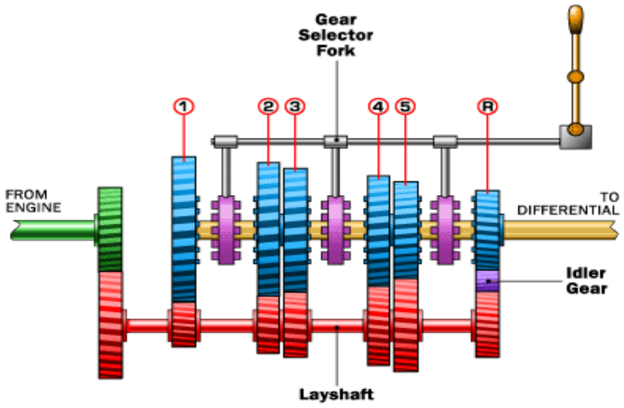

Figure 3 – Explosion View of a Transmision System for Automotive (Harris 2006)

Product modularity is the use of standardized and interchangeable components or units that enable the configuration of a wide variety of end products (Schilling 2000). Product modularity allows a product to be decomposed into a set of smaller building blocks or modules. We want to highlight that this study is about product modularity in the design engineering context. Other contexts are not the focus of this research, such as process or production engineering.

Therefore, Ulrich's definition appears to be better fitting under this context. Thus, the functional view of a product is particularly suitable for design engineering contexts. In addition, this functional approach in design engineering matches to further similar definitions about product modularity (Kogut and Bowman 1995, Lee and Tang 1997, Momme et al. 2000).

New development can change or create new architectures or interfaces, which, later on, will be reflected in the form of standards (module level standards). Therefore, standards integrate all the defined "visible" rules (Baldwin and Clark 1997). Walz (1980) definition of modularity goes further in line with our statements. It is about a constructed of standardized units of dimensions for flexibility and variety of use. (No matter whether architectures, interfaces or standards).

The product modularity approach has become a common practice in R&D. Different R&D team members can autonomously and concurrently design and test modules on a development network, making it possible, for instance, to reduce the time dedicated to the detailed design of new products (Sanchez and Mahoney 1996, Sanchez 1999). R&D teams working with product modularity include engineers from various domains who integrate their knowledge to develop new products (Sanchez and Mahoney 1996, Sanchez 1999). Numerous studies have shown the importance of collaboration in R&D projects (Ahuja 2000, van der Vegt and Janssen 2003, Kratzer et al. 2004, Langfred 2005, Carnabuci and Brueggeman 2009, Janhonen and Johanson

2011). Previous research has argued that a significant number of characteristics play a role in the success of these collaborations. However, this study narrows the setting to some elements regarded as essential under this distinctive collaboration context of R&D teams.

Drawing upon the earlier definition of R&D teams and after carrying out a literature review on R&D team research literature, we conclude two essential factors:
1) team interaction (Pearce and Gregersen 1991, Gassmann and von Zedwitz 1999, Bishop and Scott 2000, Van der Vegt and Janssen 2003, Langfred 2005) and 2) knowledge diversity (Ahuja 2000, Sethi et al. 2001, Carnabuci and Brueggeman 2009, Sandberg et al. 2015).

In particular, under the R&D team context, this research regards both team interaction and knowledge diversity as critical. These two essential elements are particularly important because they best fit the definition of R&D teams. Moreover, they were previously noted as having a relevant impact on innovation in organizations (Argyres 1999, Van der Vegt and Janssen 2003). The effects of modularity on innovation have attracted increasing attention (Sanchez and Mahoney 1996, Helfat and Eisenhardt 2004, Karim 2006, Pil and Cohen 2006). As suggested by the knowledge-based theory of the organization (Nonaka 1994, Zander and Kogut 1995, Grant 1996a, Kogut and Zander 1996), the ability to create knowledge is essential for an organization to survive. Organizations are seen as communities that generate and transfer knowledge (Kogut and Zander 1996, Nickerson and Zenger 2004). In this context, knowledge is created and transferred to individuals and teams, providing chances and an environment to innovate (Kogut and Zander 1992, Tsai and Ghoshal 1998)

In addition, organizational implications of product modularity are an increasingly significant area of research (Sanchez and Mahoney 1996, Schilling 2002, Ethiraj and Levinthal 2004, Fleming and Sorenson 2004). Research related to organization design identifies that organizations should be designed to reflect the nature of the task they perform (Mac Cormack et al. 2012). Therefore, it is expected that R&D teams developing products with a certain degree of modularity and the product structure must be similarly aligned. Related studies (Henderson and Clark 1990, Brusoni and Prencipe 2001, Tiwana 2008, Cabigiousu et al. 2013, Furlan et al. 2014) expect that team communication must be aligned to the technical interdependencies between or modules of the product. The reasoning is that if there are technical connections between different aspects of a product, there should be a matching communication between the team members working on those features. (Baldwin 2008). Under this context, a critical issue in strategic management is how to manage complex organizational and technological systems that enable firms to compete effectively in dynamic environments and innovate (Hargadon and Eisenhardt 2000, Pil and Cohen 2006).

1.2. Research Gaps

However, collaboration in R&D teams working with product modularity is somewhat paradoxical. The following arguments support this condition. On one hand side, a substantial stream of literature affirms that product modularity offers an approach to collaboration that considerably diminishes the need for coordination, reduces the communication efforts. (Sanchez and Mahoney 1996, Baldwin and Clark 1997, Fine 1998, Schilling 2000), and supports autonomous development (Fine 1998, Baldwin and Clark 2000, Tiwana 2008). Conversely, collaboration among R&D teams within this context involves the need to be participative and to deliver important efforts in knowledge exchange (Brusoni and Prencipe 2001, Steinmueller 2003), as it is required for the integrative process to bring the different modules together. This "a priori" apparent contradiction makes this research particularly interesting since product modularity can influence both collaboration and innovation outcomes. Therefore, this study narrows the analysis to essential characteristics regarded as critical under the collaboration context of R&D teams (i.e., team interaction, knowledge diversity) and explore their impact on innovation.

Furthermore, despite the rapid increase in the use of product modularity for diverse applications, there is little consensus on its actual definition or its nature as a multidimensional construct (Gershenson et al. 2003, Ro et al. 2007). Various studies have made an effort to bridge the various perspectives in the literature (Ulrich and Tung 1991, Huang and Kusiak 1998, Gershenson et al. 2003), but the challenge in understanding the concept remains. We define product modularity as a multidimensional concept in terms of the module standardization and reconfiguration, following Gershenson et al. (2003) and Salvador (2007). Module standardization refers to the extent to which something is constructed by joining a set of standardized parts that have been made separately (Pels and Erens 1992), while reconfiguration is the degree to which the product components can be reused to facilitate a broad range of new product variations by mixing and matching the modules (Mikkola and Gassmann 2003). We part in our theorizing that both module standardization and reconfiguration should take the essential pieces of the definition of product modularity. Modularity could in general, and other contexts are used for other purposes, which are not specifically aiming for module standardization or reconfiguration. However, under the design engineering and innovation context, the definition that this research takes has full validity. We can apply product modularity for achieving other objectives, but it is not the focus of this research.

Furthermore, a multidimensional view definition of product modularity is not new (Ulrich 1995, Baldwin and Clark 1997, Lee and Tang 1997, Fine 1998, Gershenson et al. 2003, Salvador 2007). Previous research and definitions on modularity, emphasize consistently both aspects of separability versus recombination. However, we are the first to carry out an empirical assessment. This study takes a combined approach in order to introduce definitional clarity and structure to guide the empirical research. While the dimensions of module standardization and reconfiguration are differentiated and complementary, there is no conclusive evidence regarding the effects of module standardization and reconfiguration on innovation. The existing research has produced ambiguous findings and contrasting lines of argumentation on the impact of product modularity on innovation, possibly because the studies do not incorporate a multidimensional perspective (Pil and Cohen 2006, Brusoni et al. 2007).

Additionally, regarding whether team communication is expected to be structured in order to mirror the tasks they carry out, there have been several studies (Sosa et al. 2007, MacCormack et al. 2012, Furlan et al. 2014, Colfer and Baldwin 2016). However, few systematic empirical studies exist on this relationship despite the popular notion of the mirroring hypothesis in organizational design and the corresponding impact on innovation.

Moreover, although the literature has tended to identify innovation performance indicators as unidimensional, organizations actually aim to achieve various performance objectives simultaneously (Baum et al. 2000, Dussauge et al. 2002). Efficiency and effectiveness are central criteria in assessing performance (Schmidt and Finnigan 1992, Neely 1998), with the challenge for organizations being to balance the two in their R&D teams (Fox 2013). There appears to be a poor fit between practical and academic research on innovation performance. It is therefore essential to establish an additional multidimensional view of innovation of R&D organizations, since, in practice, organizations target multiple performance objectives at once, balancing between strategies aiming at efficiency or effectiveness (Mouzas 2006).

Finally, the latest advances in communication technologies (ICT) have enabled organizations to establish and extend coordination structures from different locations. Despite the rapid increase of organizations predominantly communicated via e-mail (Mathews et al. 1998, Tsai 2000, Muncer et al. 2000a, Frantz and Carley 2008, Bird et al. 2008, Lin 2010), little is known about the characteristics and performance of such organizations.

This dissertation aims to fill the gaps outlined above by investigating the role of product modularity and its implications for innovation in the R&D team context. Studying this subject is important because innovation is essential for organizations, and the further challenges of a world growing more global and interlinked have accelerated the establishment of new forms of organization and increased the pressure to innovate. R&D teams that jointly develop products and technologies with a particular degree of product modularity have become a common organizational form. It is therefore of fundamental significance to study in greater depth the effects of product modularity on innovation in the organizational context of R&D teams.

In particular, it is crucial to understand what areas of the product modularity and team organization, managers need to pay particular attention to cope with the impact of misalignments and promote innovation. This research also delivers evidence that there is a relationship between the alignment of product modularity and organizational designs, and this degree of alignment has an impact on innovation.

1.3. Research Design and Sample

The empirical testing was conducted in a large leading multinational company in the automotive industry with R&D teams in all regions (i.e., America, Europe and Asia). The focus on leading firms in an industry is a common empirical approach (Gulati 1995, Gulati and Garguilo 1999) as it allows the exploration of organizations in a more favorable innovation context. The unit of analysis is the different R&D teams that develop different kinds of technical products with a different degree of product modularity. Moreover, R&D teams are a common form of organization in the industry, since they are perceived as the technological "gatekeeper" in the organization (Jankowski 1998, Obstfeld 2005). Additionally, the application of product modularity is relatively spread out in the automotive industry (Sako 2003, Fourcade and Midler 2004, Ro et al. 2007, Zirpoli and Becker 2011a, MacDuffie 2013), and this application enjoys a relatively high degree of innovation outcomes (Camuffo 2004, Fixson et al. 2005, Ro et al. 2007). Finally, the automotive industry enjoys a high degree of innovative activities (Pires 1998, Takeishi and Fujimoto 2001, Camuffo 2004, Fixson et al. 2005, Ro et al. 2007), which makes it a useful research setting.

In regard to the essential construct of product of modularity, the literature on the possible measures typically quantified it on a continuous scale (Gershenson et al. 2003, Guo and Gershenson 2007, Hölttä et al. 2012). In this paper, we extend past research and test empirically for the first time a multidimensional view of product modularity (i.e., module standardization and reconfiguration). This is especially important in the research context of design engineering because innovation includes new configurations that, by definition, cannot be known at the point of designing the components. Consequently, we need to define modularity at the level of the product system which requires a higher complexity in the definition and metrics than one dimension (Salvador, 2007: 226). Thus, we develop a definition and measures of product modularity that include module standardization and reconfiguration.

In addition, and regarding the dependent variable, we go one step further and measure innovation as a multidimensional construct (i.e., effectiveness and efficiency) since, in practice, organizations target multiple performance targets at the same time. (Baum et al. 2000, Dussauge et al. 2002).

In order to test our hypotheses, we were able to collect data from multiple sources. First, as a primary data source in the process, a survey data collection using a structured questionnaire sent to 140 R&D teams involved in running projects was carried out. In addition to the primary collected survey data, two additional data sources were used to triangulate the survey data. First, the number of patents and R&D investments were obtained from secondary company data. This data was collected for 81 R&D teams. Second, over data from 150 thousand emails was captured over a five-month period for 27 R&D teams.

1.4. Structure of this Dissertation

In order to answer the research question and deliver the indicated contributions, this dissertation contains three empirical studies that shed light on these issues. The research question is composed fundamentally of three building blocks: product modularity, collaboration, and innovation.

We start our analysis in Chapter 2. This first empirical study examines collaboration in R&D teams from an organizational point of view, by analyzing the impact of the critical elements of collaboration (team interaction, knowledge diversity) on innovation, under the moderating effect of product modularity. The hypotheses and results suggest that, in this context, there is a negative impact of team interaction on innovation, whereas knowledge diversity shows a positive impact. Further, product modularity moderates negatively in both relationships: one, team interaction and innovation; and two, knowledge diversity and innovation. Due to the unpredictable and, in part, unusual outcomes of the moderating effect of product modularity, this study suggests further elaboration of the concept of product modularity and exploration of the potential direct influences of product modularity on innovation. Hence, these outcomes become the trigger for the subsequent empirical study.

The second empirical study, exposed in Chapter 3, builds on and extends the first while focusing on the dimensions of product modularity and the effects on innovation. This study considers a more fine-grained approach to product modularity, aiming to resolve ambiguous results of past research. In the R&D team context, in particular, product modularity is ubiquitous. It is, therefore, necessary to further granulate this concept and study the effects on innovation at the team level in greater depth. Empirical studies of the effects of product modularity on innovation have been scant and ambiguous, providing divergent definitions and dimensions for product modularity. Some researchers have suggested that product modularity stimulates innovation, while others argue that it inhibits it. We adopt a definition of product modularity as a multidimensional construct composed of module standardization and reconfiguration and investigate the impact of modularity on two dimensions of innovation (i.e., effectiveness and efficiency). Specifically, we find a U-shaped relationship between module standardization and innovation effectiveness, with a negative impact on innovation efficiency. Furthermore, reconfiguration has an inverted U-shaped relationship with innovation effectiveness and a positive effect on innovation efficiency.

In addition to investigating the impacts of collaboration and product modularity on innovation, we go one step further in the third empirical study (Chapter 4) and look at how forms organize themselves under this particular R&D team context. Building on the insights from the second empirical study (Chapter 3) that product modularity can have contradictory effects on innovation, we conceptualize modularity as two-dimensional (module standardization and reconfiguration), and we empirically explore the mirroring hypothesis separately. Additionally, we offer nuance in terms of the effects of the alignment between product modularity and team interaction on innovation. This study explores the issue of the degree of alignment between module standardization and reconfiguration with team interaction within R&D teams and, ultimately, we evaluate the impact on innovation at the team level. The results suggest a U-shaped relationship between the alignment of team interaction and module standardization on innovation. Furthermore, the degree of alignment of team interaction and module reconfiguration proposes an inverted U-shape relationship with innovation.

Chapter 5 summarizes the main findings and provides general conclusions. In addition, we propose managerial implications of the findings. Finally, we conclude this chapter with a discussion of the limitations of the studies and offer potential areas for future research. Table 1 represents the summary of the research agenda in the three central chapters of the dissertation.

1.5. Overall Contribution

This dissertation aims to offer significant contributions to academic and managerial objectives. Essentially, this dissertation unpacks our theoretical understanding of the concept of product modularity in R&D organizations by establishing the two essential dimensions of product modularity (i.e., module standardization and reconfiguration). Moreover, we study the effects of module standardization and reconfiguration on innovation at the R&D team level. We thus resolve earlier ambiguities identified by previous research on product modularity. By analyzing the two dimensions of modularity, we find that, for example, module reconfiguration has an inverted U-shaped relationship with innovation effectiveness, and we estimate an optimum level of module reconfiguration. In addition, the study aims to resolve the prevailing poor fit between innovation practice and theory by adopting, empirically, effectiveness and efficiency views of innovation. For managers of R&D teams, this means that strategic decisions on innovation objectives hold direct and nuanced implications for product modularity, such as priorities for standardization or additional efforts for reconfiguration.

Furthermore, this dissertation contributes to a deeper understanding of the dynamics of the collaboration process and extends the literature in the field of organization science and team organizations. Specifically, we enhance the understanding of collaboration in the R&D teams developing products with a certain degree of modularity. This is realized by filling the gap and investigating the impact of R&D collaboration on innovation at the product level. Moreover, our aim is to put the R&D organization into an everyday context by conceptually and empirically analyzing the impact of the essential collaboration characteristics of R&D teams (team interaction and knowledge diversity) on innovation, under the moderating effect of product modularity.

Moreover, with this dissertation, we enhance the understanding of the concept of alignment between task and organizational structure at the team level. In addition, we provide evidence of the impact of this alignment on innovation. We contribute to the literature that studies the "mirroring" hypothesis (Brusoni and Prencipe 2001, Langlois, 2002, Sosa et al. 2004, MacCormack et al. 2012, Furlan et al. 2014), by proposing that the alignment can influence innovation. We suggest that aiming for an optimized alignment between product modularity and team interaction can be beneficial to innovation at the team level. It is essential for managers to anticipate where misalignment is more likely to occur—that is, to distinguish which areas of the product and team require particular attention to identifying critical design interfaces and ensure the most effective team interactions.

Table 1 Summary of the three Empirical Studies

Chapter	Title	Research Question	Dependent Variable	Data sources	Contributions
Chapter 2	**The Product Modularity Paradox: Collaboration and Innovation in R&D Teams**	*What is the impact of team interaction and knowledge diversity on innovation in distributed R&D teams and how are these relationships influenced by product modularity?*	*Innovation*	1. Survey dataset (101 teams) 2. Nr of patents and investments (81 teams) 3. email communication (27 teams)	* Team interaction has a negative impact on innovationn. * Knowledge diversity has a positive impact on innovation. * Product modularity moderates negatively the relationship between team interaction and innovation. * Product modularity moderates negatively the relationship between knowledge diversity and innovation. * Investigating the impact of R&D collaboration on innovation at the product level. * Conceptually and empirically analyze impact of the essential collaboration characteristics of distributed R&D teams (team interaction, knowledge diversity) on innovation, under the moderating effect of product modularity. * Better understand the process of collaboration in distributed R&D teams and to extend the present body of knowledge with an empirical insight into this problem.
Chapter 3	**Unpacking Product Modularity and Innovation: The Case of R&D Teams**	*What is the impact of module standardization and reconfiguration (the two dimensions of product modularity) on innovation effectiveness and efficiency in dispersed R&D teams?*	*Innovation effectiveness and Innovation efficiency*	1. Survey dataset (101 teams) 2. Nr of patents and investments (81 teams)	* Module standardization has a U-shaped relationship with innovation effectiveness, with a negative impact on innovation efficiency. * Reconfiguration has an inverted U-shaped relationship with innovation effectiveness and a positive effect on innovation efficiency. * Study the effects of module standardization and reconfiguration on innovation at the R&D team level. * Resolve poor fit between innovation practice and theory by adopting, empirically, an effectiveness and efficiency view of innovation. * Unpack our theoretical understanding of the concept of product modularity in R&D teams by establishing a multidimensional view of product modularity. (module standardization and reconfiguration).
Chapter 4	**The two mirrors of modularity: Product modularity and innovation in distributed R&D**	*1) How does the alignment of module standardization and team interaction impact innovation?* *2) How does the alignment of module reconfiguration and team interaction impact innovation?*	*Innovation*	1. Survey dataset (101 teams) 2. Nr of patents and investments (81 teams) 3. email communication (27 teams) 4. Interviews (12 expertise)	* Enhance the understanding of the concept of alignment between task and organizational structure at the team level by applying a multidimensional definition of product modularity. * Provide evidence of the impact of this alignment on innovation. * Aiming for an optimized alignment between product modularity and team interaction can be beneficial to innovation at team level. * Exploration of Email communication data among R&D teams as unique source of investigation.

CHAPTER 2

THE PRODUCT MODULARITY PARADOX. COLLABORATION AND INNOVATION IN R&D TEAMS[1]

ABSTRACT

Large organizations build internal, R&D teams for collaboration and the sharing, creation, and distribution of knowledge, teams which are difficult to structure and integrate. To reduce complexity and to foster innovation, organizations can introduce product modularity as one essential strategy for R&D teams to develop their products in collaboration. Collaboration in R&D teams working with product modularity is, however, paradoxical, as it requires autonomy, on one hand, working and keeping modules separate in design, and yet interdependent on the other hand, as teams need to be participative in the integrative process of bringing different modules together. Research into intra-organizational collaboration is scant, and the lack thereof calls for more empirical evidence of the effects of collaboration on innovation. Drawing upon the knowledge-based view of the firm, we examine collaboration in R&D teams by analyzing the effects of the central elements of collaboration (team interaction, knowledge diversity) on innovation, under the moderating effect of product modularity. Analyzing survey data from 101 teams and 550 engineers in a global automotive firm, we find a negative impact of team interaction on innovation, whereas knowledge diversity shows a positive impact on innovation. Furthermore, product modularity moderates negatively both relationships, those being team interaction and innovation, along with knowledge diversity and innovation. These findings contribute to the literature and management practice of product modularity within the context of R&D teams.

Keywords: product modularity, collaboration, team interaction, knowledge diversity, use of ICT, R&D, teams, innovation.

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[1] A condensed version of this paper was presented at the International Conference on Innovation, Management and Industrial Engineering (IMIE 2016), Kurume, Japan. I would like to thank the anonymous reviewers and the participants of IMIE meeting for their feedback.

2.1. INTRODUCTION

Global R&D organizations are becoming ubiquitous in an increasingly competitive environment. In this highly competitive context, innovation is essential for the competitiveness and survival of the organization. Innovation refers to the development and execution of new ideas to solve problems (Van de Ven et al. 1976, Dosi 1988). In this competitive context, large organizations build R&D teams to innovate (Boutellier et al. 1998, Townsend et al. 1998). We define an R&D team as a form of an organization whose members include engineers from diverse specialized domains and integrate their knowledge to develop new products (Sanchez and Mahoney 1996, Sanchez 1999, Robbins 2001, Emmitt and Gorse 2007), bound by a long-term common interest or goal, and who communicate and coordinate their work through ICT. Under this context, the collaboration of R&D organizations becomes essential (O'Leary and Bingham 2007), and in this particular R&D team setting, collaboration elements such as team interaction (i.e., emotional closeness and communication frequency) and knowledge diversity can have a significant influence on innovation outcomes (Hansen and Nohria 2004).

The challenges of managing such R&D teams are further increasing, with shorter product development cycles, continuous introduction of new technologies, and the need to co-create products and services with customers and partners. These demanding situations drive organizations to adopt different approaches to product design and development processes (Rycroft and Kash 1999), with scholars proposing the use of product modularity to manage and reduce the complexity (Baldwin and Clark 2000). Product modularity is defined as the use of standardized, interchangeable components to configure a variety of end products (Schilling 2000). A product can be divided into loosely coupled/independent parts, i.e., the modules (Ulrich 1994). The implications of modularity for organizations' innovation have attracted increasing attention (Sanchez and Mahoney 1996, Helfat and Eisenhardt 2004, Pil and Cohen 2006).

However, existing studies have limited their analysis to specific performance indicators in defined industries (Baum et al. 2000, Dussauge et al. 2002). Additionally, several studies have included collaboration as a construct in different models and observed the impact on innovation output (Klomp and van Leeuwen 2001). These studies have been mainly related to the effects of R&D investments on performance and did not examine the influence of the collaboration characteristics of R&D teams on innovation within the context of product modularity.

Furthermore, numerous studies have shown the importance of collaboration in R&D projects (Pinto and Pinto 1990, Argyres 1999, Ahuja 2000, van der Vegt and Janssen 2003, Kratzer et al. 2004, Langfred 2005, Carnabuci and Bruggeman 2009, Janhonen and Johanson 2011). Previous research has argued that a significant number of elements play a role in the success of these collaborations. However, this study narrows the setting to elements regarded as essential under this distinctive collaboration context of R&D teams. Drawing upon the above definition of R&D teams which is derived from previous studies, and after carrying out a review of R&D team research literature, we identified two essential factors: 1) team interaction (Pearce and Gregersen 1991, Gassmann and von Zedwitz 1999, Bishop and Scott 2000, Van der Vegt and Janssen 2003, Langfred 2005) and 2) knowledge diversity (Ahuja 2000, Sethi et al. 2001, Carnabuci and Brueggeman 2009, Sandberg et al. 2015).

A common principle in diverse studies is that organizational capabilities that generate new and diverse knowledge are critical for innovation (Hargadon and Sutton 1997, Galunic and Rodan 1998, Yayavaram and Ahuja 2008), of particular importance being the knowledge diversity of R&D teams. The existing literature suggests that R&D team knowledge diversity is one of the most critical aspects in order to innovate (Hargadon 1998, Dixon 1999) as, for instance, it improves a team's ability not only to identify but also to evaluate solutions (Hargadon 1998, Singh and Fleming 2010). Consequently, in recent years there has been a significant increase in the use of knowledge diversity as a method for innovation (Williams & O'Reilly 1998, Cronin and Weingart, 2007, Harrison & Klein 2007).

Furthermore, one further essential aspect that affects the exchange of knowledge among team members is the extent to which a team is interconnected (Allen 1977, Allen et al. 2007), in other words, to what extent tasks among team members are interdependent. On the contrary, a small degree of team interaction results in fewer chances for knowledge exchange and problem-solving activities (Lazer and Friedman 2007, Fleming et al. 2007a). Therefore, team interaction among team members becomes essential to improve overall innovation performance (Allen 1964, Wheelwright and Clark 1992), as effective and efficient team interaction, for instance, speeds up development time (Ulrich and Eppinger 2000) and allows teams to dedicate themselves to more creative tasks, enhancing innovation outcomes (Dorst and Cross 2001, Hertel et al. 2005)

Under this R&D context, collaboration in teams working with product modularity becomes paradoxical. The following arguments support this condition. On the one hand, a large body of literature asserts that product modularity offers an approach to collaboration among team members that significantly reduces the need for coordination and communication efforts. (Sanchez and Mahoney 1996, Baldwin and Clark 1997, Fine 1998, Schilling 2000), and supports autonomous development (Fine 1998, Baldwin and Clark 2000, Tiwana 2008), in other words, independent tasks following basic standards and design rules. On the other hand, collaboration among R&D teams within this context requires the need to be participative and to provide intense effort in knowledge exchange (Brusoni and Prencipe 2001, Steinmueller 2003), as it is required for the integrative process to bring the different modules together. This "a priori" apparent contradiction makes the research of these essential elements of collaboration on R&D teams and the impact on innovation, under the moderating effect of product modularity, particularly interesting, since product modularity can influence these relationships.

Furthermore, the latest advances in communication technologies (ICT) have enabled organizations to establish and extend coordination structures from different locations. Despite the rapid increase of organizations that communicate predominantly via email, little is known about the characteristics and performance of such organizations. Mainstream research has been dedicated to interorganizational collaboration groups (Gulati 1999, Ahuja 2000, Keast et al. 2004, Hagedoorn et al. 2006, Burt 2014), and internal teams have been under-explored.

This paper, first, examines collaboration from an organizational view of the R&D team context by analyzing the impact of two essential elements of collaboration (team interaction and knowledge diversity) on innovation under this specific R&D team context, and, second, explores the moderating effect of product modularity. We develop a theoretical framework that attempts to foresee how collaboration affects innovation in R&D teams working with product modularity. The unit of analysis of this research is centered at the team level. The research attempts therefore to address the following question:

What is the impact of team interaction and knowledge diversity on innovation in R&D teams, and how are these relationships influenced by product modularity?

Investigating this research question is thus important, since innovation is crucial for organizations' survival, and further challenges in an increasingly more global and interlinked world have accelerated the establishment of new forms of organization in order to continue to innovate. R&D teams of collaboration have become regular forms of organization. It is therefore of fundamental significance to more profoundly study the build, the forming and the structures of these types of organizations, and their effects on innovation.

The principal contribution of this paper is to enhance the understanding of intra-organizational collaboration in the R&D team context developing products with a certain degree of product modularity. We aim to contribute and extend the literature in the field of organization science and team organizations. This is realized by filling the gap and investigating the impact of R&D collaboration on innovation at the team level.

Second, we aim to put the R&D organization into an everyday context by conceptually and empirically analyzing the impact of the essential collaboration elements of R&D teams (team interaction, knowledge diversity) on innovation, under the moderating effect of product modularity.

Finally, this paper also attempts to study the interactions empirically via email and other recent communication channels among R&D team members.

This paper is organized into five sections. The first part addresses the definitions of collaboration and organizations and their main characteristics. Second, drawing on previous research, a theoretical framework is presented that links the identified features likely to impact innovation. Next, the related hypotheses are developed. The paper continues by detailing the empirical research setting and data collection, which is in turn followed by the empirical results. Finally, the paper describes these results concerning the existing literature in the discussion and conclusion section.

2.2. CONCEPTUAL BACKGROUND

As proposed by the knowledge-based theory of organization (Nonaka 1994, Zander and Kogut 1995, Grant 1996a, Kogut and Zander 1996), the competitive weapons of organizations essentially rest in their capacity to acquire information and create knowledge. This organization theory views firms as social communities specializing in efficient knowledge creation and transfer (Kogut and Zander 1996, Nickerson and Zenger 2004). In particular, under the R&D team context, knowledge is increasingly transferred among individuals and teams, since this provides opportunities for mutual learning that enhance knowledge creation and innovation (Kogut and Zander 1992, Tsai and Ghoshal 1998).

Innovation in this context is the development and implementation of new ideas to solve problems (Van de Ven et al. 1976, Dosi 1988), which predominantly derives either from combining knowledge and technologies in a novel manner (Schumpeter 1934, Nelson and Winter 1982, Fleming and Sorenson 2001, Carnabuci and Bruggeman 2009) or from recombining existing technologies so that they can acquire new functions (Henderson and Clark 1990, Yayavaram and Ahuja 2008). As indicated by Kratzer et al. (2004: p 64), "since the core product of innovation activities is knowledge, and this new knowledge can only be created through the interaction between knowledge specialists with various backgrounds of expertise," collaboration could be considered at the core of these innovation activities.

Numerous studies have shown the importance of collaboration in R&D projects (Pinto and Pinto 1990, Langfred 2005, Ahuja 2000, Janhonen and Johanson 2011). Furthermore, various studies have claimed very diverse collaboration elements that have a significant effect on innovation (Kratzer et al. 2004, Jacobs et al. 2007). Under the R&D team context, text, this research regards both team interaction and knowledge diversity as critical. These two essential elements are particularly important because they best fit the definition of R&D teams. Moreover, they were previously noted as having a relevant impact on innovation in organizations (Argyres 1999, Jacobs et al. 2007). We further elaborate on these two aspects in the following section.

2.2.1. Team Interaction

Concerning the first element of collaboration in the R&D team context, team interaction, a team gathers a certain number of members who have interdependent jobs but a joint responsibility for team-level outcomes (Hackman 1987, Guzzo and Dickson 1996). R&D teams working with product modularity are frequently applied in knowledge-intensive contexts, where integrating diverse competences is required to solve problems (Denison et al. 1995, Keller 2004). Under this context, research studies view organizations as problem-solving entities (Nickerson and Zenger 2004, Brusoni et al. 2007). Solving complex problems requires interactions among team members (Thompson 1967, Bishop and Scott 2000, Mac Cormack 2012, Furlan et al. 2014). Team interactions under the R&D team context underpin how people understand each other and how knowledge is transferred. Team interaction is believed to be one of the most essential elements that influence team performance and innovation (Pinto and Pinto 1990, Saavedra et al. 1993, Szulanksi 1996, Janhonen and Johanson 2001, Van der Vegt and Janssen 2003, Sosa et al. 2004, Langfred 2005, Hertel et al. 2015, Sosa et al. 2015, Young-Hyman 2017) as team interactions, for instance, speed up development time (Ulrich and Eppinger 2000) and allow teams to dedicate themselves to more creative tasks, enhancing innovation outcomes (Dorst and Cross 2001, Hertel et al. 2005). Such interactions are fundamental in knowledge-intensive work settings, where integrating diverse knowledge is needed to solve problems and innovate (Denison et al. 1996, Keller 2001, Lurey and Raisinghani 2001). There is also growing recognition of the need to understand how members interact within teams if communication is to be efficient and effective (Pearce and Gegersen 1991, Morelli et al. 1995, Gupta and Wilemon 1996, Langfred 2000, Robbins 2001, Emmitt and Gorse 2007, Terwiesh et al. 2002, Gokpinar et al. 2010, Cormack et a. 2012, Sosa et al. 2015). For the purpose of this research, team interaction refers to the degree to which the team members coordinate in order for the group to accomplish its work (Kiggundu 1983, Brass 1985, Guzzo and Shea 1992, Jehn and 1997, Hertel et al. 2005). The success of such team interactions depends on two central factors: the frequency of communication (Arrow 1974, Szulanski 1996, Terwiesch et al. 2002), and the closeness of the overall relationship among the members of the team (Janis 1982, Arrow 1974, Johnson and Johnson 1989, Marsden, 1990, Szulanski 1996, Sethi et al. 2001, Terwiesch et al. 2002, Bano et al. 2016).

With regard to the theorization of the relationship between team interaction and innovation, previous studies have viewed team interaction as an essential element for innovation in organizations. A substantial amount of literature has argued that increasing degrees of team interaction improve innovation. Prior work has suggested that, in high dynamic technological environments which require a high degree of rapid organizational and technical adjustments, team interaction plays a fundamental role and has positive effects on innovation. (Ernst 2005, Pero et al. 2010). For instance, complex, non-routine tasks require more information processing than simple tasks (Tushman 1977, Daft and Macintosh 1981). And, through more intense communication needed to support increasing information processing, increasing trust among team members (Jehn and Shah 1997, Hertel 2003a) takes place. Trust gives team members the belief that the knowledge shared will not be copied or misused (Krackhardt 1992, McEvily et al. 2003). Consequently, new knowledge and insights can be produced (Kratzer et al. 2004), which ultimately positively affects innovation (Borgatti and Foster 2003, Obstfeld 2005). Hence, effects on innovation are contingent on environmental dynamics (Ethiraj and Levinthal 2004, Ernst 2005, Pero et al. 2010).

Since our theorizing and study focus on a stable and mature environment with relatively predictable technological change (Uotila et al. 2009), a certain degree of team interaction is existing within this setting, but the negative effects have a much higher significance than the positive ones. (Sanchez and Mahoney 1996, Hoetker 2006). Consequently, team interaction will diminish innovation. We have derived three principal points of view from the literature.

Firstly, team members who are intimately related and who communicate frequently may start to dissuade each other from work-related issues and enjoy themselves by debating topics unrelated to work. This process can lead to the extreme that no critical evaluation of each other's ideas takes place anymore and a so-called "groupthink" emerges (Nyström 1979, Janis 1982, Amabile and Conti 1999), which refers to a high level of concurrence seeking and conformance by members of the group. This situation can lead that individuals rely too heavily on the knowledge of their immediate peers and team colleagues with whom they feel most comfortable (Perry-Smith and Shalley 2003). Such behavior adversely affects the creativity of a team's decisions, because it leads to an incomplete survey of alternatives, being less meticulous (Paulus and Dzindolet 1993, Nicholas 1994), and having a reduced selective perception of information and options (Janis 1982), which ultimately diminishes innovation.

Second, with increasing degrees of team interaction, close and frequent communication can result in lower group standards (West and Farr 1992, Paulus and Dzindolet 1993, Nicholas 1994) because the development and maintenance of strong contacts can be time-consuming, it may divert attention from performing productive innovation tasks (Alderfer 1977, Ancona and Bresman 2007), and team members can be more inclined, for instance, to compare their performance with others in the unit instead (Paulus and Dzindolet 1993). Consequently, this situation can also lead to norms of adhering to established standards and conventions, which can potentially stifle experimentation and creativity (Uzzi and Spiro 2005). This situation can ultimately lead to the diminishment of innovation.

Finally, as research shows, high levels of communication and strong team interaction can create mutual production blocking (Diehl and Stroebe 1987, Muller 1999, Hertel et al. 2005) which is the propensity of team members to obstruct others from sharing ideas, can limit cognitive capacity (Nijstad 2000), may become affected by inactivity and lock-in (Maurer and Ebers 2006), and can lead to a tendency of group members to let others be innovative (Diehl and Stroebe 1987, Kratzer et al. 2004), which ultimately diminishes innovation.

In sum, under this context, task independence is expected to affect the innovation of R&D teams negatively. High degrees of team interaction will decrease the innovation of teams by leading to free-riding, by lowering the group's performance standards, and by dissuading team members from current running activities. Therefore, this research proposes a negative relationship between team interaction and innovation:

H1: Team interaction has a negative impact on innovation

2.2.2. Knowledge Diversity

Knowledge diversity, regarded as the second essential element of collaboration in R&D teams, can be understood and framed within the knowledge-based theory of the organization (Nonaka 1994, Zander and Kogut 1995, Grant 1996a, Kogut and Zander 1996). As already discussed, this theoretical framework suggests that the competitive weapons of organizations essentially lie in their capacity to create knowledge. Consequently, knowledge creation and management are especially crucial in team-based organizations (Cohen and Ledford 1994, Kirkman and Shapiro 2001, Ancona and Bresman 2007). Sharing knowledge is one of the essential aspects of effective teamwork: to accomplish their mission, teams must integrate and exchange information throughout a "performance episode" (Salas et al. 2008). Accordingly, knowledge is increasingly transferred between individuals, teams, and organizations, since this provides chances for joint learning and mutual aid that encourage knowledge creation and innovation (Kogut and Zander 1992, Tsai and Ghoshal 1998).

One of the main strategic reasons for setting-up R&D teams is to combine the core competencies of specialists from different locations. These R&D teams are explicitly structured to provide "distribute expertise" (Hollenbeck et al. 1998), with a different set of skills and knowledge bases (Richardson 1972, Arora and Gambardella 1990, Powell et al. 1996) in the innovation process. It is typically the case in R&D teams working with product modularity, which enjoy a very diverse variety of expertise.

Knowledge diversity in an R&D team context refers to the degree to which members of an individual's communication network are heterogeneous in a relevant dimension or domain (Rogers and Kincaid 1981). Recent literature has argued that, in high-tech, dynamic environments, increasing degrees of knowledge diversity affect innovation negatively. Previous studies have suggested, for instance, that the diversity of knowledge can create information and idea overload, and because many of the viewpoints in an R&D team are in balance with one another, high knowledge diversity also makes it difficult to resolve differences among perspectives (Olson et al. 1995, Sethi et al. 2001). Hence, it is likely that in this highly dynamic environment, knowledge diversity will diminish innovation.

However, since our study focuses on a mature, stable and stablished development environment with relative predictable technological change (Uotila et al. 2009, Brusoni et al. 2001, Furlan et al. 2014), we hypothesize that knowledge diversity has a positive impact on innovation. In this situation, the positive effects of knowledge diversity should have a much higher implication than the negative ones. We extract three principal arguments for this statement from the literature.

First, the more different and diverse knowledge can take place in the team set up, the more this can provide an individual with a greater variety of information input and non-redundant knowledge (Krackhardt 1992). More specifically, this heterogeneity can influence an employee's access to information about innovation or new technology. It may also enhance an organization's ability to innovate and create new ideas (Cohen and Levinthal 1990). When team members interact with diverse technical areas, employees become more knowledgeable about new technology and more resourceful in using it, which positively affects innovation (Kanter 1983).

Second, since the number of functional areas and domains represented on the team increases with increasing levels of knowledge diversity, so does the variety of perspectives brought to the team (Sethi et al. 2001, Nakata and Im 2010). This situation, in turn, increases the possibility of discovering novel linkages (Osborn 1963, Milliken and Martins 1996, van Knippenberg and Schippers 2007) and subsequently can encourage innovation. The development of a vehicle, for instance, combines highly specialized expertise in the engine, electronics, transmission, and materials. All these domains support the integration of innovations in each area.

Third, these teams experience a certain degree of task conflict (i.e., caused by knowledge diversity), facilitating a particular environment where each other's task is validated, actively reducing potential mistakes (Bowers et al. 2000). This situation supports taking more suitable choices than those without task conflict (Simon and Peterson 2000). This condition can lead team members, with an appropriate level of team conflict, to become more effective in solving given problems (Phelps and Damon 1989), influencing performance by increasing creativity (Dorst and Cross 2001) and ultimately having a positive impact on innovation.

Based on arguments outlined above, we suggest that knowledge diversity in the R&D team context affects innovation positively. Thus, this results in the following hypothesis:

H2: Knowledge diversity has a positive impact on innovation

2.2.3. Moderating Effect of Product Modularity on the Relationship between Team Interaction and Innovation

The notion of product modularity has been widely suggested as a strategic decision for dealing with a global context increasing in its complexity (Starr 1965, Pine 1993, Sanchez and Mahoney 1996, Fine 1998, Baldwin and Clark 2000, Ulrich and Eppinger 2000, Du et al. 2001, Garud et al. 2003), and its implications for an organization's innovation have attracted increasing attention (Sanchez and Mahoney 1996, Helfat and Eisenhardt 2004, Pil and Cohen 2006). The general concept of modularity refers to the degree to which a system or product can be separated and recombined (Schilling 2000). Product modularity allows a product to be decomposed into a set of smaller building blocks or modules. Following this approach, different team members can autonomously and concurrently design and test modules on a development network (Sanchez and Mahoney 1996, Sanchez 1999).

We theorized above that team interaction negatively affects innovation. The higher the degree of team interaction, the lower the degree of innovation. This effect occurs primarily due to the three arguments outlined earlier: risk of relying on much on each other and "groupthink" effect, too much time-consuming in communication that leads to dedication to other tasks not related to performance, and finally mutual communication or production blocking that result in reduced cognitive capacity.

We argue that product modularity plays a significant role in making the relationship between team interaction and innovation more negative. As pointed out earlier, collaboration in R&D teams working with product modularity is somehow paradoxical, as it requires, on one hand, to be autonomous while working to keep a modularly defined design, yet on the other hand interdependent, as they need to be participative in the integrative process of bringing different modules together. We expect therefore that product modularity moderates the relationship between the essential elements of collaboration with innovation.

First, with regards to risk relying too much on each other and the effects of "groupthink," increasing the effects of product modularity would affect innovation negatively because teams need to increasingly concentrate on designing specific modules which will require less coordination with each other or among stages and domains (Langlois 2002). This circumstance leads to a decrease in knowledge sharing/transferring needs among the different teams (Simon 1962, Brooks 1995), negatively affecting the relationship between team interaction and innovation. This indicates that, if we represent the relationship between team interaction and innovation as a straight negative line, product modularity will further increase the negative slope of this line.

Second, with regards to too much time-consuming in communication that leads to dedication to other tasks not related to innovation and, third, related as well to the production blocking risks, the following arguments come into view. When a complex product is modularized, the product is composed of some less complex parts which can be independently developed by engineers (von Hippel 2005) from inside and outside the organization (Sanchez and Mahoney 1996); this circumstance relaxes the degree of information sharing needs. This situation would support the reduction of time-consuming in exchanging information among team members and significantly reduce time consumption as well as the risk of production blocking. This condition would ultimately negatively affect the relationship between team interaction and innovation.

In sum, the above indicates that product modularity negatively moderates the relationship between team interaction and innovation. Therefore, we suggest that:

H3: Product modularity negatively moderates the relationship between team interaction and innovation

2.2.4. Moderating Effect of Product Modularity on the Relationship between Knowledge Diversity and Innovation

Furthermore, we extend our logic by considering the impact of product modularity on the relationship between knowledge diversity and innovation, both constructs at the R&D team level. Recall that our arguments to support the positive effects of knowledge diversity on innovation are essentially these three: the access to a greater variety of information and non-redundant knowledge and new technologies, the facilitative environment for perspectives and ideas sharing, and the certain degree of conflict that supports better problem-solving.

First, with regards to access to new information, knowledge, and technologies, and due to the reason that R&D team members need to understand the standards used in product modules (Sethi et al. 2001, Nakata and Im 2010), and compatible interface with other components within the development team, increasing time and efforts will be allocated in the comprehension of the modules. This situation would take away dedication from pure design activities and idea creation (Persson and Aehlstroem 2006, Gomes and Dahab 2010), and it may at the same time negatively affect product innovation (Shapiro and Varian 2003).

Second, with regards to a facilitating environment for knowledge and ideas sharing, and because such modular designs make product development more predictable (Chersbrough 2003, Sabel and Zeitlin 2004, Evans and Davis 2005, Ernst 2005) , common modules are repeatedly reused, leading to similar product design (Robertson and Ulrich 1998) and reducing the need for idea-sharing among team members and, likewise, innovation. A bicycle, for instance, is mainly integrated by components (i.e., wheel, pedal, saddle and frame) that are reused in further designs and all across models with predictable features and a very low degree of innovation.

Third, with regards to a certain degree of conflict that supports better problem-solving: developers can develop their modules with variant ideas, but they do not need to understand or possess the knowledge of the whole product or be concerned about interactions with other modules (Langlois and Savage 2001). Consequently, modular components tend to be clustered according to technological similarities (Gershenson et al. 2003). This reusable nature of modules reduces the need for interaction and problem-solving due to limited product differentiation or diversity, high product similarity, and lack of newness (Ulrich and Tung 1991, Robertson and Ulrich 1998).

Overall, the above indicates that product modularity negatively moderates the relationship between knowledge diversity and innovation. Therefore, we suggest that:

H4: Product modularity negatively moderates the relationship between knowledge diversity and innovation

A summary of the theorized effects is shown in Table 2.

Table 2 Summary of Hypothesis and Conclusions

H	Summary of hypothesis	Impact
H1	Team Interaction - Innovation	Negative
H2	Knowledge Diversity - Innovation	Positive
H3	Moderation of Product Mod. on Team Interaction - Innovation	Negative
H4	Moderation of Product Mod. on Knowledge Diversity - Innovation	Negative

2.3. RESEARCH DESIGN

2.3.1. Research Context: Automotive Industry

We conducted this research on R&D teams in a large leading multinational company in the automotive industry. Past studies on innovation have used a similar strategy of focusing on the leading firms in an industry (Gulati 1995, Gulati and Gargiulo 1999), as it allows the researchers to obtain all required data. We chose this industry for several reasons. First, the automotive industry enjoys a high level of innovation (Camuffo 2004, Ro et al. 2007), and it relies significantly on the creation of new patents. Second, technological collaboration has been and continues to be a significant feature of this industry on a global extension in the past years, especially regarding R&D activities. Finally, in this industry, the application and use of product modularity are widely extended (Ro et al. 2007, MacDuffie 2013, Cabigiosu et al. 2013).

2.3.2. Survey Data

As the primary data source in the process, a survey data collection using a structured questionnaire sent to the R&D teams involved in running projects was carried out. The survey was conducted in English. All teams were formal groups, in that employees were assigned, viewed themselves as parts of, and were seen by others as parts of teams, and these groups interacted and shared resources to accomplish mutual tasks and goals (Shea and Guzzo 1987). Participants were stretched across the three global regions in different countries in Europe, America, and Asia. These were individuals working on a variety of technology projects, a broad range of R&D domains, and experience levels within the organization which made the sample highly heterogeneous. All respondents were asked to complete a developed web-based questionnaire. This approach allowed respondents time to think about their replies, which minimizes the possibility of researcher bias (Ticehurst and Veal 2000, Zikmund 2000). In order to enhance the construct validity of the survey measures, the survey was pre-tested with a small group of team members or different regions. After the analysis of the reliability of each of the preliminary scales and exclusion of potential phrasing ambiguity, and in order to achieve completeness and clarity of meanings for all items, the survey was modified and used to capture the related data.

In order to select the most representative sample, a list of all R&D projects undertaken during the time of data collection was created. Based on that, we excluded very small size projects (i.e., those with less than three project engineers) and projects that were not primarily related to team activities. Including only completed projects could lead to an over-representation of successful projects, biasing the result. We, therefore, included projects belonging to all different phases of development (conception, detail design, validation, and the start of production). After this initial data preparation, we ended up with a list of 140 potential projects.

An introduction letter sent by email informed the potential respondents about the nature of the study. It was explained that data would be collected and treated confidentially, that for data matching procedures each questionnaire contained a unique identification number. Participation was voluntary. We surveyed team members across R&D regions for six weeks. A reminder with a copy of the questionnaire was sent to respondents who had not answered after three weeks. There were no significant differences between early and late respondents (we compared the average mean response values on key dimensions, such as innovation, module standardization, and reconfiguration[2]), which might suggest that nonresponse bias was not a serious concern (Armstrong and Overton 1977). A total of 695 questionnaires were distributed, and 550 completed questionnaires were returned, for a response rate of 79%.

2.3.3. Level of Analysis

The unit of analysis was the different R&D projects and the teams that develop different kinds of technical products with a different degree of product modularity[2]. Studying team-level variables based on data collected at the individual level brings the issue of aggregation from the individual to the team level of analysis (George and James 1993). Although aggregation is sometimes considered a controversial issue (e.g., Campion et al. 1993), recommendations were fulfilled to allow for such aggregation. First and most important, all relevant items of the questionnaire referred to the group and product level, and the measured aspects were understood

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[2] Since the literature has not provided strong arguments for attributing different weights to the elements, the average (incorporating similar weights per element) is used.
[2] The unit of analysis is at team level. One team develops one project or product at a time.

as shared views of the group or product developed. We assessed the degree of interrater agreement within the teams, which indicates the homogeneity of team members' perceptions (James et al. 1984). These results were consistent with recent studies and support aggregation to the group level (in more than 80% of the tested cases, interrater consistency was above 0.8). In addition, we calculated the intra-class correlation (ICC) for every team (total 101 teams), in order to estimate the interrater reliability (variables: knowledge diversity, team interaction, innovation effectiveness, innovation efficiency, module standardization and reconfiguration). The average ICC between measures was 0.75, with a 95% confidence interval, indicating a high degree of reliability (Campion et al. 1993).

2.3.4. Research Variables and Measures

This study relied on existing scales from the literature (described in more detail below) for the survey dataset. The questions were rated according to a seven-point Likert scale, which required respondents to indicate their level of agreement or disagreement by marking an "X" at the appropriate number (from 1 = Strongly Disagree to 7 = Strongly Agree).

2.3.4.1. Dependent Variable: Innovation

The dependent variable - innovation at team level - was operationalized, using existing and adapted items applied in recent studies, as a combination of four dimensions: A) market newness, B) patent creation (Griliches 1998, Katila 2000, Wang and Ellinger 2011), C) new product revenues as related to R&D costs, and D) patentable discoveries. The market newness (A) dimension assesses whether, during the product development period, the product contains any new technologies for that particular market (Hauser and Zettelmeyer 1997, Criscuolo et al. 2005, Yin et al. 2011, Schwartz et al. 2011). Based on previous research (Criscuolo et al. 2005, Yin et al. 2011, Schwartz et al. 2011), four items were used to operationalize market newness in the questionnaire: 1) "This product is new to the market or customer" (Jansen et al. 2006); 2) "The product possesses technical specifications, functionalities, components, or materials differing from the current ones" (Gunday et al. 2011); 3) "The product we developed is the first of its kind" (Darroch 2005), and 4) "The product has unique features to the market or customer" (Garcia and Calantone 2002).

The patent creation (B) dimension refers to the number of applied (filed or not filed) or current and potential innovation patents during the product development time (start of project until start of mass production) (Werner and Souder 1997, Bremser and Barsky 2004, Chiesa et al. 2009, Jalles 2010). This dimension was evaluated in the questionnaire with two items: 1) "This product has or is acquiring patents" (Wang and Ellinger 2011), and 2) "The product has patentable innovations" (Lau et al. 2007).

The new product revenues as related to R&D costs (C) and patentable discoveries (D) dimensions were measured through three adapted questionnaire items based on previous research (Garcia and Calantone 2002, Jimenez and Sanz 2011) capturing these measures: 1) the product's revenue generation compared to the R&D expenditure; 2) the product's patentable discoveries by R&D expenditure (Jimenez and Sanz 2011), and 3) whether the investment was reasonable compared to the innovative features developed for the product (Garcia and Calantone 2002).

The above survey items were scored on seven-point Likert scales ranging from "Completely disagree" (1) to "Completely agree" (7). The overall measure was constructed by taking the average of the nine described items. Reliability was evaluated through Cronbach's alpha. The Cronbach's alpha value for the dependent variable, innovation, was 0.820, indicating that the items were internally consistent and therefore the constructs were reliable (Streiner 2003, Hair et al. 2006).

2.3.4.2. Independent Variables Team Interaction

Our analysis focuses on the team level, and as such we consider team interaction as a construct at the team level. Team interaction refers to the combination of the degree of emotional intensity (Granovetter 1973, Krackhardt 1992, Hansen 2002) and communication frequency (Granovetter 1982, Krackhardt 1992). Seven items adopted from earlier research work were used to measure team interaction (Pearce and Gregersen 1991, Liden et al. 1997). To measure team interaction within the teams, the team members completed the survey using the following two key dimensions: first, communication frequency; and second, emotional intensity. With regard to communication frequency, the next items were used: 1) "Team members are in contact with each other on a regular basis in order to conduct regular business" (Lurey and Raisinghani 2001); 2) "Team members are in contact with each other on a regular basis for social, non-business, purposes" (Lurey and Raisinghani 2001); and 3) "Within your team, how often do you communicate" (Cummings and Cross 2003, Janhonen and Johanson 2011). With regard to emotional intensity, the following items were applied: 1) "Friendly attitude exists in the team" (Pinto and Pinto 1990); 2) "Team members feel strong ties to the team" (Sethi et al. 2001); 3) "Team members are committed to maintaining close interpersonal relationships" (Sethi et al. 2001), and 4) "Communication and intimacy of the relationship in the team is easy" (Szulanski 1996). The above survey items were scored on seven-point Likert scales ranging from "Completely disagree" (1) to "Completely agree" (7). The measure was constructed by taking the average value of the seven items. The Cronbach's alpha value of the team interaction scale was 0.763, which indicated internal consistency (Streiner 2003, Hair et al. 2006).

Knowledge Diversity

Knowledge diversity refers to the degree to which the knowledge held by the team members is distributed across different technological areas or, conversely, is concentrated in a few (Carnabuci and Operti 2013). Following prior research (e.g., Taylor and Greve 2006, Hoisl et al. 2014), this variable was measured using four existing and adapted questions applied in previous research: 1) “Team knowledge about many different technologies is combined” (Birkinshaw 2002); 2) “Team enjoys a variety of technical knowledge areas to develop the related product” (Danese and Filipini 2010); 3) “The diversity in the knowledge within the team makes the discussions difficult” (reverse question) (Cummings and Teng 2003), and 4) “Our team possesses diverse knowledge” (Zheng et al. 2011). The overall measure was constructed by taking the average value of the four items. The Cronbach’s alpha value of the knowledge diversity scale was 0.888, which also indicated internal consistency (Streiner 2003, Hair et al. 2006).

2.3.4.3. Moderating Variable: Product Modularity

Product modularity was defined as the use of standardized and interchangeable components or units that enable the configuration of a wide variety of end products (Schilling 2000). This variable was measured by the survey using six existing and adapted questions applied in recent studies: 1) “Product in design uses common component modules” (Danese and Filippini 2010); 2) “Product components are standardized” (Lau et al. 2007); 3) “Product can be decomposed into separate standard modules” (Lau et al. 2007); 4) “Components are interchangeable across different products” (Jacobs et al. 2007); 5) “Product components can be reused in other products” (Lau et al. 2007), and 6) “Products can be re-configured into further end products.” (Jacobs et al. 2007). As described earlier, items were scored on a seven-point Likert scale ranging from “Strongly disagree” (1) to “Strongly agree” (7). The overall measure was constructed by taking the average value of the six items. Regarding this moderating variable, the Cronbach’s alpha value of product modularity (0.761) showed internal consistency and construct reliability (Streiner 2003, Hair et al. 2006).

2.3.4.4. Control Variables

We controlled for ten variables - product modularity (the direct effect of the moderator), the use of ICT, the number of years of experience at the company, total work experience, team size, project length, experience in the number of fields, number of roles in the project, level of education, and the geographical dispersion of the team. Appendix 1 provides the arguments and operationalization of these variables.

2.3.5. Method

Our dependent variable (innovation) is operationalized as the average of nine seven-point Likert scales. As such, we performed OLS regression models to examine the hypothesized effects. Since theoretically, the innovation measure is not a fully continuous variable, the analyses were re-analyzed with ordered logistical regressions. These findings are the same.

Finally, we executed Harman's single factor score, in order to confirm that results are not affected by common method bias (Podsakoff et al. 2003). The total variance for a single factor was 22% (less than 50%), suggesting that data and results are not affected.

2.3.6. Data Triangulation

In addition to the primary collected survey data, two additional data sources were used to triangulate the survey data. First, the number of patents and R&D investments were obtained from secondary company data. This data could be obtained for 81 R&D teams. Second, data from over 150 thousand emails were captured for a five-month period of 27 R&D teams. That data was used to triangulate the communication frequency (an element of team interaction). Table 3 shows a comparison of the key variables across these three data sources and generally shows consistent values, which in turn confirms the data quality of the survey data.

Table 3 Comparing Descriptive Statistics from the three Datasets: Survey, Secondary Data, and Email Data.

Variables	Dataset Survey				Dataset Secondary data				Dataset email			
	N:101				Sub-set N:81				Sub-set N:27			
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
Innovation*	0.2305	0.132	0.00	0.65	0.2285	0.1256	0.00	0.64	0.2350	0.1315	0.00	0.51
Number of Patents*	0.3323	0.2132	0.00	0.86	0.1337	0.2360	0.00	1.00				
Patents vs R&D invest*	0.4854	0.1361	0.00	0.86	.0204	0.1135	0.00	1.00				
Com. Frequency*	0.6949	0.1627	0.00	1.00					0.3270	0.2771	0.00	0.97
Team Interaction	5.4070	0.6200	3.57	7.00	5.4281	0.5749	3.71	7.00	5.2459	0.5708	3.57	6.57

* Standardized values (0-1)

Table 4 Descriptive Statistics and Correlation of Variables.

Variable	Mean	Std. Dev.	Min	Max	1	2	3	4	5	6	7	8	9	10	11	12	13
1. Innovation	4.04	0.92	2.43	7.00	1												
2. Team interaction	5.40	0.62	3.57	7.00	.15	1											
3. Knowledge Diversity	5.50	0.68	2.33	7.00	.38**	.41**	1										
4. Product Modularity	4.84	0.85	2.00	7.00	.02	.23*	.26**	1									
5. Use of ICT	2.48	0.64	1.00	4.25	.02	-.05	.24*	.16	1								
6. Experience Company	9.81	4.34	1.00	21.75	.21*	-.01	-.00	-.08	-.02	1							
7. Total Experience	15.17	5.54	5.00	34.00	-.14**	-.27**	-.21*	-.12	-.08	.39**	1						
8. Team Size	7.06	4.07	1.00	22.00	.11	-.09	-.04	.06	.18	.32**	.25	1					
9. Project Length	19.65	7.06	3.00	37.00	.02	.23*	-.10	-.22*	-.08	.17	.18	.42**	1				
10. Nr. Fields Experience	2.27	1.09	1.00	6.00	.14	.22*	.17	.30**	-.02	.07	.06	.09	-.11	1			
11. Nr. of Roles Project	1.37	0.54	1.00	4.00	-.12	.05	.13	.25*	.13	.16	.13	.21*	-.26**	.17	1		
12. Level of Education	2.38	0.38	1.67	3.20	.19	.13	-.07	-.02	-.14	.05	.00	.03	-.04	.07	.04	1	
13. Geographical Dispersion	1.56	0.57	1.00	3.00	-.18	.01	-.17	-.15	-.10	.08	.15	-.01	.09	-.03	.00	.08	1

*. Correlation is significant at the 0.05 level (2-tailed). / **. Correlation is significant at the 0.01 level (2-tailed).

2.4. ANALYSIS AND RESULTS

2.4.1. Regression Results

The different descriptive statistics for all variables of the survey dataset are presented in Table 4. For example, the average time taken for the development of the products reported from the survey was 19.6 months, indicating that these were important new development programs. The majority of the respondents had at least a bachelor's degree or a higher level of education. This information indicates that the respondents were highly educated, which makes sense since the sample was focusing on R&D teams.

The results of the OLS regression models are shown in Table 5. All estimated models are significant ($p<0.001$). Model 1 incorporates team interaction, while Model 2 incorporates the moderating effect of product modularity on the team interaction – innovation relationship. Models 3 and 4 are the same but for knowledge diversity. Models 5 thru 8 simultaneously incorporate team interaction, knowledge diversity and moderating effects. With regard to the direct effects of team interaction, the negative and significant value of team interaction (β = - 0.35, p = 0.04) in Model 7 supports Hypothesis H1, although this coefficient is insignificant in the other models. With regard to the direct effect of knowledge diversity, the positive and significant impact on innovation (β = 2.45, p = 0.000) in Model 7 supports H2. The other models consistently show this positive and significant direct effect.

With regard to moderating effects, the results in Models 2, 6 and eight cannot confirm a negative moderating effect of product modularity on the relationship between team interaction and innovation, which means that H3 is not supported. Finally, the significant and negative results shown in Models 4, 7 and 8 of the moderation of product modularity on the relationship between knowledge diversity and innovation reveal the negative moderating impact of product modularity (e.g., Model 7: βknowledge diversity*product modularity = - 0.40, p = 0.005), supporting Hypothesis H4.

Table 5 Regression Results: Team Interaction, Knowledge Diversity, and Product Modularity as Moderator on Innovation

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
Team Interaction	0.03	1.07			-0.26	0.25	-0.35*	-0.26
	(0.17)	(0.67)			(0.18)	(0.67)	(0.17)	(0.67)
Knowledge Div divdiversity			0.45***	2.08**	0.54***	0.51***	2.45***	2.42***
			(0.13)	(0.65)	(0.14)	(0.15)	(0.67)	(0.70)
Team Int*P.Mod		-0.22				-0.10		-0.02
		(0.13)				(0.13)		(0.13)
Kdiv*ProdMod				-0.35*			-0.40**	-0.40**
				(0.14)			(0.14)	(0.14)
Product Mod.	-0.04	1.13	-0.09	1.88*	-0.05	0.50	2.24**	2.31*
	(0.12)	(0.74)	(0.10)	(0.79)	(0.11)	(0.72)	(0.79)	(0.95)
Use of ICT	0.33*	0.32*	0.23t	0.29*	0.21	0.21	0.27*	0.27*
	(0.14)	(0.14)	(0.13)	(0.13)	(0.13)	(0.13)	(0.13)	(0.13)
Exp. at	0.07**	0.07**	0.06**	0.06**	0.06**	0.06**	0.06**	0.06**
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Total Experience	-0.03t	-0.04*	-0.02	-0.02	-0.03t	-0.03t	-0.03t	-0.03t
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Team Size	0.01	0.00	0.02	0.01	0.01	0.01	0.00	0.00
	(0.03)	(0.03)	(0.03)	(0.02)	(0.03)	(0.03)	(0.02)	(0.03)
Project Length	-0.00	0.00	-0.00	-0.00	0.00	0.01	0.01	0.01
	(0.02)	(0.02)	(0.01)	(0.01)	(0.02)	(0.02)	(0.01)	(0.01)
Nr. Fields of	0.13	0.16t	0.09	0.09	0.12	0.14	0.12	0.13
	(0.09)	(0.09)	(0.08)	(0.08)	(0.08)	(0.08)	(0.08)	(0.08)
Nr. of Roles	-0.33t	-0.38*	-0.40*	-0.29t	-0.46**	-0.48**	-0.36*	-0.36*
	(0.18)	(0.18)	(0.17)	(0.17)	(0.17)	(0.18)	(0.17)	(0.17)
Education	0.51*	0.50*	0.55*	0.65**	0.62**	0.61**	0.75***	0.75***
	(0.23)	(0.23)	(0.22)	(0.21)	(0.22)	(0.22)	(0.21)	(0.22)
Geo. Dispersion	-0.26t	-0.27t	-0.20	-0.21	-0.17	-0.18	-0.18	-0.18
	(0.15)	(0.15)	(0.15)	(0.14)	(0.15)	(0.15)	(0.14)	(0.14)
Constant	2.50*	-3.07	0.49	-9.21*	1.01	-1.52	-9.98*	-10.30*
	(1.16)	(3.65)	(1.10)	(3.98)	(1.15)	(3.47)	(3.93)	(4.59)
Adj. R-square	17%	18%	27%	30%	28%	28%	32%	32%
Model	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AIC	263.53	262.60	250.36	245.29	249.94	251.24	242.53	244.51
BIC	294.91	296.60	281.75	279.29	283.93	287.86	279.14	283.73

tp<0.10; *p<0.05; **p<0.01; ***p<0.001 / Non Standardized β values for all variables /
Standard errors in brackets.

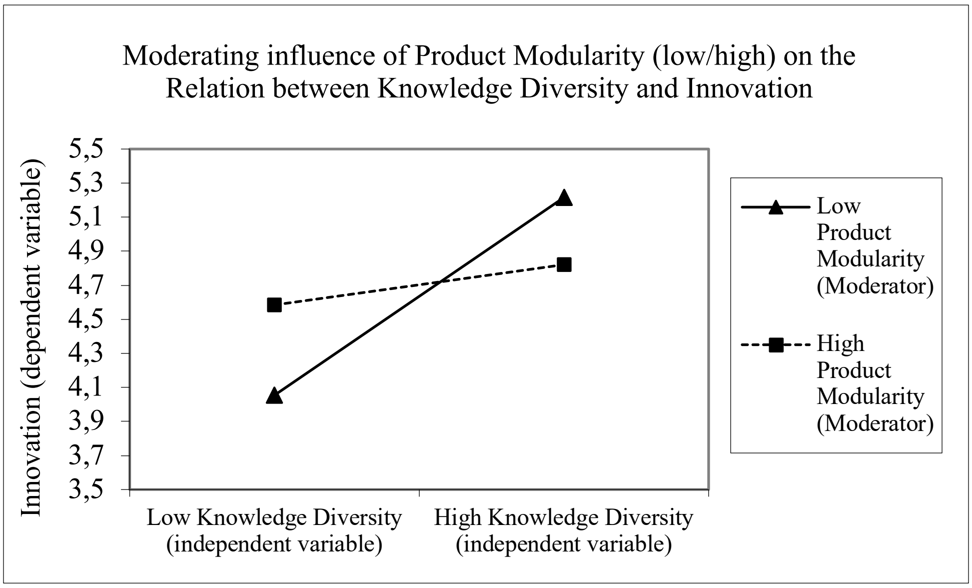

Figure 4 - The Moderating Influence of Product Modularity (high and low) on the Relationship between Knowledge Diversity and Innovation.

Figure 4 shows the interaction plot of the moderating influence of product modularity on the relationship between knowledge diversity and innovation. The figure shows that there is a positive relationship between knowledge diversity and innovation, in both cases of low or high levels of product modularity (moderator). These results provide strong support for Hypothesis H2 and are consistent with previous findings. In addition, the interaction effects displayed reveal that, under conditions of lower levels of product modularity and increasing knowledge diversity, the overall innovation outcomes are higher. On the other hand, lower innovation outcomes are associated with either the combination of increasing levels of product modularity and lower levels of knowledge diversity or the combination of low level of product modularity and knowledge diversity. These results provide strong support for Hypothesis H4.

2.4.2. Robustness Checks

We performed checks for possible non-linearity effects of our hypothesis (U-shaped or inverted U-shaped), by including the squared coefficients of team interaction and knowledge diversity in the regression models. The results showed that there are no significant non-linear effects.

In addition, we carried out the regression models with three alternative specifications (see Appendix 2 for reported results). The tables use the same model sequence as Table 5. First, we replaced the dependent variable innovation by the number of patents. In line with our theorization and findings, the results reported (see Appendix 2, Table 6) indicate that the team interaction has a negative relationship with innovation (Models 5 and 7, e.g., Model 7: βteam interaction = -0.62, p = 0.04). The results also confirm that knowledge diversity has a positive effect on innovation (Models 3, 5 and 6, e.g., Model 6: βknowledge diversity = 0.53, p = 0.02), which is also in line with our theorization and findings. With regard to the moderating influence of product modularity on both relationships, Models 2, 6, and 8 indicate a negative moderating influence on the relationship between team interaction and the number of patents (e.g., Model 8: βteam interaction*product modularity = -0.55, p = 0.01). However, with regard to the expected negative moderating influence of product modularity on the relationship between knowledge diversity and the number of patents the Models 4, 7, and eight could not confirm this.

In the second robustness check, we substitute the dependent variable innovation by patents vs. R&D investment. The regression results with this setting are reported in Appendix 2, Table 7. The theorized negative relationship between team interaction and innovation could be confirmed based on Model 8: (βteam interaction = -1.19, p = 0.07). Furthermore, the results in Models 3, 4, 5, 6, 7, and 8 indicate a positive relationship between knowledge diversity and innovation, also in line with our theorization and findings (e.g., Model 8: βknowledge diversity = 3.05, p = 0.0). We could not confirm, however, a negative moderating effect of product modularity on the relationship between team interaction and innovation since a positive moderating influence is found (e.g., Model 8: βteam interaction*product modularity = 0.26, p = 0.04). Finally, the reported results in Models 4, 7, and 8 confirm that product modularity negatively moderates the relationship between knowledge diversity and innovation (e.g., Model 8: βknowledge diversity*product modularity = -0.54, p = 0.00), in line again with our theorization and findings.

In a third robustness check, we replace the independent variable team interaction by communication frequency. The results reported in Appendix 2, Table 8, do not confirm that team interaction has a negative relationship with innovation, in contrast with our first findings and theorization. In line with our theorization and previous findings, Models 3, 4, 5, 6, 7, and 8 confirm the positive relationship between knowledge diversity and innovation (e.g., Model 8: βknowledge diversity = 2.03, p = 0.00). In addition, the results confirm that product modularity has a negative moderating effect on both relationships: team interaction and innovation in the Models 2, 6, and 8 (e.g., Model 8, βteam interaction*product modularly = -0.20, p = 0.03), and knowledge diversity and innovation in the Models 4, 7, and 8 (e.g., Model 8, βknowledge diversity*product modularity = -0.33, p = 0.02).

In general, these results of these three robustness checks show that even with some different measures, similar results are achieved.

2.5. DISCUSSION AND CONCLUSIONS

This study looked at the impact of the essential aspects of collaboration in R&D teams on innovation (i.e., team interaction and knowledge diversity). Additionally, this research studied the moderating effect of product modularity on this relationship. The theoretical framework suggested that the two fundamental elements of collaboration in this context, team interaction, and knowledge diversity, have different effects on innovation. Team interaction has a negative impact on innovation, while knowledge diversity has a positive effect on innovation - furthermore, product modularity moderates negatively both relationships - team interaction and innovation, and knowledge diversity and innovation.

2.5.1. Theoretical Implications

Our findings are of theoretical interest for several reasons. First, our results enhance the understanding of intra-organizational collaboration in the R&D teams developing products with a certain degree of modularity. Collaboration has been shown to affect innovation outcomes (Dyer and Singh 1998, Ireland et al. 2002), but our understanding of its generation and implementation in practice remains limited. Within the context of R&D teams, we identify the principal elements that play an important role in collaboration: team interaction and knowledge diversity. In particular, we contribute to a deeper understanding of collaboration in this context and extend the literature in the field of organization science.

Second, this study positions the R&D organization into an everyday context by conceptually and empirically analyzing the impact of the identified essential collaboration elements of R&D teams (team interaction, knowledge diversity) on innovation, under the moderating effect of product modularity. This research contributes to the literature by providing empirical support and contributing to the literature that studies team collaboration (Van der Vegt and Janssen 2003, Hertel et al. 2005, Langfred 2005, Gressgard 2011, Fjeldstad et al. 2012) and innovation (Kratzer et al. 2004, Svihla 2010, Qian et al. 2013). Although several researchers in the field of innovation and teams suggested the importance of collaboration on innovation (Svihla 2010, Gressgard 2011), few studies have empirically identified these elements and examined this relationship, in particular in the R&D team context.

Third, our study aimed to indicate that team interaction has a negative relationship with innovation. Consistent with previous research, higher levels of team interaction may affect the collaboration in such a manner that mutual production blocking occurs (Muller 1999), can limit the cognitive capacity (Nijstad 2000) and can inhibit innovation (Woodman et al., 1993).

Fourth, we have argued that knowledge diversity has a positive relationship with innovation in the R&D team context. Consistent with our arguments, a positive relationship between knowledge diversity and innovation was found. Having a high variety of knowledge among team members will make it easier for the team to innovate. (Brown and Eisenhard 1995, Kazanjian et al. 2000, Cummings and Cross 2003). Hence, our study confirmed the observation made in extant research that knowledge diversity is critical for innovation (Granovetter 1973, Hargadon 2002, Johansson 2006). We contribute to this discourse by pointing to the need for strategies to promote knowledge diversity (Sandberg et al. 2015). In the knowledge-based view of the firm, organizations that can draw on diverse knowledge competencies from across the organization can better integrate their knowledge resources and have a strategic competitive advantage over other organizations.

Our fifth contribution lies in the effort made to provide evidence of the moderating effect of product modularity on the relationship between team interaction and innovation. Our study theorized that product modularity moderates negatively the relationship between team interaction and innovation. However, the empirical results could not demonstrate this hypothesis. One of the possible reasons for not observing the expected effect could be related to the context of the single firm that was analyzed. It's important to emphasize and bring this research into context. This research tests the related hypothesis under the conditions of a stable, mature, structured organization and product. In a stable environment such as one in which technological dynamism and organizational is low, firms do not face any significant risk of technological obsolescence (Uotila et al. 2009), bringing the concept of stable and mature product with a certain degree of product modularity in the most suitable context. Teams may already have established stable communication channels, which might not be influenced by a major or minor degree of product modularity. Hence, in this context, the theoretical statements involving product modularity moderating the relationship between team interaction and innovation might not hold.

However, these unexpected results of the moderating effects of product modularity may bring up the need to further explore the direct influence of product modularity on innovation in the future.

Furthermore, our study theorized that product modularity moderates negatively the relationship between knowledge diversity and innovation. In line with our arguments, the empirical results confirmed this hypothesis. An increasing degree of product modularity, as the related development modules are more reusable and can be further recombined (Gershenson et al. 2003), will decrease the need for interaction, knowledge exchange among team members, and at the same time reduce the exchange of ideas that innovate (Ulrich and Tung 1991, Robertson and Ulrich 1998).

Finally, this paper contributes to the literature studying interactions via email communication. Despite the rapid increase of organizations that communicate predominantly via email, little is known about the structure and performance of such organizations. The use of email communication becomes fundamental for the analysis of the interactions among team members. Email data can turn into a unique source of investigation, enhancing prior research in this area (Tsai 2000, Ahuja 2000, Frantz and Carley 2008). The empirical results show that the communication frequency behaves in a similar direction with the data collected out of the survey, bringing further robustness to our findings.

2.5.2. Managerial Implications

The practical implications of the results for the management of R&D teams are straightforward. They confirm that, under the R&D team context working with product modularity, innovation strongly depends on the team's collaborative setting, including team interaction and knowledge diversity within the group. This situation suggests that changes in the team setting could produce substantial improvement in innovation (Amabile 1998). These results suggest that, if management wants to motivate innovation at the team level, it is best to create diverse work teams in which members perceive high knowledge diversity and low team interaction. These results are significant because they emphasize the need for team organizational changes in order to improve innovation within organizations to enhance competitiveness in current challenging environments. In particular, such an approach requires attention to the structure and management of the teams. There must be an extensive experience available within the R&D team members, as this experience has positive effects on innovation.

We believe that these results are critical at all stages of research and can be applied when new teams are being formed, or in adjusting the configuration and management of teams. Managers can use these results to support and fine-tune their team designs and innovation practices. (Otter 2005). In managerial terms, to achieve a high level of innovation within the team context working with product modularity, it is best to keep team interaction to a low or moderate level. In particular, this would mean, for instance, avoiding high-frequency contacts (Amabile and Conti 1999, Kratzer et al. 2004), thereby holding as few meetings and discussions as necessary during the development. With this approach, it could be avoided that some sub-groups are formed. Sub-groups forming could inhibit innovation (Leenders et al. 2002, Kratzer et al. 2004, Ancona and Bresman 2007). These findings suggest that the team should be arranged by the level of team interaction in the team. Communication structures should be monitored. Managers should be aware of the contingent nature of the effects of team interaction on innovation. Not understanding these contingencies could reduce an organization's ability to innovate.

However, simultaneous with both or either of these processes, R&D managers could also assess team members' potential knowledge bases. Such a knowledge-gap analysis would allow the managers to assess the relative overlap of the parties' knowledge bases, to avoid situations where there is either too much or too little overlap, perhaps by using bibliometric analysis (Lane and Lubatkin 1998). As Hamel (1991) suggested, too much overlap would require too much unlearning, and too little overlap would require too much teaching. With such an analysis in hand, a manager could use this information to select among the alternative sources or recipients. Furthermore, a possible job rotation program could be installed, in order to enhance the knowledge diversity mid-term.

2.5.3. Limitations and Future Research

The results of this study are of course subject to a number of limitations. The first potential limitation is the study's relatively small sample size, although it is higher than those used in most other studies of innovation and teams (Zander and Kogut 1995, Szulanski 1996, Lane and Lubatkin 1998, Tyler and Steensma 1998, Bresman et al. 1999). An even larger sample would be desirable for reasons of statistical power. Future research on the factors affecting innovation could benefit from this study's empirical setting and replicate the study.

Second, because this study focused on one organization, the results may not generalize to a diverse group of companies. Single group studies are limited in generalizing their findings to their particular contexts. Future studies replicating this research across other sectors, teams, and organizations would be important to advance our findings.

Furthermore, this study deals with relatively stable and mature products developed in a developed industry context, in which the product development process consists of well-defined and established steps. The findings of our research may not generalize to teams that operate in very uncertain or rapidly changing environments, where, for instance, increasing team interaction is seen as a driving factor for innovation in teams (Borgatti and Foster 2003, Kratzer et al. 2004, Obstfeld 2005, Turner and West 2010). Therefore, effects on innovation might be contingent on environmental dynamics (Ethiraj and Levinthal 2004, Ernst 2005, Pero et al. 2010) and our arguments may be limited to established markets and large organizations. Future studies on teams could help draw implications for the organizations involved in a more dynamic and industrial context.

Finally, and due to the unpredicted and partially peculiar outcomes of the moderating effect of product modularity, it is suggested to further elaborate on the concept of product modularity and explore the potential direct influences of product modularity on innovation.

2.5.4. Final Conclusions

To date, intra-organizational team collaboration research studies have been scarce (Bell and Kozlowski 2002, Hinds and Kiesler 2002, Hertel et al. 2005). Teams are an important organizational structure for innovation; this team-level research forms a solid base on which to build future research addressing the continued evolution of organizational forms, practices, and technologies supporting science and technology innovation. The results of the present study show that team interaction and knowledge diversity can be beneficial to innovation. By including a variety of variables and measures from different fields, and by using first-hand, firm-level data, this study improves the empirical foundation of research on this topic and offers an original methodological roadmap that could be replicated in other settings. The general outcomes of this study are important and helpful for further theoretical exploration of R&D team collaboration and for practical issues on how to manage R&D teams successfully. Together, we aim that these results provide a useful step toward the development and advance of R&D teams.

APPENDIX 1: Argumentation and Operationalization of Control Variables

We controlled for *team size*, since prior research has suggested that this can affect group dynamics (Pelled 1996) and influence team interactions (Markham et al. 1982, Taylor and Greve 2006), as well as having an impact on teams' ability to utilize knowledge and, ultimately, innovate. Team size was measured in the survey by asking the respondents to indicate the number of people involved in the team (in line with Ancona and Caldwell 1992, Pelled 1996, Tsai 2000, Van der Vegt and Jansen 2003).

Furthermore, the literature suggests that there are inevitably some designers who typically innovate and perform better than others and that this is usually attributable to differences in cognitive ability and *level of education* (Curtis et al. 1988, Moilanen et al. 2014). Consequently, a team's overall contribution to innovation will also depend on its educational background (Kafouros 2008). In addition, engineers' level of education has often been related to a cumulative knowledge base (Spanos and Voudouris 2009). This situation may have consequent effects on the degree of alignment between team interaction and product modularity, since engineers tend to become more familiar with product structure and support, easing the interactions among team members. Level of education was measured with the following survey item: "Please indicate your level of education: Mid. School / Bachelor / Master / PhD / Other (please indicate)" (Bozionelos 2008).

We controlled, as well, for *project length,* which is an integral part of teamwork, especially for team learning (McGrath 1991, Kasl et al. 1997). Kelly and McGrath (1985) concluded that having more time is linked with greater team creativity. Time is needed as an incubation mechanism to articulate ideas, provide input, identify challenges, and innovate (West 2002). Furthermore, project length can also influence the degree of alignment between product modularity and team interaction, due to the increasing opportunities for interaction among members and the accruing knowledge on the modularity of the product (Lovelace 1986). Project length was measured with the following item: "Please indicate the project length in months (from nomination to SOP)" (adapted from Lovelace 1986, Kim and Oh 2002, Tiwana 2008).

The variable *years of experience at the company* was added as a control, since it has been frequently argued that the innovation of teams decreases with their experience (Kratzer et al. 2004). For instance, Lovelace (1986) asserts that the innovation performance of research scientists decreases in accordance with the length of time they are part of a group. We measured years of experience at the company from a survey question, using the number of years since joining the organization.

The variable *number of fields of experience* was also added as control. Research has shown that a member's different levels of experience with diverse domains and technologies play a role in their interactions with other team members (Staples et al. 1999, Kirkman et al 2004). Less technically experienced team members may be less inclined, or able, to communicate and might therefore form the kinds of relationships that diminish innovation (Patel et al. 2012). Number of fields of experience was measured with the following item: "Please indicate the number of fields in which you have gathered prior work experience: Mechanics; Software; Project Management; Systems Engineer; Hardware; PCB Layout; Testing; Other (please indicate)" (Staples et al. 1999).

Number of roles in the project was considered because having a variety of roles represented allows teams to be more adaptable and flexible in responding to problem-solving demands, which improves innovation outcomes (Ittner et al. 2002, Cavalluzzo and Ittner 2004, Salas et al. 2005a). On the other hand, team members may in such cases experience higher workloads and more pressure than when dedicating themselves to solely one role, which in turn can negatively affect their ability to commit to innovation activities (Shea and Guzzo 1987, Hackman 1990, Klein 2001). Number of roles was measured with the following question: "Your role/s in this project?: Hardware; Mechanics; Software; Testing; Systems Engineer; PCB Layout; Project Manager; Other (please indicate)" (Ittner et al. 2002).

Furthermore, *work experience in total* can also influence innovation since more experienced employees may benefit more from interactions with other coworkers or require fewer interactions to accomplish their tasks effectively and efficiently (Young-Hyman 2017). Work experience in total was measured in the questionnaire using the total number of years since the start of the respondent's professional career.

APPENDIX 2: Further Robustness Check Regression Results

Table 6 Robustness Check: Results, Substituting Innovation by Number of Patents as the Dependent Variable

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
Team Interaction	-0.25	2.90**			-0.60*	2.04t	-0.62*	2.13t
	(0.27)	(1.02)			(0.29)	(1.06)	(0.29)	(1.11)
Knowledge Div			0.48*	0.36	0.68**	0.53*	1.00	0.19
			(0.21)	(1.12)	(0.23)	(0.23)	(1.14)	(1.15)
Team Int*PMod		-0.65**				-0.53*		-0.55*
		(0.20)				(0.21)		(0.21)
Kdiv*ProdMod				0.03			-0.07	0.07
				(0.24)			(0.24)	(0.23)
Product Mod.	-0.01	3.52**	-0.12	-0.27	-0.01	2.87*	0.38	2.54
	(0.18)	(1.12)	(0.17)	(1.35)	(0.18)	(1.13)	(1.36)	(1.56)
Use of ICT	0.75**	0.72***	0.65**	0.64**	0.61**	0.61**	0.62**	0.60**
	(0.22)	(0.21)	(0.22)	(0.23)	(0.22)	(0.21)	(0.22)	(0.22)
Exp. at Company	0.13***	0.13***	0.12**	0.12**	0.13**	0.12***	0.13***	0.12**
	(0.04)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
Total Experience	-0.06*	-0.07*	-0.04	-0.04	-0.06*	-0.06*	-0.06*	-0.06*
	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
Team Size	0.00	-0.02	0.02	0.02	0.01	-0.01	0.01	-0.01
	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)
Project Length	-0.00	0.01	-0.01	-0.01	0.01	0.01	0.01	0.01
	(0.03)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.03)	(0.02)
Nr. Fields of Exp.	0.15	0.25t	0.07	0.07	0.13	0.22t	0.13	0.22t
	(0.14)	(0.13)	(0.13)	(0.13)	(0.13)	(0.13)	(0.13)	(0.13)
Nr. of Roles	-0.29	-0.43	-0.30	-0.31	-0.45	-0.53t	-0.43	-0.55t
	(0.29)	(0.28)	(0.28)	(0.29)	(0.28)	(0.28)	(0.29)	(0.29)
Education	0.81*	0.77*	0.78*	0.78*	0.94*	0.87*	0.96*	0.85*
	(0.37)	(0.35)	(0.36)	(0.36)	(0.36)	(0.35)	(0.37)	(0.36)
Geo. dispersion	-0.27	-0.29	-0.21	-0.21	-0.16	-0.20	-0.16	-0.20
	(0.24)	(0.23)	(0.24)	(0.24)	(0.24)	(0.23)	(0.24)	(0.23)
Constant	1.09	-15.70**	-2.02	-1.29	-0.80	-14.09*	-2.65	-12.51
	(1.84)	(5.56)	(1.82)	(6.82)	(1.88)	(5.48)	(6.72)	(7.57)
Adj. R-square	20%	27%	23%	22%	27%	30%	25%	30%
Model significance	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AIC	356.70	347.71	352.05	354.03	349.12	343.70	351.02	345.59
BIC	388.08	381.71	383.43	388.03	383.11	380.31	387.63	384.82

tp<0.10; *p<0.05; **p<0.01; ***p<0.001 / Non Standardized β values for all variables / Standard errors in brackets.

Table 7 Robustness Check: Results, Substituting Innovation by Number of Patents/R&D Investments as the Dependent Variable

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
Team Interaction	0.45**	0.24			0.23	-0.50	0.12	-1.19t
	(0.17)	(0.67)			(0.18)	(0.68)	(0.17)	(0.65)
Knowledge Div			0.50***	2.78***	0.42**	0.47**	2.66***	3.05***
			(0.13)	(0.64)	(0.14)	(0.15)	(0.66)	(0.68)
Team Int*PMod		0.04				0.15		0.26*
		(0.13)				(0.13)		(0.13)
Kdiv*ProdMod				-0.49***			-0.47***	-0.54***
				(0.13)			(0.14)	(0.14)
Product Mod.	-0.07	-0.30	-0.03	2.74***	-0.07	-0.86	2.63**	1.59t
	(0.11)	(0.73)	(0.11)	(0.77)	(0.11)	(0.72)	(0.79)	(0.92)
Use of ICT	0.11	0.11	0.00	0.08	0.02	0.01	0.09	0.10
	(0.14)	(0.14)	(0.14)	(0.13)	(0.14)	(0.14)	(0.13)	(0.13)
Exp. at Company	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Total Experience	-0.04*	-0.04*	-0.04*	-0.04*	-0.04*	-0.04*	-0.04*	-0.03*
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Team Size	0.04	0.04	0.04	0.03	0.04t	0.05t	0.04	0.04t
	(0.03)	(0.03)	(0.03)	(0.02)	(0.03)	(0.03)	(0.02)	(0.02)
Project Length	-0.01	-0.01	-0.00	0.00	-0.01	-0.01	-0.00	-0.01
	(0.02)	(0.02)	(0.01)	(0.01)	(0.02)	(0.02)	(0.01)	(0.01)
Nr. Fields of	0.16t	0.15t	0.17*	0.17*	0.15t	0.13	0.16*	0.12
	(0.08)	(0.09)	(0.08)	(0.07)	(0.08)	(0.08)	(0.08)	(0.08)
Nr. of Roles	-0.42*	-0.41*	-0.57**	-0.42*	-0.52**	-0.50**	-0.40*	-0.34*
	(0.18)	(0.18)	(0.17)	(0.17)	(0.18)	(0.18)	(0.17)	(0.17)
Education	0.27	0.28	0.41t	0.55**	0.36	0.37t	0.52*	0.57**
	(0.23)	(0.23)	(0.22)	(0.21)	(0.22)	(0.22)	(0.21)	(0.21)
Geo. dispersion	-0.18	-0.18	-0.09	-0.11	-0.11	-0.10	-0.12	-0.10
	(0.15)	(0.15)	(0.15)	(0.14)	(0.15)	(0.15)	(0.14)	(0.14)
Constant	2.14t	3.23	1.43	-12.21**	0.97	4.64	-11.96**	-7.27
	(1.14)	(3.64)	(1.11)	(3.88)	(1.16)	(3.50)	(3.91)	(4.46)
Adj. R-square	24%	23%	30%	38%	30%	40%	38%	31%
Model	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AIC	260.19	262.0	252.41	240.19	252.56	253.13	241.67	238.76
BIC	291.57	296.0	283.79	274.19	286.55	289.74	278.28	277.99

tp<0.10; *p<0.05; **p<0.01; ***p<0.001 / Non Standardized β values for all variables / Standard errors in brackets.

Table 8 Robustness Check: Results, Substituting Team Interaction by Communication Frequency as an Independent Variable

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
Team Interaction	-0.00	0.83t			-0.06	0.95*	-0.06	0.87t
	(0.12)	(0.49)			(0.11)	(0.46)	(0.11)	(0.44)
Knowledge Div			0.45**	2.08**	0.46**	0.49**	2.10**	2.03**
			(0.13)	(0.65)	(0.13)	(0.13)	(0.66)	(0.64)
Team Int*PMod		-0.18t				-0.22*		-0.20*
		(0.10)				(0.09)		(0.09)
Kdiv*ProdMod				-0.35*			-0.35*	-0.33*
				(0.14)			(0.14)	(0.14)
Product Mod	-0.04	0.54	-0.09	1.88*	-0.09	0.61t	1.89*	2.42**
	(0.11)	(0.35)	(0.10)	(0.79)	(0.11)	(0.32)	(0.79)	(0.81)
Use of ICT	0.33*	0.31*	0.23t	0.29*	0.25t	0.23	0.31*	0.29*
	(0.15)	(0.15)	(0.13)	(0.13)	(0.14)	(0.14)	(0.14)	(0.14)
Exp. at Company	0.07**	0.06**	0.06**	0.06**	0.06**	0.05*	0.06**	0.05**
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Total Experience	-0.04*	-0.03*	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Team Size	0.01	0.01	0.02	0.01	0.02	0.02	0.01	0.02
	(0.03)	(0.03)	(0.03)	(0.02)	(0.03)	(0.02)	(0.02)	(0.02)
Project Length	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00
	(0.02)	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Nr. Fields of Exp.	0.13	0.13	0.09	0.09	0.09	0.08	0.08	0.08
	(0.08)	(0.08)	(0.08)	(0.08)	(0.08)	(0.08)	(0.08)	(0.08)
Nr. of Roles Project	-0.34t	-0.29	-0.40*	-0.29t	-0.39*	-0.32t	-0.28	-0.22
	(0.18)	(0.18)	(0.17)	(0.17)	(0.17)	(0.17)	(0.17)	(0.17)
Education	0.52*	0.41t	0.55*	0.65**	0.56*	0.42t	0.66**	0.53*
	(0.23)	(0.24)	(0.22)	(0.21)	(0.22)	(0.22)	(0.21)	(0.22)
Geo. dispersion	-0.26t	-0.26t	-0.20	-0.21	-0.18	-0.17	-0.19	-0.18
	(0.16)	(0.15)	(0.15)	(0.14)	(0.15)	(0.15)	(0.14)	(0.14)
Constant	2.60*	0.18	0.49	-9.21*	0.51	-2.55	-9.24*	-11.50**
	(0.99)	(1.69)	(1.10)	(3.98)	(1.10)	(1.72)	(4.00)	(4.05)
Adj. R-square	17%	19%	27%	31%	26%	33%	30%	33%
Model significance	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AIC	263.55	262.06	250.36	245.29	252.07	248.22	246.90	243.54
BIC	294.93	296.05	281.75	279.29	286.07	284.83	283.51	282.77

tp<0.10; *p<0.05; **p<0.01; ***p<0.001 / Non Standardized β values for all variables / Standard errors in brackets.

CHAPTER 3

UNPACKING PRODUCT MODULARITY AND INNOVATION: THE CASE OF R&D TEAMS[3]

ABSTRACT

This study investigates the effects of product modularity on innovation, a crucial factor for the long-term survival of any organization. We adopt a definition of product modularity as a multidimensional construct composed of module standardization and reconfiguration and investigate the impact of modularity on two dimensions of innovation (i.e., effectiveness and efficiency) in a sample of 140 R&D teams from a large organization in the automotive industry. The findings reveal a U-shaped relationship between module standardization and innovation effectiveness, with a negative impact on innovation efficiency. Module reconfiguration, however, stands in an inverted U-shaped relationship with innovation effectiveness and a positive effect on innovation efficiency. These findings contribute to the literature by unpacking our theoretical understanding of the concept of product modularity in R&D organizations since the multidimensional approach resolves some of the ambiguity from previous studies. This is one of the first studies to empirically measure product modularity in more than one dimension with effects on innovation.

Keywords: Module standardization, Reconfiguration, Product modularity, Innovation, Teams, R&D.

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[3] This chapter has been re-submitted to Research Policy after a revise and resubmission round and is currently under review. A condensed version of this paper was presented at the Academy of Management conference (2017), USA. I would like to thank the anonymous reviewers and the participants of AOM meeting for their feedback. In addition, an earlier version of this paper was presented as well at the International conference on Innovation and Management (IAM 2015), Sapporo, Japan, as well as at the DRUID conference (2017) in Denmark. I would like to thank the anonymous reviewers and the participants of IAM and DRUID meetings for their feedback. Moreover, we would like to acknowledge Professor Yu Tianli for his support. Additionally, we would like to thank Professor Geert Duijsters for his valuable comments on this paper.

3.1. INTRODUCTION

Many global organizations struggle with how to manage their research and development (R&D). Managers responsible for R&D must leverage and exploit a geographically distributed body of knowledge in an effective manner. To this end, R&D organizations build teams that collaborate in order to share knowledge and create and distribute their R&D activities, yet they are difficult to structure and integrate (Szulanski 1996, Gassmann and Von Zedtwitz 1999). This situation drives organizations to adopt different product design and development processes (Rycroft and Kash 1999, Krishnan and Ulrich 2001, Hagedoorn et al. 2006), with researchers suggesting that the use product modularity supports the management and the complexity reduction of their R&D processes (Baldwin and Clark 2000). Product modularity is defined as the use of standardized, interchangeable components to configure a variety of end products (Schilling 2000). Numerous examples can be found in the computer, bicycle, and automotive industries (Teece 1986, Baldwin and Clark 1997, Suzik 1999).

Despite the rapid increase in the use of product modularity for diverse applications, there is little consensus on its exact definition or its nature as a multidimensional construct (Gershenson et al. 2003, Ro et al. 2007). Various studies have made an effort to bridge the different perspectives in the literature (Ulrich and Tung 1991, Huang and Kusiak 1998, Gershenson et al. 2003) but ambiguity in understanding the characteristics of this concept remains. We define product modularity as a multidimensional concept in terms of module standardization and reconfiguration, following Gershenson et al. (2003) and Salvador (2007). Module standardization refers to the extent to which something is constructed by joining a set of standardized parts that have been made separately (Pels and Erens 1992), while reconfiguration is the degree to which the product components can be reused to facilitate a broad range of new product variations by mixing and matching the modules (Mikkola and Gassmann 2003). One key reason for adopting a multidimensional definition of modularity is that any technological system consists of several distinct, integral sub-systems or modules that can be both independent and interdependent, to some extent, at the same time (Simon 1962). This interpretation incorporates, in other words, decomposition, or standards, and reconfiguration, or reuse.

However, product modularity is usually treated as a single joint construct, and existing empirical studies do not reflect the multidimensional perspective (Salvador 2007). This study takes a combined approach for the purpose of introducing definitional clarity and structure to guide the empirical research. While the dimensions of module standardization and reconfiguration are differentiated and complementary, there is no conclusive evidence regarding the effects of module standardization and reconfiguration on innovation. The existing research has produced ambiguous findings on the impact of product modularity on innovation, possibly because the studies do not incorporate a multidimensional perspective (Pil and Cohen 2006, Brusoni et al. 2007).

With regard to the first dimension of product modularity, module standardization, one stream of the literature suggests that it can improve an organization's ability to innovate (Ulrich and Eppinger 2003) since it reduces the coordination necessary among development stages (Langlois and Robertson 1992, Langlois 2002), facilitating faster problem solving and the adoption of more radical solutions (Erixon et al. 1994, Hargadon and Eisenhardt 2000). On the other hand, it has also been argued that module standardization could limit an organization's ability to innovate, causing it to miss value-creating opportunities because it cannot escape the limits of the existing standardization strategies (Brusoni et al. 2007) and requiring new products to be compatible with current ones (Ulrich 1995, Prencipe et al. 2003). These arguments suggest that module standardization could have varying effects on innovation.

Similarly, existing theory presents contrasting lines of argumentation for the second dimension of product modularity, module reconfiguration. On the one hand, a high degree of reconfiguration is thought to increase the innovation of R&D teams by multiplying design options (Sanderson and Uzumeri 1995, Ethiraj and Levinthal 2004). A contrasting stream of research argues that reconfiguration could diminish innovation because re-usability leads to similar product design and predictability (Sabel and Zeitlin 2004, Ernst 2005). In sum, and despite the increasing importance of product modularity in R&D teams, the empirical studies on its relationship with innovation are limited in number and have produced ambiguous results.

Global research and development in manufacturing presents a pertinent empirical domain for studying these relationships because of the following: its distributed knowledge creation efforts, its diversity of inputs, the critical role of technological interfaces, the managerial need to coordinate knowledge creation across locations and, lastly, the innovation-based competition in global industries such as automotive. Organizations build teams that collaborate to share knowledge, create, and distribute their R&D activities (Gassmann and Von Zedtwitz 1999); R&D teams play an essential role in innovation since they function as a primary technological interface (Jankowski 1998). The R&D teams that work with product modularity include engineers from diverse specialized domains who integrate their knowledge to develop new products (Sanchez and Mahoney 1996, Sanchez 1999). As suggested by the knowledge-based theory of the firm (Nonaka 1994, Zander and Kogut 1995, Grant 1996, Kogut and Zander 1992), organizations are social communities specializing in efficient knowledge creation and transfer (Kogut and Zander 1992). Increasingly, this knowledge is transferred between geographically distributed individuals since this provides opportunities for mutual learning and collaboration that stimulate knowledge creation and innovation (Kogut and Zander 1992, Tsai and Ghoshal 1998). In a highly competitive environment, innovation is essential for the competitiveness and survival of the organization (Boutellier et al. 1998, Townsend et al. 1998). A case in point is the particular context of the automotive industry, which has long been a subject of studies on modularity (Takeishi and Fujimoto 2001, Ro et al. 2007) and was chosen as our empirical setting.

Although the literature has tended to identify innovation performance indicators as unidimensional, organizations actually aim to achieve various performance objectives simultaneously (Baum et al. 2000, Dussauge et al. 2002). Efficiency and effectiveness are central criteria in assessing performance (Schmidt and Finnigan 1992, Neely 1998), with the challenge for organizations being to balance the two in their R&D teams (Fox 2013). There appears to be a poor fit between practical and academic research on innovation performance. It is therefore essential to establish an additional multidimensional view of the performance of R&D organizations since in practice organizations target multiple performance objectives at once, balancing between strategies aiming at efficiency or effectiveness (Mouzas 2006). Altogether, there is no conclusive evidence regarding the relationships between the two dimensions of product modularity (module standardization and reconfiguration) and innovation. This study, therefore, aims to address the following question:

What is the impact of module standardization and reconfiguration (the two dimensions of product modularity) on innovation effectiveness and efficiency in R&D teams?

Investigating this research question is important because innovation is crucial for organizations' survival. The challenges of a competitive environment growing more global and interlinked every day have accelerated the establishment of new forms of organization and increased the pressure to innovate. R&D teams that jointly develop products and technologies with a particular degree of product modularity have become a widespread organizational form. It is therefore of fundamental significance to study the effects of product modularity on innovation in greater depth.

The principal contribution of this paper is to unpack our theoretical understanding of the concept of product modularity in R&D organizations by establishing the effects of module standardization and reconfiguration on innovation at the R&D team level. We thus resolve earlier ambiguities identified by previous research on product modularity. By analyzing the two dimensions of modularity, we find that, for example, module reconfiguration has an inverted U-shaped relationship with innovation effectiveness, and we conjecture an optimum level of module reconfiguration. In addition, the study aims to resolve the prevailing poor fit between innovation practice and theory by adopting, empirically, an effectiveness and efficiency view of innovation. For managers of R&D teams, this means that strategic decisions on innovation objectives hold direct and nuanced implications for product modularity, such as priorities for standardization or additional efforts for reconfiguration.

This paper is organized as follows. The first section addresses the conceptual framework behind the research. Second, we present the literature informing our hypotheses and the relationships between module standardization and reconfiguration and innovation effectiveness and efficiency. Then, we elaborate on the research design, the data collected and the analyses. Subsequently, we discuss the results and present the main conclusions and explanation of the key contributions to theory. We also propose an agenda for future research.

3.2. CONCEPTUAL FRAMEWORK

3.2.1. Innovation as a Multidimensional Construct

In the context of knowledge creation and transfer among R&D teams and team members (Kogut and Zander 1992), innovation is perceived as the development and implementation of new ideas to solve problems (Dosi 1988). This innovation derives predominantly from either combining knowledge and technologies in a novel manner (Schumpeter 1934, Nelson and Winter 1977, Fleming and Sorenson 2001, Carnabuci and Bruggeman 2009) or recombining existing technologies so that they can acquire new functions (Henderson and Clark 1990, Yayavaram and Ahuja 2008).

As indicated by previous research, innovation is complex, multidimensional, and hardly measurable along a single dimension (Chiesa et al. 1996, Werner and Souder 1997, Brookes and Backhouse 1998, Hansen 2002, Guan and Ma 2003). From a practical point of view, organizations need to pay equal attention to efficiency and effectiveness performance (Mouzas 2006). Effectiveness indicates the extent to which requirements are met (Neely 1998) and efficiency is a measure of how the organization's resources are utilized economically in providing a given level of satisfaction (Neely 1998). A major challenge for global organizations is the simultaneous achievement of both effectiveness and efficiency while ensuring that the two elements are not contradictory (Mass 2005, Bae and Chang 2012) and achieving an optimum relationship between the costs and benefits of modularization.

Focusing solely on efficiency can result in short-term profitability (Mouzas 2006) but prevent organizations from achieving differentiation and innovation in their environments (Mass 2005). Conversely, focusing solely on effectiveness can result in "unprofitable growth" if the opportunity cost of capital is higher than the resulting profit (Mouzas 2006). In the end, success often depends on a balance between strategies aimed at maximizing efficiency and those pursuing effectiveness (Chen et al. 1995, Ford and Håkansson 2006). There appears to have been a poor fit to date, however, between the practical and academic research on innovation, with the latter failing to make this differentiation.

Setting up such a multidimensional view of innovation is important because, in practice, organizations target multiple objectives at the same time, balancing between strategies aiming at efficiency and at effectiveness (Mouzas 2006). Moreover, research into the intra-organizational aspects of R&D organizations with regard to innovation has not been structured in the literature according to such a multidimensional view.

3.2.2. Key Dimensions of Product Modularity

In response to global competition, organizations have to cope with a high degree of product variation and customization, globalization, short product life cycles, and rapidly increasing development costs (Pine 1993, Kotler 2003). The notion of product modularity has been widely proposed as a strategic decision for dealing with this increasingly complex environment (Starr 1965, Sanchez and Mahoney 1996, Baldwin and Clark 1997, 2000, Ulrich and Eppinger 2000, Garud et al. 2011). Although such ideas are not new in the literature on technological design (Simon 1962, Alexander 1964), product modularity is becoming increasingly important today because of the increased complexity of modern technology. Despite the intensive increase of its use in various singular applications, product modularity is a multidimensional construct.

A review of the literature shows that product modularity is a technical concept that originated in various domains, including mechanical and industrial engineering (Cusumano 1991, Langlois and Robertson 1992, Von Hippel 1994, Baldwin and Clark 1997, Cabigiosu et al. 2013). Since its inception, researchers have selectively chosen definitional views depending on the goals and viewpoints of their research (e.g., strategy, management science, operations, etc.) and the prevailing product modularity perspectives within their field of study, further aggravating the definitional ambiguity and making it difficult to understand the characteristics of the concept.

Remarkably, in a comprehensive literature review paper on product modularity, Salvador (2007) concludes that product modularity is a set of two different constructs - component combinability (mainly related to reconfiguration of components) and component separability (primarily associated with a separation of standards). We can identify further definitions from the literature that reflect a similar multidimensional view, with minor variances. By one definition, product modularity refers to the use of standardized and exchangeable components that allow the configuration of a wide variety of finished products (Schilling 2000). Similarly, Danese and Filippini (2010, p: 1192) indicate that "product components can be standardized, shared and reused in a range of products so that new products could frequently and easily be launched by modifying and combining different qualified modules from the existing designs." In other words, product modularity refers to the degree to which a system can be separated (decomposition in standard components) and recombined (reconfiguration of components). Importantly, modularization impacts the cost of knowledge sharing that can be significant from a strategic point of view (Sanchez and Mahoney, 1996; Brusoni and Prencipe, 2006).

3.2.2.1. Module Standardization

The first dimension of product modularity, module standardization, refers to the process of deconstructing a system into individual modules, which involves dividing the relevant information into discrete elements or pieces (Pels and Erens 1992, Baldwin and Clark 1997). The literature relates module standardization to commonality and product architecture. The commonality is reflected by the components within the product. Evans (1963) and Lee and Tang (1997) define standardization as the use of conventional components. Evans (1963) treats the use of standard components as integral to modular product architecture. Agreeing, Ulrich (1995) states that product modularity involves the application of unit standardization as architectural elements. Standardization refers to the use of common components, in which one of the critical elements is the interface (Sanchez and Mahoney 1996, Lampel and Mintzberg 1996, Lee and Tang 1997).

A standard is a "document, established by consensus and approved by a recognized body that provides, for common and repeated use, rules, guidelines or characteristics" (Gamber et al. 2008). In order to make best of use of modularity, standards need to be available in the form guidance supporting the product development (Baldwin and Clark 2000, Brusoni et al. 2007, Jacobs et al. 2007). Along with serving to catalyze new technological knowledge, therefore, technical guidelines and standards are an essential factor in innovation (Gamber et al. 2008).

3.2.2. 2. Module Reconfiguration

The second dimension, module reconfiguration, is probably one of the most commonly understood aspects of product modularity. It refers to the degree of reuse of product components for forming new product variations. Products are modular when diverse product configurations can be obtained from mixing and matching components taken from a given set (Salvador 2007). The assumption of a given set may appear strong at first, yet, arguably, few innovation projects in an advanced industrial environment design every component from scratch (Cabigiosu and Camuffo 2017). Products with a high degree of module reconfiguration allow for a broad range of product variations (Starr 1965), while for those with a lower degree it can be challenging to transfer individual components to other lines or use them for future product development projects (Fujita 2002, Mikkola and Gassmann 2003). The implications of the module reconfiguration mechanisms for organizations' innovation have attracted increasing attention (e.g., Ethiraj and Levinthal 2004, Helfat and Eisenhardt 2004, Pil and Cohen 2006, Danese and Filippini 2010). As with module standardization, however, the existing theory comprises contrasting lines of argumentation that require further research and clarification.

3.2.3. Module Standardization and Reconfiguration and Innovation

3.2.3.1. Impact of Module Standardization on Innovation Effectiveness

This section describes the theorizing on the relationship between module standardization and innovation effectiveness. Initial high costs to knowledge sharing impact negatively whereby increasing benefits promote innovation effectiveness adding to a U-shaped relationship. Module standardization has been regarded as an essential element for innovation and performance in organizations (Langlois 2002, Pil and Cohen 2006). However, for a stable and mature environment with relatively low technological dynamism, low or moderate levels of module standardization will diminish innovation effectiveness (Uotila *et al.* 2009). We have derived two principal points of view from the literature.

First, the R&D process is serendipitous, intrinsically unstructured, and consists of sharing ideas from various fields of expertise (Kim et al. 2003). Therefore, R&D involves activities that are difficult to control through formal mechanisms such as standards (Langfield-Smith 1997, p: 208), which are the very premise of module standardization. As a form of centralized control, standardization impedes the effectiveness of innovative activities (Amabile 1998, Shalley et al. 2004, Davila et al. 2009). Second, R&D developers need to understand standards and be knowledgeable about compatible boundaries with other components before they are able to apply these standards (Ulrich 1995, Schilling 2000). At low or moderate levels of module standardization, this process of understanding and learning increases the dedicated development time and raises the effort to acquire the related knowledge. This situation, in turn, reduces the possibilities for the team member to dedicate himself more deeply to the creation of new ideas, decreasing innovation effectiveness (Shapiro and Varian 1999).

However, at higher levels of module standardization, the costs of knowledge sharing go down due to the capacity for information hiding inherent in modular designs (Parnas, 1972) and various positive effects outweigh the costs. Adding the positive effects to the negative effects, we expect a U-shaped relationship (Haans et al. 2016). Firstly, increasing levels of module standardization provide the full benefits of the division of labor by reducing the degree of interdependence among the parts of the system (Langlois 2002) and decreasing the information processing load related to searching for solutions because the targeted design problems can be resolved at a modular level that has fewer, but specific, interdependencies among the relevant components (Pil and Cohen 2006). Consequently, developers can design using various ideas but they do not need to understand the whole product (Langlois and Savage 2001). Thus, a product with a high degree of module standardization accelerates autonomous innovation, that is, innovation effectiveness requiring little coordination among teams (Langlois 2002). Secondly, the reduction in complexity through higher levels of module standardization (Simon 1962, Henderson and Clark 1990, Von Hippel 1990, Kogut and Zander 1993) allows developers, in return, to concentrate their attention on particular components (Rosenberg 1982, Langlois and Robertson 1992, Sanchez 1999). This makes it easier to manage product complexity (Hargadon and Eisenhardt 2000) and ultimately enhances innovation effectiveness. Third, higher levels of module standardization accelerate the clustering according to technological similarities, such as common materials or specific guidelines (Gershenson et al. 2003). This situation enables a sharing of knowledge among the subsystem developers (Belderbos et al. 2004), helping them acquire ever-more experience with certain kinds of problems. As a result, it allows them to more quickly consider alternative or new solutions (Danese and Filippini 2010) and solve problems more quickly and reliably and thus enhances autonomous (component) and modular innovation effectiveness (Baldwin and Clark 2000).

Furthermore, higher levels of module standardization allow a product to be independently and synchronously deconstructed into a set of smaller, de-coupled sub-systems, different team designs, and test modules. This approach reduces the time that needs to be dedicated to designing products (Sanchez and Mahoney 1996, Sanchez 1999). At higher degrees of module standardization, and without the need to spend time coordinating with other parties, developers can focus on perfecting their skills and building on their technical knowledge, which in turn supports innovation effectiveness. In sum, we argue that at low or moderate levels of module standardization the high costs of knowledge sharing dominate and inhibit innovation effectiveness due to the extra costs and efforts required. However, after a certain point, a higher level of module standardization leads to improvements in innovation effectiveness as the benefits start to outweigh the initially negative effects. Therefore, the relationship between module standardization and innovation effectiveness is likely to be a U-shaped relationship decreasing initially until some point benefits outweigh costs. Therefore, we hypothesize that:

H5a: Module standardization has a U-shaped relationship with innovation effectiveness.

3.2.3.2. Impact of Module Reconfiguration on Innovation Effectiveness

This section relates module reconfiguration to innovation effectiveness. We argue that simultaneously increasing positive and negative effects combine into an inverted U-shaped relationship. Numerous studies have argued that reconfiguration in R&D promotes innovation effectiveness. We have distilled four main positive effects from the literature. First, the number of design options that developers need to consider is reduced when they are working with reconfiguration since the workload involved in finding design solutions or solving problems is correspondingly decreased (Pil and Cohen 2006). Consequently, the product design becomes less complex and the task of evaluating and developing innovative products is less demanding, ultimately promoting innovation effectiveness (Pil and Cohen 2006).

Second, organizations with higher module reconfiguration levels create innovation through rapid trial-and-error learning (Langlois and Robertson 1992, Sanchez 1999, Baldwin and Clark 2000, Meyer et al. 2018). This suggests that module reconfiguration enhances an organization's ability to finding a suitable product design, leading to better product performance (Pil and Cohen 2006). This learning process helps create new product ideas for more innovative modules, enhancing innovation effectiveness.

Third, by recombining different modules, the teams build up "combinatorial innovation" (Shapiro and Varian 1999, Ethiraj and Levinthal 2004). This means that developers can try many configurations of existing modules, while at the same time developing innovative new ones (Mikkola 2006). This, in turn, results in many creative products being built on the available modules, increasing the level of innovation effectiveness.

Fourth, engineers can reconfigure modules or elements of prior solutions and rely on analogical reasoning to generate new design alternatives, accelerating the rate at which incremental performance improvements are made (Usher 1954, Clark 1985). This, in turn, improves innovation effectiveness across design cycles.

However, another body of the literature argues that increasing levels of module reconfiguration could inhibit an organization's ability to innovate new products and notes distinct disadvantages. In other words, negative effects on innovation effectiveness arise when the levels of module reconfiguration increase. First, because such reconfigured designs make product development more predictable (Chesbrough 2003, Sabel and Zeitlin 2004, Ernst 2005), many organizations seem to apply modular design to the degree that weakens the innovation process by minimizing opportunities (Fleming and Sorenson 2001). This kind of predictable structure can limit organizations to value-generating alternatives because they cannot escape the boundaries set by the existing modular design strategies (Brusoni et al. 2007), thus decreasing innovation effectiveness.

Second, the reusable nature of the modular architecture can also limit innovation due to limited product differentiation and high product similarity (Ulrich and Tung 1991, Robertson and Ulrich 1998). This leads to easier, faster imitation (Baldwin and Clark 2000, Pil and Cohen 2006) and increases the risk that competitors will develop similar products (Huang 2000, Ernst 2005), which ultimately reduces innovation effectiveness.

Third, high levels of module reconfiguration reduce the degrees of freedom to create radically innovative products because of the compatibility constraints, whereby new products must fit with existing ones (Prencipe et al. 2003). This, in turn, limits the opportunity for creating new ideas, which diminishes innovation effectiveness.

Thus, at some point, due to the above-mentioned arguments, at high levels of module reconfiguration, the negative effects outweigh the positive ones. To reconcile both perspectives and combine the simultaneous positive and adverse effects, this study proposes an inverted U-shaped relationship between product modularity and innovation effectiveness. We suggest that module reconfiguration has a positive effect on innovation effectiveness up to an optimum point, simultaneously resulting in increasing negative effects and, after the optimum, the negative effects will outweigh the positive ones. Further, increasing module reconfiguration beyond the optimum leads to a decrease in innovation effectiveness. This section relates module reconfiguration to innovation effectiveness. We argue that for low to moderate levels of module reconfiguration benefits of knowledge sharing dominate while for higher levels of module reconfiguration negative effects outweigh the benefits and add to an inverted U-shaped relationship. Numerous studies have argued that reconfiguration in R&D promotes innovation effectiveness (Shapiro and Varian 1999, Ethirak and Levinthal 2004, Mikkola 2006). We have distilled four main positive effects from the literature.

First, the number of design options that developers need to consider is reduced when they are working with reconfiguration since the workload involved in finding design solutions or solving problems is correspondingly lower (Pil and Cohen 2006). Consequently, the product design becomes less complex and the task of evaluating and developing innovative products is less demanding, ultimately promoting innovation effectiveness (Pil and Cohen 2006). Second, organizations with higher module reconfiguration levels create innovation through rapid trial-and-error learning (Langlois and Robertson 1992, Sanchez 1999, Baldwin and Clark 2000, Meyer et al. 2018). This suggests that module reconfiguration enhances an organization's ability to finding a suitable product design, leading to better product performance (Pil and Cohen 2006). This learning process helps create new product ideas for more innovative modules, enhancing innovation effectiveness. Third, by recombining different modules, the teams build up "combinatorial innovation" (Shapiro and Varian 1999, Ethiraj and Levinthal 2004). This means that developers can try many configurations of existing modules, while at the same time developing innovative new ones (Mikkola 2006). This, in turn, results in many creative products being built on the available modules, increasing the level of innovation effectiveness. Fourth, engineers can reconfigure modules or elements of prior solutions and rely on analogical reasoning to generate new design alternatives, accelerating the rate at which incremental performance improvements are made (Usher 1954, Clark 1985).

At higher degrees of module reconfiguration negative side effects connected to the ease of knowledge sharing negatively impact innovation. Beyond a certain point, too high levels of module reconfiguration inhibit a team's ability to innovate. Subtracting these negative effects from the described positive effects results into an inverted U-shaped relationship (Haans et al. 2016). Diverse factors, such as extreme predictability or imitation risks, outweigh the initially high benefits of low-cost knowledge sharing with module reconfiguration, thus diminishing innovation outcomes. We have derived three main arguments from the literature.

First, because such reconfigured designs make product development more predictable (Chesbrough 2003, Sabel and Zeitlin 2004, Ernst 2005), many organizations seem to apply modular design to the degree that weakens the innovation process by minimizing opportunities (Fleming and Sorenson 2001). This kind of predictable structure can limit organizations to value-generating alternatives because they cannot escape the boundaries set by the existing modular design strategies (Brusoni et al. 2007), thus decreasing innovation effectiveness.

Second, the reusable nature of the modular architecture can also limit innovation due to limited product differentiation and high product similarity (Ulrich and Tung 1991, Robertson and Ulrich 1998). This leads to easier, faster imitation (Baldwin and Clark 2000, Pil and Cohen 2006) and increases the risk that competitors will develop similar products (Huang 2000, Ernst 2005), which ultimately reduces innovation effectiveness. Third, high levels of module reconfiguration reduce the degrees of freedom to create radically innovative products because of the compatibility constraints, whereby new products must fit with existing ones (Prencipe et al. 2003). This, in turn, limits the opportunity for creating new ideas, which diminishes innovation effectiveness.

In sum, the initially high benefits face side-effects that inhibit knowledge sharing. Combining the positive effects with the increasingly negative effects results in an inverted U-shaped relationship between product modularity and innovation effectiveness. We suggest that module reconfiguration has a positive effect on innovation effectiveness up to an optimum point, simultaneously resulting in increasing negative effects and, after the optimum, the negative effects will outweigh the positive ones. Further, increasing module reconfiguration beyond the optimum leads to a decrease in innovation effectiveness.

H5b: Module reconfiguration has an inverted U-shaped relationship with innovation effectiveness.

3.2.3.3. Impact of Module Standardization on Innovation Efficiency

This section theorizes a negative relationship between module standardization and innovation efficiency. Innovation efficiency is influenced by innovation expenditures such as cost, time, and resources (Wheelwright and Clark 1992), where the achievement of a desired outcome or goal is determined with a minimum of effort, cost, or waste (Reed 1991). Efficiency focuses on the optimization of input versus output (Campbell 2005, Lai and Yik 2008, Madritsch 2009) and represents a relative usage value based on how many resources, investments, and costs have been utilized. This economic principle helps determine both efficiency and productivity.

Mature organizations in established markets tend to develop products with relatively slow, and predictable technological change (Brusoni et al. 2001, Argyres and Bigelow 2010, Furlan et al. 2014). In this context of R&D in large organizations, high degrees of module standardization bring increasing levels of costs and resources. First, and especially given the very high complexity of technology development, some argue that it is no longer possible to freeze interface standards as an operationalization of module standardization (Ernst 2005). This means that it is necessary to continuously negotiate adjustments, which creates additional costs and interfaces and generates further tensions that can have a negative impact on innovation efficiency. Second, standardization can create unplanned, extensive fixed and variable product costs (Kaplan and Haenlein 2006) as a result of overdesign. R&D engineers become overwhelmed by the excessive possibilities afforded by standardization, which could, in turn, lead to confusion and a failure to select suitable standards, constraining innovation efficiencies. Third, the extensive use of standards might additionally affect cooperative net loss (caused by the division), along with coordination cost and conflict of interest between the individual modules (Thompson 1967). This increase in costs and efforts would, in turn, also reduce innovation efficiency. Finally, the widespread use of standards brings with it a lengthy and very costly search for new and better architecture (Ernst 2005). All these additional costs and higher levels of effort might be greater than the expected innovation benefits (e.g., patents), diminishing innovation efficiency.

This study, therefore, suggests that, given R&D teams, module standardization has an adverse effect on innovation efficiency:

H6a: Module standardization has a negative relationship with innovation efficiency.

3.2.3.4. Impact of Module Reconfiguration on Innovation Efficiency

This section theorizes a positive relationship between module reconfiguration and innovation efficiency, building upon three lines of argumentation. First, since module reconfiguration allows product variety to be managed without an explosion of costs, the literature often associates reconfiguration with decreasing costs and increasing flexibility in resources allocation (Jacobs et al. 2007, Lau et al. 2007). Without such reconfiguration, more intense collaboration across design interfaces would be necessary (Eppinger and Chitkara 2006), and this could lead to increased costs. Utilizing reconfiguration could thus reduce costs, thereby improving innovation efficiency. Second, the act of recombining and reconfiguring during development reduces the number of processes overall, leading to a reduction in life-cycle costs (Newcomb et al. 1998, Gershenson and Stauffer 1999) and, in turn, supporting innovation efficiency. Third, when product variety is required, module reconfiguration becomes useful for cost-saving activities (Hillstrom 1994). Numerous of these advantages of module reconfiguration have been reported, such as increasing reuse and remanufacturing in product retirement (Graedel and Allenby 1996), achieving reductions in investment costs (Fisher et al. 1999), or even reducing assembly time, labor costs, and inventory costs. Thus, module reconfiguration leads to greater flexibility in terms of responding to changes and a reduction in development costs and, ultimately, innovation efficiency (Hopwood 1995, Sosale et al. 1997).

In sum, this study, therefore, suggests that module reconfiguration has a positive effect on innovation efficiency:

H6b: Module reconfiguration has a positive relationship with innovation efficiency.

Table 9 Summary of Hypotheses and Conclusions

H	Summary of hypothesis	Impact
H5a	Standardization - Innovation Effectiveness	U-shape
H5b	Reconfiguration - Innovation Effectiveness	Inverted U-shape
H6a	Standardization - Innovation Efficiency	Negative
H6b	Reconfiguration - Innovation Efficiency	Positive

Table 9 summarizes the theorized effects of standardization and reconfiguration on innovation efficiency and effectiveness.

3.3. RESEARCH DESIGN

3.3.1. Context and Data

The empirical testing was conducted in a large multinational organization from the automotive industry that has R&D teams in three global regions (i.e., Europe, America, and Asia). Past innovation and organization studies have used a similar strategy of focusing on the leading organizations in an industry (e.g., Gulati 1995, Gulati and Garguilo 1999) as it allows the exploration of organizations in a more favorable innovation context. The unit of analysis was the different R&D teams that develop diverse kinds of technical products with a different degree of product modularity. These R&D teams form the R&D network and develop different kinds of products with a diverse degree of module standardization and reconfiguration. Additionally, the R&D teams play an integral role in innovation since they function as a primary technological interface (Jankowski 1998). Furthermore, the automotive industry is a suitable context for empirical testing of the theoretical framework because it enjoys a high degree of innovation, relies significantly on the creation of new patents, and broadly applies the modularity concept (Takeishi and Fujimoto 2001, Fixson et al. 2005, Ro et al. 2007, Schulze et al. 2015, Jacobides et al. 2018).

To test our hypotheses, we sent a structured questionnaire to the R&D team members running various projects. Participants included individuals working on a variety of technology projects in a wide range of R&D domains, from different regions, locations, and experience levels within the organization, which made the sample highly heterogeneous. All of the teams could be considered formal groups, in that employees, were assigned to, viewed themselves as, and were seen by others as teams and interacted and shared resources to accomplish mutual tasks and goals (Shea and Guzzo 1987). All respondents were asked to complete a web-based questionnaire specially developed for this study. This approach allowed respondents the time to think about their replies, which minimizes the risk of researcher bias and was an appropriate method for reaching the geographically distributed population (Ticehurst and Veal 2000, Zikmund 2000). To enhance the construct validity of the survey measures, the survey was pre-tested with a small group of team members from different regions. This allowed us to analyze the reliability of each of the preliminary scales and exclude potential phrasing ambiguity in order to achieve completeness and clarity of meaning for all items, whereupon the survey was modified and used to capture all related data.

In an effort to select the most representative sample, we created a list of all the projects being undertaken at the time of data collection. Based on that, we excluded very small projects (i.e., those with fewer than three project engineers). We decided not to focus on including only completed projects, since that could lead to an over-representation of successful projects, biasing the result. Hence, the data covered projects in all phases of development (i.e., conception, detail design, validation, and the start of production). After our initial data preparation, we ended up with a list of 140 projects. The organization provided a list with all team member per project.

An introduction letter sent by e-mail informed the potential respondents about the nature of the study. It explained that the data would be collected and treated confidentially, and that each questionnaire contained a unique identification number for the data matching procedures (e.g., to match respondents to their respective teams). Participation was voluntary. The survey collection took six weeks. A reminder with a copy of the questionnaire was sent to respondents who had not answered after three weeks. There were no significant differences between early and late respondents (we compared the average mean response values on key dimensions, such as innovation effectiveness, module standardization, and reconfiguration), which suggests that nonresponse bias was not a serious concern (Armstrong and Overton 1977). A total of 695 questionnaires were distributed, and 550 completed questionnaires were returned, for a response rate of 79%.

The sample consisted of individuals who worked in R&D teams, with the average team having seven members. According to Mueller et al. (2000), "normal" group size is between three and 15 members; our study falls primarily into this category.

3.3.1.1. Level of Analysis

The literature on teams has mainly focused on the analysis at the full product level, i.e., level 0 of the product hierarchy (Sethi et al. 2001, Kratzer et al. 2004, Hertel et al. 2005, Carnabuci and Operti 2013, Sandberg et al. 2015). This is also the level that our study focusses on (Gershenson et al. 2003, Pil and Cohen 2006), for both the dependent (innovation) and independent variables (module standardization and reconfiguration). In our understanding, and under the collaborative R&D team context, considering innovations at the component or module level would not affect our hypothesis and results differently, as long as we find ourselves in innovation contexts that do not change the system architecture. Innovation at the component or module level will result in modular changes within the system architecture without altering the overall design of it. (Henderson and Clark 1990).

Moreover, when team-level variables are studied based on perceptual data collected at the individual level, it elevates the issue of aggregation in the individual-level measures to the team level of analysis (George and James 1993). Although aggregation is sometimes considered controversial (e.g., Campion et al. 1993), in this case, the recommendations for allowing such aggregation were fulfilled. First and most important, most items on the questionnaire referred to the group and product level, and the aspects being measured were understood to pertain to the shared views of the group or the product being developed. We assessed the degree of interrater agreement within the teams (i.e., multiple respondents per team filled in the survey) as an indication of the homogeneity of team members' perceptions (James et al. 1984). This indicated satisfying agreement within the teams, which is a precondition for group-level aggregation (interrater greater than 0.8 in more than 80% of the cases tested). In addition, we calculated the intra-class correlation (ICC) for every team (total 101 teams), in order to estimate the interrater reliability (variables: knowledge diversity, team interaction, innovation effectiveness, innovation efficiency, module standardization and reconfiguration). The average ICC between measures was 0.75, with a 95% confidence interval, indicating a high degree of reliability (Campion et al. 1993). In sum, these results were consistent with recent studies and support aggregation to the group level. Finally, each of the variables in the model was recorded, as needed, within the same data range, and all scores of multiple team members were averaged at the team level.

3.3.2. Research Variables and Measures

This study relied on existing scales from the literature (described in more detail below). The questions were rated according to a seven-point Likert scale, which required respondents to indicate their level of agreement or disagreement by marking an "X" at the appropriate number (from 1 = Strongly Disagree to 7 = Strongly Agree).

3.3.2.1. Dependent Variables

There are two dependent variables in this research: innovation effectiveness and innovation efficiency, all measures at the team level. *Innovation effectiveness* was operationalized as the combination of two dimensions: market newness and patent creation (Griliches 1998, Katila 2000, Wang and Ellinger 2011). Market newness assesses whether, during the product development period, the product contains any new technologies for that particular market (Hauser and Zettelmeyer 1997, Yin et al. 2011, Schwartz et al. 2011). A total of four items sourced from recent studies were used in the investigation: 1) "This product is new to the market or customer" (Jansen et al. 2006); 2) "The product possesses technical specifications, functionalities, components, or materials differing from the current ones" (Gunday et al. 2011); 3) "The product we developed is the first of its kind" (Darroch 2005), and 4) "The product has unique features to the market or customer." (Garcia and Calantone 2002).

With regard to the second dimension, patent creation refers to the number of patents applied for (filed or not filed) or current and potential innovation patents during the product development time (start of project until start of mass production) (Werner and Souder 1997, Bremser and Barsky 2004, Cebeci and Sezerel 2008, Chiesa et al. 2009, Jalles 2010). This dimension was evaluated in the questionnaire with two items: 1) "This product has or is acquiring patents." (Wang and Ellinger 2011), and 2) "The product has patentable innovations." (Lau et al. 2007) The overall measure innovation effectiveness was constructed by taking the average value of the six items.

Innovation efficiency was determined based on three items designed to quantify new product revenues as related to R&D costs and patentable discoveries. This variable was measured through three adapted questionnaire items based on previous research (Garcia and Calantone 2002, Jimenez and Sanz 2011) concerning 1) the product's revenue generation compared to the R&D expenditure; 2) the product's patentable discoveries by R&D expenditure (Jimenez and Sanz 2011); and 3) whether the investment was reasonable compared to the innovative features developed for the product (Garcia and Calantone 2002). The overall measure was constructed by taking the average of these three questions.

The construct validity of the measures for the dependent variables was verified by employing factor analysis. Factor analysis was performed on the corresponding items for every construct to ensure that all the related items fell into only one factor (all factor loadings were above .719 and within acceptable fit). The factor results confirmed that all the elements fell into a single factor, replicating the intended structure. Reliability was evaluated through both the composite reliability score for each multiple indicator construct and Cronbach's alpha. The Cronbach's alpha values for the two dependent variables, innovation effectiveness, and innovation efficiency were 0.826 and 0.763, respectively, indicating that the items were internally consistent and therefore the constructs were reliable (Hair et al. 1998, Streiner 2003).

3.3.2.2. Independent Variables

The two key dimensions of product modularity, module standardization, and reconfiguration, were measured using existing and adapted questions from recent studies. Product modularity was defined on the questionnaire as "the use of standardized and interchangeable components or units that enable the configuration of a wide variety of end products" (Schilling 2000).

Module standardization refers to the extent to which something is constructed by joining a set of standardized parts that have been made separately (Pels and Erens 1992). It was measured using mainly two key dimensions: first, the use of common assemblies and components and second, the use of standardized components. Three items adopted from previous studies were used to measure module standardization (Jacobs et al. 2007, Lau et al. 2007, Danese and Filippini 2010), aiming at the degree to which standard components and common assemblies were used: 1) "Product in design uses common component modules" (Danese and Filippini 2010); 2) "Product components are standardized" (Lau et al. 2007), and 3) "Product can be decomposed into separate standard modules." (Lau et al. 2007). As described earlier, items were scored on a seven-point Likert scale ranging from "Strongly disagree" (1) to "Strongly agree" (7). The overall measure was constructed by taking the average value of the three questions.

Module reconfiguration refers to the degree of reuse of product components to form new product variations. Products with a high degree of module reconfiguration allow for a broad range of product variations from the mixing and matching of modules (Fujita 2002, Mikkola and Gassmann 2003). This variable was measured in line with Lau et al. (2011) and Jacobs et al. (2007) through three adapted questionnaire items: 1) "Components are interchangeable across different products" (Jacobs et al. 2007); 2) "Product components can be reused in other products"(Lau et al. 2007), and 3) "Products can be re-configured into further end products (Jacobs et al. 2007)." The overall measure was constructed by taking the average value of the three questions.

Factor analysis on the related items for the independent variables was used to check the intended structure. Each item loaded explicitly on their expected factor (all factor loadings above 0.702 and within acceptable fit), and all factors had eigenvalues greater than 1, supporting the factor approach. Cronbach's alpha values for the two constructs, module standardization, and reconfiguration were 0.618 and 0.805, respectively, indicating that the items were internally consistent and hence the constructs were reliable (Hair et al. 1998, Streiner 2003). Therefore, all these initial analyses provide reasonable confidence that the measures used in the present study are valid and reliable.

Finally, for further robustness purposes and in order to confirm that the results were not driven by the potential effects of a common methods bias, we ran Harman's single factor score.

Results indicate that the total variance for a single factor was 25.81% (less than 50%), which suggests that our data and results were not affected by common method bias.

3.3.2.3. Control Variables

We considered the following control variables sourced from previous studies investigating performance on R&D teams: years of experience at the company and total years of experience (Kratzer et al. 2004); team size (Ancona and Caldwell 1992, Pelled 1996, Tsai 2000, Van der Vegt and Jansen 2003); project length (Lovelace 1986); number of fields of experience (Staples et al. 1999), number of roles in the project (Salas et al. 2005a); level of education (Bozionelos 2008); and the geographical distribution of the team members. Appendix 3 provides the arguments and operationalization of these variables. See Appendix 6 for the full survey.

3.4. ANALYSIS AND RESULTS

Table 10 reports the descriptive statistics of and correlations between the variables. For example, the average time taken for the development of the products (i.e., project length) reported in our study was 19.6 months, indicating that these were significant new development programs. Furthermore, the average team size was seven members, and average total team experience was over five years. Moreover, the results show relatively low bivariate correlations between the variables, which indicates no reason for concern. OLS regression analysis was performed to investigate the relationship between module standardization and reconfiguration (the independent variables) and innovation effectiveness and efficiency (the dependent variables). Since the innovation measure could theoretically be considered to not be a fully continuous variable, the analyses were re-analyzed with ordered logistical regressions. These findings are similar.

Table 11 presents the results of the regression analyses for both innovation effectiveness (Models 1 to 6) and efficiency (Models 7 to 12). All models displayed contain the full set of defined control variables, and all the models are overall significant. The model sequence started with standardization as a linear variable (Models 1 and 7). This was followed by the addition of the square variable of standardization (Models 2 and 8) to test for the U-shaped and inverted U-shaped relationships. In contrast and in addition to only the control variables, Models 3 and 9 incorporate reconfiguration as a linear variable, while Models 4 and 10 additionally incorporated the square variable of reconfiguration. In both Models 5 and 11, the linear variables for module standardization and reconfiguration were simultaneously incorporated, while Models 6 and 12 additionally incorporate both squared variables.

Focusing on innovation effectiveness Model 6 is the model with the best relative quality based on the lowest value of the Akaike Information Criterion (AIC: 320) and one of the lowest

Bayesian Information Criterion (BIC: 354). With regard to module standardization Model 6 shows a negative and significant linear coefficient (βstandardization linear = -1.60, $p = 0.04$) and a positive and significant coefficient for the squared standardization variable (βstandardization squared = 0.15, $p = 0.10$). With regard to module reconfiguration Models 6 shows a positive and significant linear coefficient (βreconfiguration linear = 2.32, $p = 0.01$) and a positive and significant coefficient for the squared standardization variable (βreconfiguration squared = -0.23, $p = 0.002$).

Table 10 Descriptive Statistics and Correlation of Variables

Variable	Min.	Max.	Mean	Std. Dev.	1	2	3	4	5	6	8	9	10	11	12	13
1. Innovation Effe.	1.25	7	3.65	1.23	1											
2. Innovation Effi.	1	7	4.57	0.86	0.44	1										
3. Standardization	1	7	4.78	0.98	-0.16	-0.14	1									
4. Reconfiguration	2	7	4.89	1.04	0.15	0.22**	0.43**	1								
5. Exp. at company	1	21.75	9.81	4.33	0.24	0.08	-0.08	-0.05	1							
6. Total Experience	5	34	15.17	5.54	-0.08	-0.20*	-0.04	-0.16	0.39**	1						
8. Team Size	1	22	7.06	4.07	0.12	0.04	0.08	0.03	0.32**	0.25*	1					
9. Project Length	3	37	19.65	7.06	-0.02	0.09	-0.25*	-0.13	0.17	0.18	0.42**	1				
10. Nr. Fields	1	6	2.27	1.08	0.08	0.20*	0.25*	0.25*	0.07	0.06	0.09	-0.11	1			
11. Nr. of Roles	1	4	1.37	0.54	-0.01	-0.28*	0.21*	0.22*	0.16	0.13	0.21*	-0.26*	0.17	1		
12. Level of Ed.	1.67	3.2	2.38	0.38	0.14	0.21*	0.03	-0.06	0.05	0.00	0.03	-0.04	0.07	0.04	1	
13. Geo. Dispersion	1	3	1.56	0.57	-0.16	-0.15	-0.11	-0.14	0.01	0.15	-0.08	0.09	-0.03	0.03	0.08	1

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

Table 11 Regression Results with Module Standardization, Reconfiguration, Innovation Effectiveness, and Innovation Efficiency Variables

Innovation Effectiveness							Innovation Efficiency					
Variables	M 1	M 2	M 3	M 4	M5	M 6	M 7	M 8	M 9	M 10	M 11	M 12
Standardization	-0.27*	-0.76			-0.38**	-1.60*	-0.14t	-0.59			-0.25**	-0.47
	(0.13)	(0.63)			(0.14)	(0.77)	(0.08)	(0.41)			(0.09)	(0.50)
Standardization		0.06				0.15t		0.05				0.03
Squared		(0.07)				(0.09)		(0.05)				(0.06)
Reconfiguration			0.16	1.52*	0.29*	2.32**			0.20*	0.41	0.28***	0.58
			(0.12)	(0.72)	(0.13)	(0.83)			(0.08)	(0.46)	(0.08)	(0.54)
Reconfiguration				-0.15t		-0.23*				-0.02		-0.03
Squared				(0.08)		(0.09)				(0.05)		(0.06)
Experience at	0.08**	0.08**	0.09**	0.08**	0.08**	0.08*	0.03	0.03t	0.04t	0.04t	0.03t	0.03
Company	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Total	-0.04t	-0.04	-0.03	-0.03	-0.03	-0.03	-0.04*	-0.04*	-0.03*	-0.03*	-0.03*	-0.03*
Experience	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.01)	(0.01)
Team Size	0.04	0.04	0.03	0.01	0.04	0.02	0.02	0.02	0.01	0.01	0.02	0.02
	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Project Length	-0.02	-0.02	-0.01	-0.01	-0.03	-0.01	0.00	0.00	0.01	0.01	-0.00	-0.00
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Nr. Fields of	0.11	0.10	0.03	0.03	0.06	0.06	0.21**	0.21**	0.14*	0.15*	0.17*	0.17*
Experience	(0.11)	(0.11)	(0.11)	(0.11)	(0.11)	(0.11)	(0.07)	(0.07)	(0.07)	(0.07)	(0.07)	(0.07)
Nr. of Roles in	-0.14	-0.16	-0.25	-0.14	-0.24	-0.10	-0.48**	-0.50**	-0.58***	-0.57***	-0.58***	-0.56***
Project	(0.24)	(0.25)	(0.25)	(0.25)	(0.24)	(0.24)	(0.16)	(0.16)	(0.16)	(0.16)	(0.15)	(0.16)
Level of	0.43	0.41	0.46	0.47	0.49	0.44	0.46*	0.44*	0.50*	0.50*	0.52**	0.51*
Education	(0.31)	(0.31)	(0.32)	(0.31)	(0.31)	(0.30)	(0.20)	(0.20)	(0.20)	(0.20)	(0.19)	(0.20)
Geographical	-0.36t	-0.31	-0.30	-0.42t	-0.32	-0.38t	-0.20	-0.15	-0.15	-0.17	-0.16	-0.16
dispersion	(0.21)	(0.22)	(0.21)	(0.22)	(0.21)	(0.21)	(0.14)	(0.14)	(0.14)	(0.14)	(0.13)	(0.14)
Constant	4.37***	5.33**	2.24t	-0.72	3.45**	1.50	4.77***	5.65***	3.06***	2.59*	3.86***	3.67**
	(1.16)	(1.67)	(1.17)	(1.93)	(1.20)	(1.98)	(0.76)	(1.09)	(0.74)	(1.24)	(0.76)	(1.28)
Model sig	0.02	0.03	0.05	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Adj. R-squared	11%	10%	8%	11%	15%	18%	22%	28%	25%	24%	31%	29%
AIC	326.19	327.48	329.14	327.01	322.67	319.80	240.01	240.64	236.28	238.03	228.96	232.57
BIC	352.34	356.24	355.29	355.87	351.43	353.79	266.17	269.40	262.43	266.80	257.73	266.57

tp<0.10; *p<0.05; **p<0.01; ***p<0.001 / Non Standardized β values for all variables / Standard errors in brackets.

To test for the presence of the theorized U-shaped and inverted U-shaped relationships with innovation effectiveness (for standardization and reconfiguration, respectively), we followed the three steps described in Lind and Mehlum (2010). The first step is to investigate the significance of the linear and squared coefficients. The just described results; a negative linear coefficient with a positive squared coefficient for module standardization seems to indicate and U-shaped relationship; while a positive linear coefficient with a negative squared coefficient for module reconfiguration seems to indicate and inverted U-shaped relationship.

The second step involves testing the significance of the lower and upper bound slopes of the potential shapes as well as their joint significance. With regard to module standardization, the lower bound slope has a significant negative coefficient of -1.31 ($p = 0.02$), and the upper bound slope has a positive coefficient of 0.45, but this coefficient is not significant ($p = 0.20$). The overall test of the presence of a U-shape reveals a p-value of 0.20 which is not significant. With regard to module reconfiguration, the lower bound slope has a positive significant coefficient of 1.40 ($p=0.002$), and the upper bound slope has a significant negative coefficient of -0.89 ($p=0.04$). The overall test of the presence of an inverted U-shape reveals a p-value of 0.04 which is significant.

The third step involves checking whether the tipping point (i.e., optimum or minimum) falls within the data range. For module standardization, the tipping point lies at 5.48 with a 90% confidence interval, based on the Fieller calculation, between 4.62 and 66.25, which falls outside the data range (1-7). For module reconfiguration, the tipping point lies at 5.06 with a 90% confidence interval, also based on the Fieller calculation, between 4.58 and 6.53, which falls inside the data range (1-7).

Figures 5 and 6 show the relationship of module standardization and module reconfiguration with innovation effectiveness. The small grey squares in the center of the figures present the data points from the survey. The black curves show the relationships based on the coefficients from Model 6. The dashed start and the end of the black curves include the slopes of the lower and upper bounds (from step 2). The dotted lines at the start and end of these curves present the predicted slopes (also based on the coefficients of Model 6) just before and beyond the data range. The extreme points with its 90% confidence interval are also incorporated. Based on these results Hypothesis H5a theorizing a U-shaped relationship between module standardization and innovation effectiveness is not confirmed, since the results reveal a negative relationship. Hypothesis H5b theorizing an inverted U-shaped relationship between module reconfiguration and innovation effectiveness is confirmed.

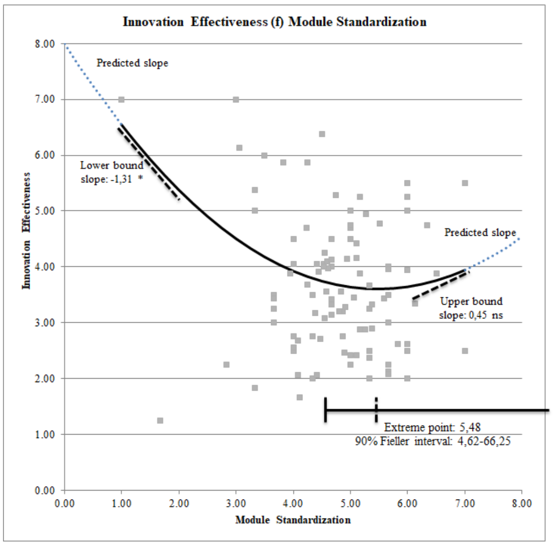


Figure 5 Innovation Effectiveness and Module Standardization

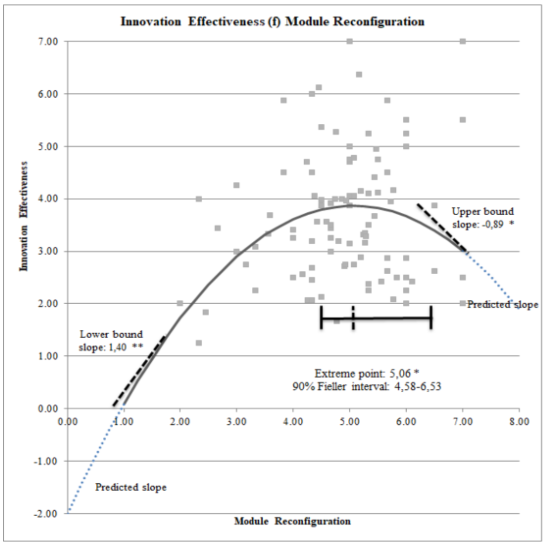


Figure 6 Innovation Effectiveness and Module Reconfiguration

Focusing on the second dependent variable, innovation efficiency (Models 7-12), Model 11 is the model with the best relative quality based on the lowest values of both the Akaike Information Criterion (AIC: 229) and the Bayesian Information Criterion (BIC: 258). With regard to module standardization Model 11 shows a negative and significant linear coefficient (βstandardization linear = -0.25, p = 0.004), supporting H6a. For module reconfiguration Model 11 shows a positive and significant linear coefficient (βstandardization linear = 0.28, p = 0.001), supporting H6b.

Figures 7 and 8 show the relationships of module standardization and module reconfiguration with innovation efficiency. The small grey squares in the center of the figures present the data points from the survey. The black lines show the relationships based on the coefficients from Model 11.

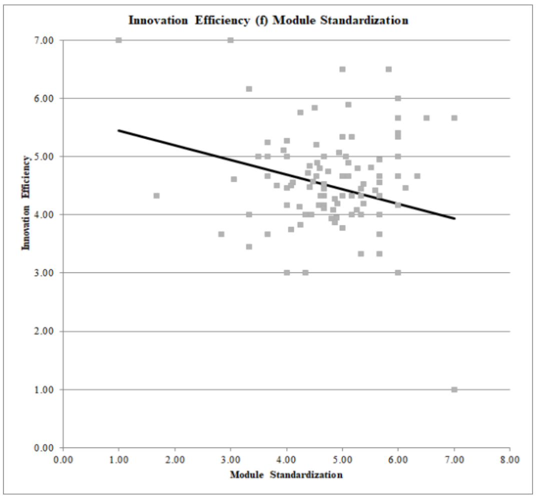


Figure 7 Innovation Efficiency and Module Standardization

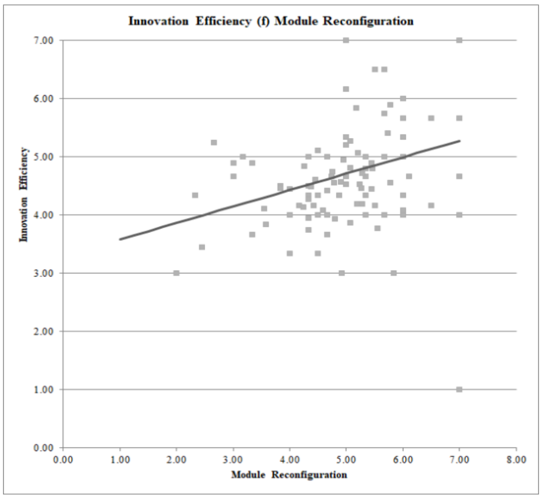


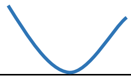
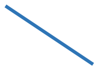
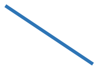
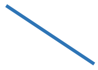
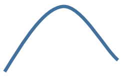
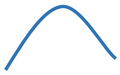
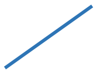
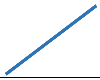
Figure 8 Innovation Efficiency and Module Reconfiguration

Table 12 summarizes the empirical results in relation to the theorized hypotheses.

As a robustness check, we additionally, manually collected secondary data on patents and R&D investments for a subset of projects (i.e., 81) to operationalize the dependent variables and carry out the same regression models that we had used for the primary data. Those analyses suggest that the variables and relationships behave in the same direction and, thus, add validity to our findings. Furthermore, and in addition to the curvilinear and linear relationships, other non-linear relationships were assessed (i.e., cubic relationships), but these did not yield better results in terms of significant coefficient and model quality. This confirms that the found curvilinear and linear effects are the best specifications for the data (i.e., Model 6 and 11).

Moreover, conceptually modules reconfiguration implies modules standardization (Cabigiosu and Camuffo 2017). As such one could argue that standardization would precede reconfiguration or that the relationship between standardization and innovation is mediated by reconfiguration. The organization that we researched has been working with product modularity for many years. Our descriptive statistics confirm this as both standardization (mean of 4.78 on a 7-point scale), and reconfiguration (mean of 4.89 on a 7-point scale) have a relatively high mean value. This indicates that both dimensions of product modularity are utilized. In addition, to investigate a potential mediating relationship of reconfiguration between the relationship of standardization and both dimensions of innovations, mediation analyses were conducted (controlling for the same control variables), and showed positive but non-significant indirect effects of standardization, though reconfiguration on both dimensions of innovation.

Table 12 Summary of Theorized and Empirical Results

	Innovation			
	Effectiveness		Efficiency	
	Theorization	Empirical	Theorization	Empirical
Standardization				
Reconfiguration				

3.5. DISCUSSION AND CONCLUSIONS

This study aimed to investigate the impact of module standardization and reconfiguration on innovation effectiveness and efficiency in R&D teams. Several conclusions, consistent with our assumptions, can be drawn from its results, providing original theoretical and managerial implications on the role that product modularity (i.e., module standardization and reconfiguration) can play for innovation.

3.5.1. Theoretical Implications

The study makes several theoretical contributions toward advancing the extant literature, enhancing the understanding of intra-organizational collaboration in particular for R&D organizations by filling in the gaps and establishing the effects of module standardization and reconfiguration on innovation (i.e., effectiveness and efficiency) at the team level.-The first and most relevant theoretical contribution of this study is that it is the first empirically tested research to adopt a multidimensional view of product modularity, suggesting that both module standardization and reconfiguration matter for innovation and exert distinct, sometimes opposite effects. The multidimensional approach has been identified in theory (Gershenson et al. 2003, Salvador 2007) but not previously tested empirically. For the first time, our findings provide insight into the optimum of module standardization and reconfiguration in consideration of the relevant innovation criteria. If we then extend the mixed and contradictory results from previous work that has studied the impact of product modularity on innovation, we can deduce a number of additional theoretical insights as outlined below.

Our second contribution lies in the effort made to align opposite viewpoints from the literature on the effects of module standardization on innovation effectiveness (Ulrich 1995, Szulanski 1996, Helfat and Eisenhardt 2004, Pil and Cohen 2006). Our study aimed to advance the literature by demonstrating that module standardization has a U-shaped relationship with innovation effectiveness. However, the empirical results could not fully demonstrate this hypothesis; rather, they showed a negative linear impact for module standardization on innovation effectiveness. One of the possible reasons for not finding this effect could be related to the context of the single firm that was analyzed. For this empirical context, we might predict that the negative effects have a much higher significance than the positive ones. Therefore, further data collection represents an opportunity for future studies.

Another factor at work could be that, in this context, the intensity of coordination among stages is high because of the limited degree of information availability and knowledge sharing (Langlois 2002). The complexity of interfaces remains and makes it difficult for engineers to concentrate on particular components to innovate (Simon 1962, Rosenberg 1982, Von Hippel 1990, Langlois and Robertson 1992, Sanchez 1999). Finally, a further possible reason could be related to the overall visibility of such standards, which, even when available, might not be easily accessible to all of the engineers. This situation could potentially lead to the development of redundant components and increase the time needed to accomplish product integration, which would reduce innovation effectiveness. It would, therefore, be interesting to see what kinds of relationships might be found in future studies.

Third, prior research has argued that reconfiguration has a positive impact on innovation effectiveness (Langlois and Robertson 1992, Pil and Cohen 2006), while another stream of the literature has claimed that it has adverse effects (Clark 1985, Fleming and Sorenson 2001). This research extends the literature by confirming that module reconfiguration has an inverted U-shaped relationship with innovation effectiveness. Specifically, when the number of design alternatives is increased through module reconfiguration (Mikkola 2006), design becomes less complex, allowing R&D teams to find more suitable technical solutions, leading to rapid trial-and-error learning (Langlois and Robertson 1992, Baldwin and Clark 2000, Meyer et al. 2018) and the creation of new product combinations. However, too much module reconfiguration can increase predictability (Chesbrough 2003, Sabel and Zeitlin 2004, Ernst 2005), which limits the generation of new ideas and innovation effectiveness. These empirical findings indicate, therefore, the need for an optimum in the relationship between module reconfiguration and innovation effectiveness. For better innovation, new products should be developed with a degree of module reconfiguration, but only up to a certain optimal level. Beyond this level, module reconfiguration becomes counterproductive to innovation effectiveness. The precise optimum level requires exploration, and future empirical studies should examine the contingencies and factors influencing the optimum.

Fourth, prior research has argued that module standardization has a negative impact on innovation efficiency. Our empirical results are consistent with the existing literature (Kaplan and Haenlein 2006). This outcome is, for example, aligned with the argument by Ernst (2005) in that all additional costs deriving from the extended use of standards would be higher than the expected innovation returns (e.g., patents). In increasingly complex technologies, especially in the context of R&D teams, it is not possible to freeze module standards from the very beginning.

That means adjustments must be continuously negotiated, creating additional unplanned fixed costs (Kaplan and Haenlein 2006) and increased variable product costs due to overdesign and directly reducing innovation efficiencies. In addition, additional costs could accrue due to a higher required degree of coordination (Thompson 1967).

Fifth, this research adds to the literature by providing empirical evidence that module reconfiguration has a positive effect on innovation efficiency. This result is consistent with the stream of research that supports the adoption of product modularity as an important driver in enhancing efficiencies (Ulrich 1994, Pil and Cohen 2000, Gershenson et al. 2003). Specifically, our analyses demonstrate that by recombining and reconfiguring modules during development, for instance, organizations can reduce the number of processes required, leading to a reduction in life-cycle costs (Newcomb et al. 1998, Gershenson and Stauffer 1999) and supporting innovation efficiency.

A final theoretical contribution relates to the concept of innovation. Our argument throughout has been that the vast body of innovation research fundamentally describes two kinds: efficiency and effectiveness (Plessis 2007). Yet, organizations aim to achieve multiple objectives at once (Neely 1998, Mass 2005) and theoretical perspectives on innovation should thus be likewise multidimensional in scope (Mouzas 2006). We have fruitfully applied such a perspective to extend the theory of modularity, and we suggest that scholars might take the next step toward developing and testing even more refined and practically informed views on innovation in organizations.

3.5.2. Managerial Implications

Our arguments and findings have several managerial implications. The results suggest that overall a product modularity strategy could provide a central foundation for achieving simultaneous improvements in multiple dimensions of innovation (effectiveness and efficiency). This creates interesting potential, especially for managers looking to maximize the impact of resources and R&D efforts on innovation. In short, these empirical findings support our arguments that decisions made with regard to instituting module standardization and reconfiguration, and to what degree, significantly affect innovation. To achieve better product performance, organizations must carefully consider the opposite effects of module standardization and reconfiguration on innovation and find an optimum balance.

These results suggest to managers that, in general, working with product modularity is an effective strategy for enhancing innovation. The application of systematically standardized and reconfigurable components reduces the need for an evident exercising of managerial authority across the R&D team interfaces, thereby reducing the intensity and complexity of an organization's managerial task in product development and giving it greater flexibility to concentrate on a larger number of products. Managers should organize their R&D teams around developing standardized components, thereby producing efficiencies in the form of new innovative products and technologies. However, managers must also remain aware of the limited effects in cases of too much or too little module standardization and reconfiguration, which could counteract their efforts to improve innovation. Thus, before deciding to invest in standards, managers need to establish what the optimum level of module standardization and reconfiguration should be.

Implementing a methodology for product modularity in the design process allows for a better, comprehensive investigation of component and final product manufacturing process alternatives. This approach supports better integration and reuse of standardized components in future designs since these are now readily available and can be quickly produced. However, the tipping point of shrinking innovation for increased manufacturing modularity should be explored so that the designer knows when to stop increasing product modularity.

It becomes evident that some form of product modularity is necessary in order for managers to cope with complex modern products and innovate. Costs related to design can rise or fall depending on the degree of module standardization and reconfiguration applied. For instance, if pre-designed standards are already available in the form of guidelines, the cost of development tends to be lower. However, if standards are being developed as a part of the development effort, the related development costs and time may increase.

In addition, for better innovation effectiveness, new products should be developed with higher degrees of module reconfiguration up to a certain optimal level. Beyond this level, modularity becomes counterproductive to innovation. In order to achieve an optimum and resolve the problems of product similarity attributed to module reconfiguration, the product design literature recommends a design method that balances product commonality and differentiation (Robertson and Ulrich 1998) by distinguishing those product components that customers value most. On the other hand, and for the same purpose, module standardization should be enhanced in order to strengthen the effects on innovation effectiveness. For this purpose, organizations could also develop a set of standards to systematically reduce the number of alternatives during the development processes (Baldwin and Clark 2000), as well as to decrease the intensity and complexity of the managerial tasks within R&D teams (Sanchez and Mahoney 1996), provide greater flexibility (Lee and Tang 1997, Fisher et al. 1999), and ultimately enhance innovation. However, and most important, they need to develop a method of balancing the product modularity dimensions (i.e., module standardization and reconfiguration) to support designers in making modularity decisions. In sum, organizations must find methods for closely monitoring these variables, with the aim of achieving an optimum in order to improve innovation outcomes subsequently.

3.5.3. Limitations and Future Research

Despite the interesting findings, our study has some potential limitations worth mentioning. First, one potential limitation relates to the single industry and organization focus. The industry segment and organization chosen are characterized by a broad range of products with a certain degree of module standardization and reconfiguration (e.g., seating systems, steering assemblies, etc.), as well as a high degree of innovative products. The heterogeneity of this industry suggests that the research results could be more generalized than in classic cases of single industry research. Nevertheless, further research support is needed before these results can be generalized. Future studies replicating this research across other sectors, teams, and organizations could increase our understanding of the impact of module standardization and reconfiguration on innovation effectiveness and efficiency.

Furthermore, longitudinal research assessing the influence of module standardization and reconfiguration over time would provide additional and even stronger support for the effects reported here. Moreover, due to the very nature of survey data, as cross-sectional, there is a risk to miss claiming causality. However, the direction of our theorized effects is supported by similar theorizing and reasoning and findings from previous studies in the team and innovation context (Garcia and Calantone 2002, Lau et al. 2007, Danese and Filippini 2010, Jimenez and Sanz 2011). Likewise, and due to the nature of the novel data and the multidimensional approach taken in this study for the first time, future studies could further corroborate the connections and confirm our statements.

In addition, despite the fact that the sampling for this study was taken primarily from respondents who were direct team members and thus the most knowledgeable sources on the phenomena being studied, another possible limitation is that of sampling bias, since we relied only on the responses of these organization team members. It is also possible that some information was excluded from this study because it did not fit with the definition of an R&D team.

Another potential limitation is that we only explored the phenomena in one type of team context, in which an R&D team works with product modularity to some degree. Such teams consist of groups of engineers collaborating interdependently (Gassmann and Von Zedwitz 2003, Van der Vegt and Janssen 2003, Langfred 2005), with a very diverse knowledge base (Yayavaram and Ahuja 2008, Carnabuci and Bruggeman 2009, Sandberg et al. 2015), using information and communication technologies (ICT) as their main exchange media (Ahuja and Carley 1998, Argyres 1999, Janhonen and Johanson 2011). Further research could also investigate other types of organizational contexts, to investigate the generalizability of these findings.

Furthermore, the current research has not differentiated between types of innovation in terms of the degree of innovativeness (e.g., incremental or radical innovation). Future studies could explore how different kinds of innovation are affected by module standardization and reconfiguration. Future research could also explore the influence on innovation in this particular context of certain key characteristics, such as the degree of knowledge diversity, the independence among team members, and the range and use of ICT.

We argue that the emergence of modularity (the creation of standards and use of reconfiguration) depends on the maturity and organization of the research setting with regard to working with product modularity. In other words, both reuse and the creation of standards (or design rules) depends on how product development is organized (MacCormack et al. 2006, Brusoni and Prencipe 2006, Haefliger et al. 2008). In software development, for example, reuse of existing components is widespread from the outset (Haefliger et al. 2008), yet major redesign efforts have a significant impact on modularity (MacCormack et al. 2006). A fascinating question in our research agenda is about what comes first: reconfiguration or standardization in modular product development. Digital entrepreneurship, for instance, depends on building products and services using existing components (Nambisan, 2017). On the other hand, the creation of design rules is costly and involves multiple organizational layers (Brusoni and Prencipe, 2006). A wider organizational argument and a comparative study could shed light on when, if so, the organization of innovation or the maturity of the context systematically relate to modularity along both dimensions.

Finally, there are organizational implications outside of this study. One interesting theme for future research would be to investigate team organizational factors and their effects on innovation in the product modularity context. This could provide fodder for the design and development of organizational structure and settings that help promote innovation in new R&D teams. To date, intra-organizational collaboration research studies have been scant. In this study, we investigate the impact of module standardization and reconfiguration on both innovation effectiveness and efficiency in R&D teams. The results of this study conclude that module standardization and reconfiguration can be beneficial to innovation effectiveness and efficiency but that the benefits vary. Further investigation of this research question is thus critical since innovation is crucial for organizations' survival. Additionally, R&D teams that develop products and technologies with a particular degree of product modularity have become conventional forms of organizing innovation. It is therefore important to more profoundly study the effects of product modularity on innovation in the R&D team context. The different views presented in this paper provide an interesting framework for this and lead to significant horizons for future research to explore this relationship.

APPENDIX 3: Argumentation and Operationalization of Control Variables

The variable *years of experience at the company* was added as a control, since it has been frequently argued that the innovation of teams decreases with their experience (Kratzer et al. 2004). For instance, Lovelace (1986) asserts that the innovation performance of research scientists decreases in accordance with the length of time they are part of a group. We measured years of experience at the company from a survey question, using the number of years since joining the organization.

Furthermore, *work experience in total* can also influence innovation since more experienced employees may benefit more from interactions with other coworkers or require fewer interactions to accomplish their tasks effectively and efficiently (Young-Hyman 2017). Work experience in total was measured in the questionnaire using the total number of years since the start of the respondent's professional career.

We controlled for *team size*, since prior research has suggested that this can affect group dynamics (Pelled 1996) and influence team interactions (Markham et al. 1982, Taylor and Greve 2006), as well as having an impact on teams' ability to utilize knowledge and, ultimately, innovate. Team size was measured in the survey by asking the respondents to indicate the number of people involved in the team (in line with Ancona and Caldwell 1992, Pelled 1996, Tsai 2000, Van der Vegt and Jansen 2003).

We controlled, as well, for *project length,* which is an integral part of teamwork, especially for team learning (McGrath 1991, Kasl et al. 1997). Kelly and McGrath (1985) concluded that having more time is linked with greater team creativity. Time is needed as an incubation mechanism to articulate ideas, provide input, identify challenges, and innovate (West 2002). Furthermore, project length can also influence the degree of alignment between product modularity and team interaction, due to the increasing opportunities for interaction among members and the accruing knowledge on the modularity of the product (Lovelace 1986). Project length was measured with the following item: "Please indicate the project length in months (from nomination to SOP)" (adapted from Lovelace 1986, Kim and Oh 2002, Tiwana 2008).

The variable *number of fields of experience* was also added as control. Research has shown that a member's different levels of experience with diverse domains and technologies play a role in their interactions with other team members (Staples et al. 1999, Kirkman et al 2004). Less technically experienced team members may be less inclined, or able, to communicate and might therefore form the kinds of relationships that diminish innovation (Patel et al. 2012). Number of fields of experience was measured with the following item: "Please indicate the number of fields in which you have gathered prior work experience: Mechanics; Software; Project Management;

Systems Engineer; Hardware; PCB Layout; Testing; Other (please indicate)" (Staples et al. 1999).

Number of roles in the project was considered because having a variety of roles represented allows teams to be more adaptable and flexible in responding to problem-solving demands, which improves innovation outcomes (Ittner et al. 2002, Cavalluzzo and Ittner 2004, Salas et al. 2005a). On the other hand, team members may in such cases experience higher workloads and more pressure than when dedicating themselves to solely one role, which in turn can negatively affect their ability to commit to innovation activities (Shea and Guzzo 1987, Hackman 1990, Klein 2001). Number of roles was measured with the following question: "Your role/s in this project?: Hardware; Mechanics; Software; Testing; Systems Engineer; PCB Layout; Project Manager; Other (please indicate)" (Ittner et al. 2002).

Furthermore, the literature suggests that there are inevitably some designers who typically innovate and perform better than others and that this is usually attributable to differences in cognitive ability and *level of education* (Curtis et al. 1988, Moilanen et al. 2014). Consequently, a team's overall contribution to innovation will also depend on its educational background (Kafouros 2008). In addition, engineers' level of education has often been related to a cumulative knowledge base (Spanos and Voudouris 2009). This situation may have consequent effects on the degree of alignment between team interaction and product modularity, since engineers tend to become more familiar with product structure and support, easing the interactions among team members. Level of education was measured with the following survey item: "Please indicate your level of education: Mid. School / Bachelor / Master / PhD / Other (please indicate)" (Bozionelos 2008).

Finally, *geographical dispersion* was controlled for to capture the distribution across the three main R&D center locations (i.e., Europe, America, and Asia). Based on the main location of each team member, a team-level variable was operationalized capturing the distribution across these three regions: that is, ranging from 1 (team members are all in the same location); 2 (team members are spread across two different locations); and 3 (team members are spread across three different locations), as adapted from Magni et al. (2013).

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CHAPTER 4

THE TWO MIRRORS OF MODULARITY.

PRODUCT MODULARITY AND INNOVATION IN R&D TEAMS[4]

ABSTRACT

Are teams structured so as to mirror the tasks they carry out, technical or otherwise, and is this related to innovation? Few empirical studies exist on this relationship, despite the popularity of the mirroring hypothesis in the literature on organizational design. Building on the insight that product modularity (as a technical task) can have contradictory effects on innovation, we conceptualize it as a two-dimensional construct - comprising standardization and reconfiguration - and empirically explore the mirroring hypothesis in terms of the separate relationships between these technical elements and team structure (e.g., team interaction). Additionally, we offer nuance in terms of the effects on innovation of the alignment between product modularity and team interaction. A survey was used to develop a dataset of 140 R&D teams from a large international organization in the automotive industry. The results suggest a negative relationship between the alignment of team interaction and module standardization on innovation. Meanwhile, the degree of alignment between team interaction and module reconfiguration has a positive relationship with innovation. Multiple data triangulations and robustness checks were conducted and produced comparable results. The findings contribute to the literature of organizational design within the context of R&D teams.

Keywords: Product modularity; Module standardization; Module reconfiguration; Alignment; Mirroring; Innovation; Teams; R&D

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4.1. INTRODUCTION

Increasingly, team members in global organizations must collaborate from multiple distant locations, using predominantly electronic communications to coordinate their work and innovate (Faraj and Sproull 2000, Colombo 2003, Zammuto et al. 2007, Puranam et al. 2014). Such global teams are no longer a new or exotic work practice but rather an established reality in many organizations (Ahuja et al. 2003, Hinds and Mortensen 2005). Previous research has forecasted that organizational design (e.g., team communication and composition) "mirrors," or becomes aligned with, the technical products being developed (Conway 1968, Henderson and Clark 1990, Sanchez and Mahoney 1996, Baldwin and Clark 2000). In other words, to improve product performance and enable innovation, the organizational ties in a project, team, or organization (the communication or interaction) should correspond to the technical dependencies in the work being performed. A key challenge in this context is the alignment or matching of the organizational structure to the product under development. Alignment refers to the degree of overlapping or matching between organizational structure and product characteristics (Sosa et al. 2004, MacCormack et al. 2012).

Product modularity has been widely proposed as a strategic choice for dealing with this increasingly complex, global business environment (Simon 1962, Sanchez and Mahoney 1996, Baldwin and Clark 2000, Ulrich and Eppinger 2000, Garud et al. 2003). It refers to the extent to which a set of components performs functions and these components connect to other components through standard elements (Ulrich 1995). When two components or product modules share design interfaces, the team members who develop those interfaces need to connect (Thompson 1967, Brusoni and Prencipe 2006). A variety of studies has explored the links between a product and the organization or team that develops it (Conway 1968, Henderson and Clark 1990, Langlois and Robertson 1992, Sanchez and Mahoney 1996, Baldwin and Clark 1997, 2000, Schilling 2000, Brusoni and Prencipe 2001, Sosa et al. 2004, Cataldo et al. 2006, Hoetker 2006, Fixson and Park 2008, Tiwana 2008, MacCormack et al. 2012, Colfer and Baldwin 2016). A significant number of studies, moreover, have investigated single projects (Henderson and Clark 1990, Brusoni and Prencipe 2001, Tiwana 2008, Cabigiosu et al. 2013, Furlan et al. 2014), focusing on the need to align team interdependence with the technical interdependencies in the product design. These studies suggest that team communication should align with the technical interdependencies between a product's components or modules. The reasoning here is that if there are technical connections between different aspects of a product, there should be a matching level of communication between the team members working on those features (Baldwin 2008).

The literature suggests that the design of organizational structures based on product structures is beneficial for product development. In research closest to our own, Sosa et al. (2004) studied the misalignment of design interfaces and communication patterns. They identified factors that make some teams better than others at aligning their cross-team interactions with design interfaces (Sosa et al. 2004). When organizational and product structures are mirrored, changes in one impact the other, hence offering potentially useful insights for improving R&D processes, product performance, and innovation (MacCormack et al. 2012). However, despite the implication in the two studies cited that a decreasing degree of alignment between team interaction and product modularity is detrimental to innovation, there have been no empirical tests of this assumption. It is here that our argument starts.

Innovation requires creating a space for novelty and engaging with the unknown. It includes developing new configurations that, by definition, cannot be known at the point of designing the underlying components. Hence, we need to define modularity at the level of the product system as a whole, which requires a greater degree of complexity in the definition of modularity than a unidimensional one (Salvador 2007: 226). For this reason, we adopt here a definition of product modularity that includes module standardization and reconfiguration. Module standardization refers to the extent to which something is constructed by assembling a set of standardized parts that have been made separately (Pels and Erens 1992), while reconfiguration is about the degree of reuse of product components that allows for a broad range of new product variations by mixing and matching modules (Mikkola and Gassmann 2003). In other words, product modularity refers to the degree to which a system can be separated (decomposition into standard components) and recombined (reconfiguration of components). This interpretation incorporates two essential elements: first, decomposition, or standards; and second, reconfiguration, or reuse. This approach is rooted in multidisciplinary reviews of product modularity (Gershenson et al. 2003, Salvador 2007, Frandsen 2017). These two dimensions of modularity may have diverse effects on the "mirroring" hypothesis, which could explain the mixed results of prior empirical research (Tiwana 2008, MacCormack et al. 2012, Cabigiosu et al. 2013, Furlan et al. 2014, Cabigiosu and Camuffo 2017, Sorkun and Furlan 2017).

Thus, this study attempts to address the following two central questions:

1) *How does the alignment of module standardization and team interaction impact innovation?*

2) How does the alignment of module reconfiguration and team interaction impact innovation?

Investigating these questions is crucial to understanding the areas of product modularity and team organization to which managers must pay particular attention in order to cope with the impact of misalignments and promote innovation. To answer these research questions, we developed a survey and distributed it to R&D teams at a large international organization in the automotive industry. The rapid increase in the aforementioned organizational forms also requires attention to the predominant form of communication being used: email. We performed a triangulation analysis using email communication data among R&D teams, providing unique access to communication patterns.

Our results provide evidence for the relationship between the alignment of product modularity and organizational design, as well as evidence that the degree of alignment impacts innovation. The findings lead to two main contributions. First, we enhance the understanding of the concept of alignment between task and organizational structure at the team level by applying a multidimensional definition of product modularity. Second, we provide evidence of the impact of this alignment on innovation. By proposing that alignment can influence innovation, we contribute to the literature that studies the mirroring hypothesis (Brusoni and Prencipe 2001, Langlois 2002, Sosa et al. 2004, MacCormack et al. 2012, Furlan et al. 2014, Cabigiosu and Camuffo 2017, Hao et al. 2017, Sorkun and Furlan 2017). We suggest that aiming for an optimized alignment between product modularity and team interaction can be beneficial to innovation. It is important for managers to anticipate where misalignment is most likely to occur—that is, to distinguish which areas of the product and the team require particular attention in identifying critical design interfaces to ensure the most effective team interactions.

In the next section, we introduce our theoretical framework and hypotheses. Section three then details our research design and analysis, with the results presented in section four. Finally, we discuss the theoretical and managerial implications of our findings in section five, as well as the study's limitations and avenues for future research.

4.2. THEORETICAL FRAMEWORK

In this section, we define the essential research constructs of team interaction, alignment (or mirroring), product modularity, and innovation.

4.2.1. Team interaction and Innovation

In product design teams, members come from different areas of the organization and diverse disciplines, and they apply a variety of information systems. Individuals also have varying levels of understanding and abilities and preferred means of communication (Tuckman and Jensen 1977, Robbins 2001). A team is defined as a distinct group of two or more individuals who cooperate interdependently to reach specifically defined objectives (Morgan et al. 1996). This definition emphasizes the composition of a team (people) working interdependently on a task toward a common goal. The team is the core building block for coordinating knowledge-intensive work (Van de Ven et al. 1976, Lovelace 1986, Keller 2001). Innovation activities are normally run using a project-management approach, and the organizational core is the innovation team (Nonaka and Takeuchi 1995, Griffin 1997, Kratzer et al. 2004).

R&D teams that employ product modularity as a method are frequently deployed in knowledge-intensive contexts, where integrating diverse competencies is required to solve problems (Denison et al. 1995, Keller 2001). Solving complex problems also requires interactions among team members (Thompson 1967, Bishop and Scott 2000, MacCormack et al. 2012, Furlan et al. 2014). Team interactions in an R&D context underpin how people understand one another and how knowledge is transferred. Such interaction is believed to be one of the most important structural variables in team performance and innovation (Pinto and Pinto 1990, Saavedra et al. 1993, Szulanksi 1996, Van der Vegt and Janssen 2003, Sosa et al. 2004, Langfred 2005, Janhonen and Johanson 2011, Sosa et al. 2015, Young-Hyman 2017), since it can speed up development time (Ulrich and Eppinger 2000), for instance, and allow teams to dedicate themselves to more creative tasks, enhancing innovation outcomes (Dorst and Cross 2001, Hertel et al. 2003a). Team interactions are thus fundamental in knowledge-intensive work settings, where integrating diverse kinds of knowledge is needed for solving problems and innovating (Denison et al. 1995, Keller 2001, Lurey and Raisinghani 2001). There is also growing recognition of the need to understand how members interact within teams if communication is to be efficient and effective (Pearce and Gregersen 1991, Morelli et al. 1995, Gupta and Wilemon 1996, Robbins 2001, Terwiesch et al. 2002, Langfred 2005, Emmitt and Gorse 2007, Gokpinar et al. 2010, McCormack et al. 2012, Sosa et al. 2015).

Researchers have documented the effect of team interaction in new product development organizations (Morelli et al. 1995, Terwiesch et al. 2002, Sosa et al. 2004, Cataldo et al. 2006, Sosa 2008, Gokpinar et al. 2010). For the purposes of this research, team interaction refers to the degree to which the team members coordinate matters in order for the group to accomplish its work (Kiggundu 1983, Brass 1985, Guzzo and Shea 1992, Jehn and Shah 1997, Hertel et al. 2003a). The success of such interaction depends on two central factors: the frequency of communication (Arrow 1974, Szulanski 1996, Terwiesch et al. 2002) and the closeness of the overall relationship among the members of the team (Arrow 1974, Janis 1982, Johnson and Johnson 1989, Marsden 1990, Szulanski 1996, Sethi et al. 2001, Terwiesch et al. 2002, Bano et al. 2016).

Building upon the above, the motivation for this research comes from the literature on organizations, where it has long been acknowledged that organizations should be conceived so as to reflect the types of tasks they execute (Burns and Stalker 1961, Lawrence and Lorsch 1967). Related studies in this framework begin with the premise that team interdependencies must be aligned to the technical interdependencies among product components. It is therefore expected that organizations and products would be correspondingly aligned (MacCormack et al. 2012). However, there has been little empirical study to date of this relationship. In sum, a critical aspect of collaboration in R&D teams is the degree of alignment between both technical and team interdependencies; this is also called the mirroring hypothesis. In the next section, we will define and further elaborate on the concept of alignment.

4.2.2. The "Mirroring" Hypothesis: Alignment between Product and Organization

Research work on the mirroring hypothesis originally started at approximately the same time with independent studies performed by Thompson (1967) and Conway (1968). The mirroring hypothesis predicts that technical dependencies correspond to organizational communication or interaction patterns. It does not imply a direction of causality between technical (e.g., product) and organizational (e.g., team) structures (Colfer and Baldwin 2016). The most common view is that product modularity exerts a powerful force toward isomorphism (i.e., similarity or alignment) in organizational architectures (Colfer and Baldwin 2016). Thus far, empirical studies on the mirroring hypothesis have focused on analyzing whether or not there is a connection between technical dependencies and organizational structures. Different studies show varying levels of correspondence between the two (Hoetker 2006, Cabigiosu and Camuffo 2012). As a whole, the most substantial support for the mirroring hypothesis has been found in studies performed on single organizations (e.g., Henderson and Clark 1990, Brusoni and Prencipe 2001), with less robust confirmation in studies across multiple organizations (e.g., MacCormack et al. 2012) and relatively weak support in open communities, for instance. While the mirroring hypothesis anticipates isomorphism in product and organizational architecture, misalignment is not only possible but may even be a strategic choice. As such, task and knowledge boundaries will not always coincide (Takeishi and Fujimoto 2001).

Empirical research related to the mirroring hypothesis has been primarily restricted not only to single organizations and to single (or a small number of) teams, but also to studies investigating collaborations across the supply chain (Hoetker 2006, Cabigiosu and Camuffo 2012). Puranam et al. (2012) argued that there are different types of interdependence among the technical components of a product. This situation requires coordination and communication. Team interaction creates a need for coordination, which is in turn facilitated by organizational ties. Team members collaborating in complex development projects confront interdependencies that may create technical challenges. They must come up with technical solutions and communicate with one another to solve problems. One would, therefore, expect a close relationship between technical dependencies and the organizational ties indicative of team collaboration or interaction. This, in turn, suggests that organizational ties will be close with respect to parts or product components where technical connections are dense and loose where the module connections are sparse (Baldwin and Clark 2000, Baldwin 2008, Cabigiosu and Camuffo 2012).

Aligning organizational ties with technical dependencies is an economical way of managing complex systems that require joint team coordination in real time. Henderson and Clark (1990) set up a relationship between product architecture and design organization and indicated the significance of matching teams to technical interfaces. Sosa et al. (2004) observed that product development teams tend to ignore certain types of technical interfaces. Likewise, Cataldo et al. (2006) analyzed the impact of alignment in a single software development project; their findings showed that tasks were executed faster when patterns of communication among members corresponded to the patterns of interdependence between components. Similarly, Gokpinar et al. (2010) explored the impact of misalignment in a single automotive development project and found that components produced with better quality were related to teams that had aligned their communications to the technical component links. We note, however, that neither Henderson and Clark (1990) nor Sosa et al. (2004), nor any other past research, measured innovation to test the impact of alignment. Aiming to fill this gap, this study captures the degree of alignment between product modularity (as a multidimensional construct) and team interaction in R&D teams and analyzes the impact of this alignment on innovation at the team level.

4.2.3. Product Modularity: a Multidimensional View

In the face of global competition, organizations must cope with high product variations and customization, globalization, short product life cycles, and rapidly increasing development costs (Pine 1993, Tidd and Bessant 2009). The notion of product modularity has been widely proposed as a strategic means of dealing with this increasingly complex environment (Sanchez and Mahoney 1996, Baldwin and Clark 1997, Ulrich and Eppinger 2000, Garud et al. 2003). Product modularity is the extent to which a set of components performs multiple functions, with individual components connecting to other components through standard elements (Ulrich 1995). Product modularity is a "relative" attribute of complex systems (Simon 1962, Baldwin and Clark 1997, 2000, Sosa et al. 2004).

Product modularity is a multidimensional construct; yet despite the rapid increase of use in diverse applications, there is little consensus on its definition (Gershenson et al. 2003, Ro et al. 2007, Frandsen 2017). Although a number of studies have attempted to bridge the various perspectives in the literature (Ulrich and Tung 1991, Huang and Kusiak 1998, Gershenson et al. 2003), the difficulty in understanding the characteristics of the concept remains. We define product modularity as a multidimensional concept in terms of module standardization and reconfiguration, following Gershenson et al. (2003) and Salvador (2007). Module standardization refers to the extent to which something is constructed by joining together a set of standardized parts that have been made separately (Pels and Erens 1992), while reconfiguration is about the degree of reuse of product components that allows a broad range of new product variations by mixing and matching modules (Mikkola and Gassmann 2003). By engaging in this multidimensional perspective of product modularity, this research aims to clarify the ambiguous findings of previous studies on the mirroring hypothesis (Tiwana 2008, MacCormack et al. 2012, Cabigiosu et al. 2013, Furlan et al. 2014, Burton and Galvin 2018). The first dimension of product modularity, module standardization, refers to the decomposition of a system into modules through the division of information into visible design rules (Pels and Erens 1992, Baldwin and Clark 1997). The design rules (or visible information) would be chiefly understood as standards. The second distinct dimension, module reconfiguration, is probably one of the most commonly understood aspects of product modularity, referring to the degree of reuse of product components in the formation of new product variations. Products are modular when multiple product configurations can be obtained by mixing and matching components taken from a given set (Salvador 2007).

For example, products with a high degree of module reconfiguration allow for a broad range of variation through the mixing and matching of modules (Simon 1965); when there is a low degree of this, it is difficult to transfer the modules to other product lines or employ them for future product development (Fujita 2002, Mikkola and Gassmann 2003). A key reason for adopting a multidimensional definition of modularity is that any technological system consists of several distinctive integral subsystems or modules that can be both independent and, to some extent, interdependent at the same time (Simon 1962). This interpretation incorporates, in other words, decomposition, or standards, as well as reconfiguration, or reuse. Adopting a multidimensional definition of product modularity is not new (Ulrich 1995, Baldwin and Clark 1997, Lee and Tang 1997, Gershenson et al. 2003, Salvador 2007); however, beyond highlighting the necessity of such a definition, existing empirical studies have not reflected this multidimensional perspective (Salvador 2007). The purpose here is to bring definitional clarity and structure to bear on the empirical research and gather evidence for the effects on innovation of the alignment between team interaction and both module standardization and reconfiguration.

4.2.4. Degree of Alignment and Impact on Innovation

4.2.4.1. Module Standardization

One stream of the literature suggests that an increasing degree of alignment between team interaction and module standardization has a negative impact on innovation. Initial high costs to sharing knowledge have negative effects, while increasing benefits promote innovation, creating a U-shaped relationship. We argue that low or moderate levels of alignment will diminish innovation. We have distilled three principal points of view from the literature to support our arguments.

First, R&D teams can be viewed as problem-solving entities (Nickerson and Zenger 2004). Solving highly complex problems that have a high degree of interdependencies (in this case among module standardization elements) requires knowledge sharing and interaction among teams (communication) (Puranam et al. 2014). However, at low or moderate levels of alignment between module standardization and team interaction, the costs for sharing knowledge and ideas among team members rise in light of the greater coordination needed. In this situation, knowledge is less successfully distributed among team members (Sosa et al. 2004), directly and negatively affecting the technological change rate (Baldwin and Clark 1997, Brusoni et al. 2001, Campagnolo and Camuffo 2009, Lau et al. 2011, Furlan et al. 2014, Burton and Galvin 2018). This ultimately has a negative impact on innovation, since changes do not occur as frequently as expected.

Second, low or moderate degrees of alignment between team interaction and module standardization lead to incomplete information structures and knowledge sharing, since the desired outputs of specific component development tasks cannot be fully specified pre-development due to inadequately defined or missing standards (Sanchez 1995). Incomplete coordination of specified, yet interdependent, development tasks also produces a need for managerial adjudication of the many technical and financial issues that arise between development team members (Nishiguchi 1994, Sanchez 1995). This negatively affects the functional interdependencies between modules (Persson and Åhlström 2006, Gomes and Dahab, 2010, Persson and Åhlström 2013), since more time and effort will have to be devoted to clarifying interfaces - which in turn reduces the time and effort dedicated to design, implicating overall high costs to knowledge sharing. In sum, this may lead to a lower likelihood of ideas being shared and, ultimately, less innovation.

Third, increasing degrees of alignment between team interactions and module standardization are related to an overall increase in investment on modular interfaces, since systems need to be running and maintained (Parmigiani and Mitchell 2009). Following this approach, for instance, organizations build dedicated teams to assure that standards are created, maintained, and applied in diverse developments. Keeping up such a knowledge base requires intensive relationships and systems (Parmigiani and Mitchell 2009, Zirpoli and Camuffo 2009), which likewise increases the costs of knowledge sharing, reduces the time dedicated to innovation activities, and consequently reduces overall innovation.

However, we argue that at higher levels of alignment between team interaction and module standardization, the costs of knowledge sharing will be reduced and the alignment will have a positive impact on innovation in a variety of ways (Stewart and Barrick 2000, Danese and Filippini 2010, Colfer and Baldwin 2016). At higher levels of module standardization, the benefits to innovation increase, whereas costs tend to decrease rapidly with innovation, resulting in a concave relationship. Adding the positive effects to the negative effects, we expect a U-shaped relationship (Haans et al. 2016).

With regard to these positive effects, increasing levels of alignment between team interaction and module standardization support more information sharing and improve project task coordination (Wageman 1995, Stewart and Barrick 2000), since R&D team members interact more closely and better understand the standards and interfaces applicable to the product they are working on and the team they interact with. In this context, a knowledge of standards supports the solving of higher, more complex problems (Sosa et al. 2004, Colfer and Baldwin

2016). Consequently, knowledge is distributed more smoothly, and the quality of problem-solving improves, producing a more cost-efficient setting (Wong 2008). This approach helps reduce the rate of errors (Gokpinar et al. 2013), eases coordination and the exchange of ideas (Jackson et al. 2003, Van der Vegt and Janssen 2003, Jacobides et al. 2018), and in turn fosters innovation.

Additionally, a team working with a high degree of alignment between team interaction and module standardization has a means of quickly linking resources together and responding to change faster and more inexpensively (Sanchez 1995) since interfaces at the product and organizational level are more transparent. Better coordination also reduces development time (Sanchez and Mahoney 1996, Christensen et al. 2002, Fine et al. 2005). Consequently, in such situations, team members are able to consider alternative or new solutions sooner (Danese and Filippini 2010) and solve problems more quickly and more reliably (Baldwin and Clark 2000). The increased development speed helps both reduce and simplify problems, by minimizing, for instance, the number of components and parts needed (Clark and Fujimoto 1991), thus achieving improvements in innovation (Takeuchi and Nonaka 1986).

Finally, high degrees of alignment between team interaction and module standardization require extensive coordination among team members since -especially in light of the extreme complexity of technology development - it is no longer possible to freeze interface standards as an operationalization of standardization (Ernst 2005). Accordingly, adjustments must be continuously negotiated. These clear coordination links create tight specifications, enabling cross-boundary knowledge creation and synergy through modules, which allows creativity to flourish (Wincent et al. 2009). As a result, teams develop increasingly advanced technologies that promote the disruption of existing knowledge configurations and sustain the focus of exploring potential opportunities in other domains (Abernathy and Utterback 1978), which improves innovation.

In sum, we argue that at low or moderate levels, the degree of alignment between team interaction and module standardization will have negative effects on innovation due to the extra costs of knowledge sharing and greater efforts required. However, after a certain point, a higher level of alignment brings increasing innovation outcomes, as the benefits start to overtake the costs and efforts involved. Therefore, the relationship between the degree of alignment of module standardization and team interaction and innovation is likely to be a U-shaped relationship. We thus hypothesize that:

H7: the alignment between team interaction and product module standardization has a U-shaped relationship with innovation.

4.2.4.2. Module Reconfiguration

In this section, we argue that for low to moderate levels of alignment between team interaction and module reconfiguration, the benefits of knowledge sharing dominate, while for higher levels the negative effects outweigh the benefits, forming an inverted U-shaped relationship. Multiple studies have claimed that at low to moderate levels, the degree of alignment between team interaction and module reconfiguration improves innovation (Sosa et al. 2004, Gokpinar et al. 2010, MacDuffie 2013). We have derived three principal points of view from the literature.

First, at low or moderate levels of alignment between team interaction and module reconfiguration, team members work partly independently of one another. This is possible because the product combinations are relatively defined (Salvador 2007). Working more independently allows individual team members to take advantage of the unique task-specific knowledge that may only be available to them (Latham et al. 1994), keeping the costs related to knowledge sharing moderate, without interfering with team coordination. This, in turn, facilitates the finding of new ideas and, ultimately, enhances innovation.

Second, low or moderate levels of alignment between team interaction and module reconfiguration will reinforce shared problem-solving, since the execution of parallel activities and frequent interaction will be strengthened (Ha and Porteus 1995). As a result, team members should notice the consequences of their knowledge sharing efforts for the rest of the team more quickly and directly (Hertel et al. 2000, Hertel et al. 2003b). They will feel that their contributions are indispensable to the team's success, which should increase their motivation and both boost the team's effectiveness as a whole and enhance technological change and innovation.

Third, at low or moderate levels of alignment between team interaction and module reconfiguration, the use of reconfigurable components and modules reduces uncertainty and the related costs (Loch et al. 1996, Langlois 2002) as team members become familiar with repeatable, reusable configurations. Accordingly, with minor adjustments, the modular components can fit a variety of products, increasing the number of possible configurations (Schilling 2000) for satisfying technical problems and thereby promoting new ideas and innovation.

Meanwhile, despite the many related benefits, higher degrees of alignment between team interaction and module reconfiguration can have negative effects that curtail innovation. After a certain point, the positive alignment benefits related to knowledge sharing diminish under the influence of such factors as extreme predictability, risk of imitation, and "groupthink" and the negative effects start to outweigh the positive ones, reducing outcomes. As such, excessively high alignment can inhibit a team's ability to innovate. Subtracting these negative effects from the positive ones described above results in an inverted U-shaped relationship (Haans et al. 2016).

We have therefore further derived two main arguments from the literature. First, high levels of alignment between team interaction and module reconfiguration require a high degree of interaction, in addition to increasing the synchronization needs among team members (Fredriksson 2006) since team members need to harmonize new modules with existing ones (Prencipe et al. 2003). As a result, once the overlap surpasses a certain point, the mutual influences become so dominant that the work environment, in terms of knowledge sharing and creating new ideas, deteriorates (Nyström 1979, Amabile and Conti 1999, Kratzer et al. 2004). Ultimately, innovation is negatively affected.

Second, higher degrees of alignment between team interaction and module reconfiguration lead to increasing product variety beyond a certain point. This condition can cause team members to rely too heavily on other team members' information (Salvador et al. 2002, Chiu and Okudan 2011). Moreover, this situation can also cause group standards to be lowered (West and Farr 1992, Paulus and Dzindolet 1993, Nicholas 1994), due to a less critical evaluation of assumptions among teams (Nyström 1979, Amabile and Conti 1999). Meanwhile, under a worsening knowledge-sharing setting (Terwiesch and Loch 1999), corrective actions to fix glitches can tax a project with delays and additional development cost and schedule overruns (Deming 1986). This, in turn, directly affects the technological change rate (Baldwin and Clark 1997, Ernst 2005, Brusoni and Prencipe 2006, Campagnolo and Camuffo 2009, Lau et al. 2011, Furlan et al. 2014, Burton and Galvin 2018), ultimately having a negative impact on innovation when changes do not occur as frequently as expected.

Based on the arguments outlined above, we posit that, at some point, the initial benefits linked to module reconfiguration will be counteracted by adverse effects that will grow larger than the positive ones. This study therefore proposes an inverted U-shaped relationship between the degree of alignment between team interaction and module reconfiguration and innovation (Haans et al. 2016). We suggest that the degree of alignment has a positive effect on innovation up to an optimum point, simultaneously resulting in increasing negative effects, and that after this optimum, the negative effects outweigh the positive ones. Further increases in the degree of alignment lead to a negative impact on innovation.

H8: the alignment between team interaction and product module reconfiguration has an inverted U-shaped relationship with innovation

A summary of the theorized effects is displayed in Table 13.

Table 13 Summary of Hypotheses and Impact

H	Summary of hypothesis	Impact
H7	Alignment Team Interaction_Standardization with Innovation	U-shape
H8	Alignment Team Interaction_Reconfiguration with Innovation	Inv U-shape

4.3. RESEARCH DESIGN

4.3.1. Research Context: Automotive Industry

The empirical testing for our study was conducted in a large, leading multinational company in the automotive industry, which has R&D teams distributed across multiple regions (i.e., America, Europe, and Asia). Focusing on leading firms in an industry is a common empirical approach (Gulati 1995, Gulati and Gargiulo 1999), since it allows for investigating organizations' operations in a favorable innovation context. The units of analysis in our case were the individual R&D teams developing different kinds of technical products with different degrees of product modularity. R&D teams are a common form of organization in the industry under study and are viewed as the technological "gatekeepers" in the organization (Jankowski 1998, Obstfeld 2005). Furthermore, organizations engaged in automotive R&D are commonly used as representative samples for studying this theoretical framework because their products are extensively built using a high number of "modules" whose interfaces are relatively well understood (Sako and Murray 1999a, b, Sako 2003, Ro et al. 2007, Zirpoli and Becker 2011, MacDuffie 2013). Additionally, the automotive industry enjoys a high degree of innovative activities (Pires 1998, Takeishi and Fujimoto 2001, Camuffo 2004, Doran 2004, Fixson et al. 2005, Ro et al. 2007), which makes for a useful research setting.

4.3.2. Survey Data

The primary data source was information collected from a web-based survey using a structured questionnaire sent to R&D teams involved in running projects. The survey was conducted in English. All of the teams were formal groups of employees that were designated, viewed themselves, and were seen by others as teams and interacted and shared resources to accomplish mutual tasks and goals (Shea and Guzzo 1987). Participants were stretched across three global regions, in different countries in Europe, America, and Asia. These were individuals working on a variety of technologies, representing a broad range of R&D domains and experience levels within the organization, which made the sample heterogeneous. To enhance the construct validity of the survey measures, the survey was pre-tested among either a small group of team members or in different regions. After the reliability of each of the preliminary scales was analyzed and any potential phrasing ambiguity eliminated, so as to achieve completeness and clarity of meaning for all items, the survey was modified and used to capture the related data.

To select the most representative sample, a list of all the projects undertaken during the time of data collection was created. Based on that list, we excluded very small-sized teams (i.e., those with fewer than three engineers). We included teams working in all phases of development (i.e., conception, detail design, validation, and start of production), since including only teams that had worked on completed projects could have led to an over-representation of successful teams, which would produce biased results. (We compared the average mean response values on key dimensions, such as innovation, module standardization, and reconfiguration.[5]) Following this selection, we were left with a list of 140 teams.

A letter of introduction sent by email informed the potential respondents about the nature of the study. We explained that the data would be collected and treated confidentially, and that each questionnaire contained a unique identification number for data-matching procedures. Participation was voluntary. We surveyed team members across R&D regions over the course of six weeks. A reminder with a copy of the questionnaire was sent to respondents who had not answered after three weeks. There were no significant differences between early and late respondents (based on comparing the average mean response values on key dimensions, such as innovation, standardization, and reconfiguration), which suggests that nonresponse bias was not a serious concern (Armstrong and Overton 1977). A total of 695 questionnaires were distributed; 347 of these were completed and usable, resulting in a response rate of 50%. The average coverage per team was over 67%, indicating the high degree of response within teams. For 101 teams, one or more responses were received. The average number of respondents per team was three to four.

4.3.3. Research Variables and Measures

4.3.3.1. Dependent Variable: Innovation

Using existing and adapted items applied in recent studies (in line with Garcia and Calantone 2002, Darroch 2005, Lau et al. 2007, Gunday et al. 2011), we operationalized the dependent variable - innovation at team level - as a combination of four dimensions: A) market newness, B) patent creation, C) new product revenues as related to R&D costs, and D) patentable

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[5] The average is used (incorporating similar weights per element) because the literature has not provided strong arguments for attributing different weights to individual elements.

discoveries. Market newness (A) assesses whether the product contains any new technologies, from the product development period, for that particular market (Hauser and Zettelmeyer 1997, Criscuolo et al. 2005, Schwartz et al. 2011, Yin et al. 2011). Based on Criscuolo et al. (2005), Schwartz et al. (2011), and Yin et al. (2011), four items were used to capture market newness in the questionnaire: 1) “This product is new to the market or customer” (Jansen et al. 2006); 2) “The product possesses technical specifications, functionalities, components, or materials differing from the current ones” (Gunday et al. 2011); 3) “The product we developed is the first of its kind” (Darroch 2005); and 4) “The product has unique features to the market or customer” (Garcia and Calantone 2002).

Patent creation (B) refers to the number of patents applied for (including both filed/granted and not yet filed/granted) or current and potential innovation patents during the product development process (start of project until start of mass production) (Werner and Souder 1997, Bremser and Barsky 2004, Cebeci and Sezerel 2008, Chiesa et al. 2009, Jalles 2010). This dimension was evaluated in the questionnaire with two items: 1) “This product has or is acquiring patents” (Wang and Ellinger 2011); and 2) “The product has patentable innovations” (Lau et al. 2007).

The new product revenues as related to the dimensions of R&D costs (C) and patentable discoveries (D) were measured through three adapted questionnaire items based on previous research (Garcia and Calantone 2002, Jiménez-Jiménez and Sanz-Valle 2011): 1) the product’s revenue generation compared to the R&D expenditure; 2) the product’s patentable discoveries by R&D expenditure (Jiménez-Jiménez and Sanz-Valle 2011); and 3) whether the investment was reasonable compared to the innovative features developed for the product (Garcia and Calantone 2002).

The above survey items were scored on seven-point Likert scales ranging from “Completely disagree” (1) to “Completely agree” (7). The overall innovation measure was constructed by taking the average of the nine above-described items. Reliability was evaluated using Cronbach’s alpha. The Cronbach’s alpha value for the innovation scale was 0.820, indicating that the items were internally consistent, and the constructs were therefore reliable (Streiner 2003, Hair et al. 2006).

4.3.3.2. Independent Variables: Product Modularity

The two key dimensions of product modularity - module standardization and reconfiguration - were also measured using existing and adapted items applied in recent studies. Product modularity was defined on the questionnaire as “the use of standardized and interchangeable components or units that enable the configuration of a wide variety of end products” (Schilling 2000).

Module standardization refers to the extent to which something is constructed by assembling together a set of standardized parts that have been made separately (Pels and Erens 1992). Module standardization was measured through two key dimensions: first, the use of common assemblies and components; and second, the use of standardized components. Three items adopted from previous studies (e.g., Jacobs et al. 2007, Lau et al. 2007, Danese and Filippini 2010) were used to measure module standardization, aiming to incorporate both dimensions: 1) "Product in design uses common component modules"; 2) "Product components are standardized"; and 3) "Product can be decomposed into separate standard modules." The above survey items were scored on seven-point Likert scales ranging from "Completely disagree" (1) to "Completely agree" (7). The measure of module standardization was constructed by taking the average value of the three items.

Module reconfiguration refers to the degree of reuse of product components in forming new product variations. Products with a high degree of module reconfiguration allow for a broad range of product variants through the mixing and matching of modules (Fujita 2002, Mikkola and Gassmann 2003). This variable was measured in line with Jacobs et al. (2007) and Lau et al. (2007) through three adapted questionnaire items: 1) "Components are interchangeable across different products"; 2) "Product components can be reused in other products"; and 3) "Products can be re-configured into further end products." The above survey items were also scored on seven-point Likert scales ranging from "Completely disagree" (1) to "Completely agree" (7). The measure of module reconfiguration was constructed by taking the average value of the three items. Cronbach's alpha values for the two constructs, module standardization and reconfiguration, were 0.618 and 0.805, respectively, indicating that the items were internally consistent and hence the constructs were reliable (Streiner 2003, Hair et al. 2006). Therefore, all these initial analyses provided reasonable confidence that the measures used in the present study were valid and reliable.

Team Interaction

For the purposes of this research, team interaction refers to the degree to which team members coordinate for the group to accomplish its work (Kiggundu 1983, Brass 1985, Guzzo and Shea 1992, Jehn and Shah 1997, Hertel et al. 2005). The success of such team interactions depends on two central factors: the frequency of communication (Arrow 1974, Szulanski 1996, Terwiesch et al. 2002) and the closeness of the overall relationship among the members of the team (Arrow 1974, Janis 1982, Johnson and Johnson 1989, Marsden 1990, Szulanski 1996, Sethi et al. 2001, Terwiesch et al. 2002, Bano et al. 2016). Our survey contained questions for team members designed to measure each of these two key dimensions: first, communication frequency; and second, emotional closeness. With regard to communication frequency, the following three items were used: 1) "Team members are in contact with each other on a regular basis in order to conduct regular business" (Lurey and Raisinghani 2001); 2) "Team members are in contact with each other on a regular basis for social, non-business, purposes" (Lurey and Raisinghani 2001); and 3) "Within your team, how often do you communicate?" (Cummings and Cross 2003, Janhonen and Johanson 2011). With regard to emotional closeness, the following four items were applied: 1) "Friendly attitude exists in the team" (Pinto and Pinto 1990); 2) "Team members feel strong ties to the team" (Sethi et al. 2001); 3) "Team members are committed to maintaining close interpersonal relationships" (Sethi et al. 2001); and 4) "Communication and intimacy of the relationship in the team is easy" (Szulanski 1996). The above seven survey items were scored on seven-point Likert scales ranging from "Completely disagree" (1) to "Completely agree" (7). The measure was constructed by taking the average value of the seven items.

In addition, we gathered data on the stability of the teams by asking the team members to gauge the extent to which the following was true: "Team members have collaborated on projects in the past" and "Team members will be collaborating in other projects in the future." The descriptive statistics confirmed that both questions have a relatively high mean value (means of 5.18 and 5.74 on a 7-point scale, respectively), confirming the existence of a stable, mature team setting.

Alignment – the "Mirroring" Hypothesis

To test the mirroring hypothesis, the alignment between the two dimensions of product modularity and team interaction needed to be operationalized. Alignment was determined by comparing, or overlapping, the degree of module standardization and reconfiguration to, or with, team interaction, as represented by the team exchanges involved in various means of coordination, as defined earlier. We therefore quantified the amount of alignment by multiplying team interaction by standardization and team interaction by reconfiguration. This approach was taken because this study aimed to explore the joint effects of both variables.

4.3.3.3. Control Variables

To control for other aspects that might influence the defined model, we took the following additional variables into account: team size, level of education, project length, years of experience at the company, total work experience, experience in a number of fields, number of roles in the project, and geographical dispersion in the team. These control variables have been suggested in previous research on performance in R&D teams. Additionally, the direct effects of team interaction, standardization, and reconfiguration are controlled for. Appendix 1 provides the arguments and operationalization of these variables.

4.3.4. Level of Analysis

Any study of team-level variables based on data collected at the individual level raises the issue of aggregation from the individual to the team level of analysis (George and James 1993). Although aggregation is sometimes considered controversial (e.g., Campion et al. 1993), we followed recommendations from the literature in our study to allow for such aggregation. First and foremost, all relevant items in the questionnaire referred to the group and product level, and the aspects measured were understood to be shared views of the group or product developed. Second, we assessed the degree of inter-rater agreement within the teams as an indicator of the homogeneity of team members' perceptions (James et al. 1984). These results were consistent with recent studies and support aggregation to the group level. (In over 80% of the tested cases, inter-rater consistency was above 0.8.) We also calculated the intraclass correlation coefficient (ICC) for every team with more than one respondent (total of 101 teams) in order to estimate the inter-rater reliability (variables: knowledge diversity, team interaction, innovation effectiveness, innovation efficiency, and module standardization and reconfiguration). The average ICC between measures was 0.75, with a 95% confidence interval, indicating a high degree of reliability (Campion et al. 1993).

In addition, we gathered data on the stability of the teams by asking members their level of agreement with these statements: "Team members have collaborated on projects in the past" and "Team members will be collaborating on other projects in the future." The descriptive statistics confirm that both statements have a relatively high mean value (means of 5.18 and 5.74 on a 7-point scale, respectively), indicating a stable and mature team setting.

All relevant items of the questionnaire thus referred to the group and product level, and the aspects measured were understood to be shared views of the group or product developed. The team/group level data was operationalized by taking the averages of the individual responses. This can, to some extent, limit the impact of potential common method bias from a few respondents. We ran a Harman's single factor score to assess this potential issue. Results indicate that the total variance for a single factor was 28.01% (less than 50%), which suggests that our data and results were not affected by common method bias (Podsakoff et al. 2003).

4.3.5. Method

Our dependent variable (innovation) is operationalized as the average of nine 7-point Likert scales. As such, we performed OLS regressions to examine the hypothesized effects. Since the innovation measure could theoretically be considered not to be a fully continuous variable, the analyses were re-analyzed with ordered logistical regressions. Those findings were the same.

Table 14 Comparing Descriptive Statistics from the three Datasets: Survey, Secondary Data, and Email Data.

Variables	Dataset Survey				Dataset Secondary data				Dataset email			
	N:101				Sub-set N:81				Sub-set N:27			
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
Innovation*	0.2305	0.132	0.00	0.65	0.2285	0.1256	0.00	0.64	0.2350	0.1315	0.00	0.51
Number of Patents*	0.3323	0.2132	0.00	0.86	0.1337	0.2360	0.00	1.00				
Patents vs R&D invest*	0.4854	0.1361	0.00	0.86	0.0204	0.1135	0.00	1.00				
Com. Frequency*	0.6949	0.1627	0.00	1.00					0.3270	0.2771	0.00	0.97
Team Interaction	5.4070	0.6200	3.57	7.00	5.4281	0.5749	3.71	7.00	5.2459	0.5708	3.57	6.57

* Standardized values (0-1)

4.3.6. Data Triangulation and Validity

We built on two additional data sources to triangulate our main findings. First, we obtained information on the number of patents and R&D investments from company data. This data was available for 81 R&D teams. Second, data from over 150,000 emails was captured from a five-month period for 27 of the R&D teams. That data was used to triangulate the communication frequency (an element of team interaction). Table 14 shows a comparison of the key variables across these three data sources, with generally shows consistent values, which in turn confirms the quality of the survey data.

Furthermore, we collected interview data to corroborate the validity of the main findings. Table 21, in Appendix 5, lists the job positions and other details of the 12 people interviewed. All interviews were semi-structured and ran between 25 and 50 minutes. They were held between July 2014 and September 2014. The idea behind gathering this interview data was to better understand the mechanisms behind the alignment relationship between product modularity (i.e., both standardization and reconfiguration) and team interaction and the effects on innovation found from the quantitative data analysis. Interviewees were asked to comment on the collaboration environment of the R&D teams in the project setting and the effects on innovation, without focusing on a specific project. We interviewed senior and executive managers from all regions, as well as chief and experienced engineers with diverse responsibilities in running projects. The interviewees were experts with insider information and experience within the organization. The questions we asked them included: "Can you explain how the global R&D units collaborate?"; "What are the main problems R&D units face, and how do you address them?"; "Could you please think about the R&D innovation indicators and rank them from most to least important?"; and "How do you think R&D collaboration can influence R&D innovation?" Our coding was aimed at exploring the causal link between product modularity and team interaction.

4.4. ANALYSIS AND RESULTS

4.4.1. Regression Results

Table 15 reports the descriptive statistics and correlations between variables out of the survey dataset. Results show a relatively low bivariate correlation between most of the variables. There is a relatively high correlation of team interaction, module standardization, and module reconfiguration with their related alignment variables (recall that the alignment variables are constructed based on these variables). Therefore, an additional robustness check was conducted in which the three control variables (i.e., team interaction, module standardization, and module reconfiguration) were excluded from the analyses. The findings (shown in Table 18, Appendix 5) are comparable and are described in the robustness check section below.

Table 16 reports the results of the regression models. All models displayed contain the full set of defined control variables for the final 347 valid observations of the 101 R&D teams. The series of regressions started with the degree of alignment between module standardization and team interaction as a linear variable (Model 1), followed by adding the square variable of alignment for module standardization (Model 2) to verify the inverted U-shaped and U-shaped relationships. We carried out the same build-up sequence for the degree of alignment between module reconfiguration and team interaction: Model 3 evaluated the variable as linear, while Model 4 evaluated the square variable of reconfiguration. The final model (Model 5) integrates all variables together.

The results displayed for Models 1 to 4 with the control variables module standardization and module reconfiguration are noteworthy. Interestingly, when one of the related alignment variables (standardization or reconfiguration) is included, the related control variable (reconfiguration or standardization) becomes insignificant in the model. So, Models 1 and 2 include the alignment between standardization and team interaction variables, and the reconfiguration control variable is significant, while the standardization control variable is not. In Models 3 and 4, the alignment between reconfiguration and team interaction variables is included, and the standardization control variable is significant, while the reconfiguration control variable is not. These findings indicated that a model was needed to control for the other effects. It was therefore important to explore the results in more detail and integrate the controls simultaneously in a single model (Model 5).

Table 15 Descriptive Statistics and Correlation of Variables

	Mean	Std. Dev	Min	Max	1	2	3	4	5	6	7	8	9	10	11	12	13
1. Innovation	4.04	0.92	2.43	7.00	1												
2. Alignment_Standard	25.82	6.35	7.00	45.04	-.09	1											
3. Alignment_Reconfig	26.70	7.42	7.71	49.00	.21*	.59**	1										
4. Team Interaction	5.41	0.62	3.57	7.00	.15	.48**	.71**	1									
5. Module Standardization	4.78	0.98	1.00	7.00	-.17	.87**	.31**	.00	1								
6. Module Reconfiguration	4.89	1.04	2.00	7.00	.20*	.52**	.91**	.38**	.43**	1							
7. Experience at Company	9.81	4.33	1.00	21.75	.21*	-.07	-.06	-.01	-.08	-.05	1						
8. Total Experience	15.17	5.54	5.00	34.00	-.14	-.17	-.24*	-.27**	-.04	-.16	.39**	1					
9. Team Size	7.06	4.07	1.00	22.00	.11	.02	-.04	-.09	.08	.03	.32**	.25*	1				
10. Project Length	19.65	7.06	3.00	37.00	.02	-.10	.02	.23*	-.25*	-.13	.17	.18	.42**	1			
11. Nr. Fields of Experience	2.27	1.08	1.00	6.00	.14	.34**	.28**	.22*	.25*	.25*	.07	.06	.09	-.11	1		
12. Nr. of Roles in Project	1.37	0.54	1.00	4.00	-.12	.05	.05	-.23*	.21*	.22*	.16	.13	.21*	-.26**	.17	1	
13. Level of Education	2.38	0.38	1.67	3.20	.19	.06	.02	.13	.03	-.06	.05	.00	.03	-.04	.07	.04	1
14. Geographical Dispersion	1.56	0.57	1.00	3.00	-.18	-.07	-.11	.01	-0.11	-0.14	.08	.15	-.08	.09	-.03	.03	.08

*. Correlation is significant at the 0.05 level (2-tailed)/ **. Correlation is significant at the 0.01 level (2-tailed).

Table 16 Results of Module Standardization, Reconfiguration and Innovation Variables (survey dataset)

Variable	Innovation				
	MODEL	MODEL 2	MODEL 3	MODEL 4	MODEL 5
Alignment_Standard	-0.05	-0.10			-0.38*
	(0.10)	(0.13)			(0.18)
Alignment_Standard_SQ		0.00			0.00t
		(0.00)			(0.00)
Alignment_Reconfiguration			-0.07	0.10	0.39
			(0.09)	(0.21)	(0.25)
Alignment_Reconfiguration SQ				-0.00	-0.00*
				(0.00)	(0.00)
Team Interaction	0.03	0.06	0.11	-0.34	-0.01
	(0.54)	(0.55)	(0.49)	(0.71)	(0.74)
Module Standardization	-0.05	0.02	-0.34***	-0.35***	0.87
	(0.60)	(0.62)	(0.10)	(0.10)	(0.74)
Module Reconfiguration	0.33**	0.32**	0.70	0.17	-0.68
	(0.10)	(0.11)	(0.51)	(0.79)	(0.91)
Experience at Company	0.06**	0.06**	0.06**	0.06**	0.06**
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Total Experience	-0.04*	-0.04*	-0.04*	-0.04*	-0.04*
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Team Size	0.03	0.03	0.02	0.02	0.01
	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
Project Length	-0.01	-0.01	-0.01	-0.01	0.00
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Nr. Fields of Experience	0.15t	0.14	0.14t	0.14	0.14
	(0.08)	(0.09)	(0.08)	(0.08)	(0.08)
Nr. of Roles in Project	-0.44*	-0.44*	-0.44*	-0.40*	-0.36*
	(0.18)	(0.18)	(0.18)	(0.18)	(0.18)
Level of Education	0.54*	0.53*	0.58*	0.57*	0.46*
	(0.23)	(0.23)	(0.22)	(0.22)	(0.23)
Geographical dispersion	-0.23	-0.21	-0.26t	-0.28t	-0.24
	(0.15)	(0.15)	(0.15)	(0.15)	(0.15)
Constant	3.09	3.41	2.68	4.32	2.75
	(2.93)	(2.98)	(2.67)	(3.27)	(3.68)
Adj. R-square	22.8%	22.6%	22.8%	22.4%	25.0%
Model significance	0.00	0.00	0.00	0.00	0.00
AIC	252.89	254.44	252.58	253.71	252.24
BIC	286.88	291.05	286.58	290.32	294.08

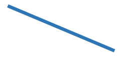
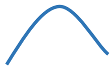
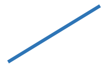
tp<0.10; *p<0.05; **p<0.01; ***p<0.001 / Non Standardized β values for all variables / Standard errors in brackets.

To investigate the theorized U-shaped relationship between the alignment of team interaction and module standardization with innovation (Hypothesis 1) and the inverted U-shaped relationship between the alignment of team interaction and module reconfiguration with innovation (Hypothesis 2), you need to look at the linear and squared coefficients. A negative linear coefficient with a positive squared coefficient indicates a U-shaped relationship, while a positive linear coefficient with a negative squared coefficient indicates an inverted U-shaped one. We followed the three steps described in Lind and Mehlum (2010) to test for these relationships. The first step is to investigate the significance of the squared coefficients. The second is to test the significance of the individual slopes, as well as their joint significance, followed by a third step, which involves checking whether the tipping point (i.e., optimum or minimum) falls within the data range.

With regard to the first step, the results show that Model 5 is the model with the best relative quality (based on having the lowest Akaike Information Criterion value: AIC = 252) and that it has an explanatory power of over 25%. With regard to the degree of alignment of team interaction with module standardization, the coefficients in Model 5 show a negative linear coefficient and a positive squared one (Model 5, β alignment standardization linear = -0.38, p = 0.038; β alignment standardization squared = 0.003, p = 0.054). This could indicate a U-shaped relationship as theorized. With regard to the degree of alignment between team interaction and module reconfiguration the results show a non-significant linear coefficient and a negative squared one (Model 5, β reconfiguration linear = 0.39, p = 0.13; β reconfiguration squared = -0.004, p = 0.04).

With regard to the second step, the analyses show that for standardization, the lower bound of the slope is negative (as expected), at -0.33, but the upper bound of the slope is also negative: -0.08 and non-significant. Additionally, the test results do not show an overall joint significance. With regard to step three, the tipping point also fell outside of the data range. Overall, these tests indicate the presence of a negative relationship in the data, and as such we reject Hypothesis 1. With regard to reconfiguration, the lower bound of the slope is positive (as expected), at 0.32, and the upper bound of the slope is negative: -0.10 and non-significant. Additionally, the test results do not show an overall joint significance. In step three, the tipping point also fell outside the data range. Overall, these additional tests indicate the presence of a positive relationship in our data (based on the positive lower bound slope). Table 17 provides a summary of the findings.

Table 17 Summary of Theorized and Empirical Results

		Innovation	
		Theorized relationship	**Empirical Evidence**
H7	**Alignment Standardization - Team Inter.**		
H8	**Alignment Reconfiguration - Team Inter.**		

4.4.2. Robustness and Validity

Furthermore, we carried out the same regression models with three alternative specifications (see Appendix 5 for the result tables 18, 19, and 20). First, we removed the three control variables, which were used to operationalize the corresponding alignment variables (i.e., team interaction, module standardization, and module reconfiguration) and thus highly correlated with them. The results reported in, Table 18, Appendix 5, indicated an overall significant Model 5 ($p < 0.000$) with the best relative quality based on the lowest AIC (248.95), with an explanatory power of over 26%. The variables in Model 5 indicate that the degree of alignment of team interaction with module standardization has a negative relationship with innovation (Model 5, β alignment standardization linear = -0.18, p = 0.03; β alignment standardization squared = 0.002, n.s.), confirming the direction of the main findings. The degree of alignment between team interaction and module reconfiguration indicates an inverted U-shaped effect on innovation (Model 5, β reconfiguration linear = 0.18, p = 0.004; β reconfiguration squared = -0.003, p = 0.02). The other two tests suggested by Lind and Mehlum (2010), however, do not confirm the existence of an inverted U-shaped relationship. The lower bound slope is positive, at 0.14, but the upper bound is negative: -0.07 and non-significant. This shows a positive effect and confirms the main findings. In sum, these results show that the main results were not driven by the correlation between the three removed control variables and the alignment variables. As such, these outcomes add some robustness to our findings.

Second, we substituted the dependent variable innovation, which was operationalized by nine survey items, by just the number of patents from the survey. The results reported (see Table 19, Appendix 5), indicate that Model 5 is again the model with the relative best quality (AIC = 355, lowest), and that it is overall significant ($p < 0.001$), with an explanatory power of over 25%. The relationships in Model 5 indicate that the degree of alignment of team interaction with module standardization has a U-shaped relationship with innovation (Model 5, β alignment standardization linear = -0.92, p = 0.003; β alignment standardization squared = 0.006, p = 0.046), in line with our theorized arguments. As with the main results, the additional two tests suggested by Lind and Mehlum (2010) do not confirm the existence of a U-shaped relationship, and the results show a negative effect. With regard to the degree of alignment between module reconfiguration and team interaction, the results show non-significant findings (Model 5, β reconfiguration linear = 0.36, p = n.s.; β reconfiguration squared = -0.005, p = 0.103). As such, only the findings with regard to the alignment between team interaction and module standardization corroborate the main findings.

Third, we substitute team interaction by communication frequency from the survey dataset. The results reported in Table 20, Appendix 5, once again indicate that Model 5 is the relative best model, being overall significant ($p < 0.000$) and having an explanatory power of over 29%. The variables in Model 5 indicate that the degree of alignment of team interaction with module standardization has a U-shaped relationship with innovation (Model 5, β alignment standardization linear = -1.28, p = 0.003; β alignment standardization squared = 0.023, p = 0.001), confirming the theorization. In line with the main findings, the two additional tests suggested by Lind and Mehlum (2010) do not confirm the existence of a U-shaped relationship and show a negative relationship, with a lower bound slope of -1.28 and a non-significant upper bound slope. In a similar manner, the degree of alignment between team interaction and module reconfiguration indicates an inverted U-shaped effect on innovation (Model 5, β reconfiguration linear = 1.34, p = 0.003; β reconfiguration squared = -0.023, p = 0.002). In line with the main findings, the two additional tests suggested by Lind and Mehlum (2010) do not confirm the existence of an inverted U-shaped relationship, with a positive lower bound, at 1.34, and a non-significant upper bound. In sum, these results suggest that the different measures of the same construct show similar results and as such these outcomes add some robustness to the main findings.

In terms of validity, analysis of the qualitative interview data supports the causal links between alignment and innovation, first of all, and contextualizes the research findings in an international engineering culture that appears common to a number of mature industries. The interviews testify to not only the importance of knowledge sharing for innovation, but also more specifically the differential role that standardization and reconfiguration play in innovation. While knowledge sharing is universally viewed as positive, the relative importance attributed to opportunities for engaging in it varies, pointing to the importance of team interaction and modularity. An overly strong alignment of standardization with team interaction may diminish innovation due to functional repetition across teams and harmonized exchange, as these quotes imply:

"Every unit has similar defined formal structures, and key 'bridge heads' in every domain exchange tasks and information. All this under the framework of Functional Responsibility. We have regular exchange meetings and work with a common global ICT[6] system. Our unique

[6] ICT = Information and Communications Technology

family culture is one of the key assets of our R&D collaboration. Everyone knows each other." (R&D Senior Manager, Europe)

"To increase the exchange of knowledge, expertise from different locations should meet and share their expertise more intensively. We should give more importance to these interactions and not only to the projects' exchange." (R&D Team Leader, Asia)

By contrast, an increasing alignment of reconfiguration with team interaction means that developers become familiar with reusable components shared from other locations and teams that facilitate experimentation and lower the cost of innovation. Organizing knowledge exchange as part of the reconfiguration efforts appears to support innovation effectiveness because of the ease of reuse that comes from strong interactions with users of similar components.

"R&D centers are arranged with a similar organizational structure and tools. We promote a familiar culture and the 'plug and play' approach." (R&D Team Leader, America)

"Some things you have to do at two, sometimes at three places. And then you discover, the other guys actually developed an incredibly good software module. This triggers everyone to understand how they developed it and how you can learn from them." (R&D Senior Manager, America)

The qualitative insights confirm that aligning team interaction with the dimensions of modularity can have different effects, requiring us to look at a larger sample in quantitative terms. Aligning team interaction with standardization increases the risk of knowledge sharing becoming stale and functionally fixed, whereas aligning team interaction with reconfiguration leverages common knowledge to innovate.

4.5. DISCUSSION AND CONCLUSIONS

The objective of this study was to contribute to the literature of organizations within the context of R&D teams. Specifically, it was designed to extend the existing view of the mirroring hypothesis which has been so extensively discussed in the literature (Brusoni and Prencipe 2001, Langlois 2002, MacCormack et al. 2012, Furlan et al. 2014, Sorkun and Furlan 2017). By building upon recent studies, our research aimed to empirically investigate the impact on innovation of the degree of alignment between team interaction and module standardization and reconfiguration in R&D teams. Several conclusions that are consistent with our assumptions can be drawn from our results, providing original theoretical and managerial implications on the role that product modularity (i.e., module standardization and reconfiguration) and organizational settings can play on innovation.

4.5.1. Theoretical Contributions

This study contributes to the literature in two principal ways. First, we enhance the understanding of the concept of alignment between task and organizational structure at the team level, contributing to the literature on organizational design. Following Gokpinar et al. (2010) and Furlan et al. (2014), we mapped a relationship between product modularity and team interaction. We then took the argument a step further, broadening the traditional view of mirroring by granulating the concept of product modularity into two essential constructs: standardization and reconfiguration. The principal reasoning for adopting this multidimensional approach is that innovation consists of creating new configurations, which correspondingly requires a greater degree of granularity in the definition of product modularity. This approach has provided new insights regarding how products and organizations mirror each other.

These findings are important, since this more accurate approach can capture potential effects that might have been neutralized or obscured in past studies. Because teams engage in incredibly diverse product development activities with varying degrees of complexity, it is crucial that a specialized approach be taken in addressing those activities (Eppinger and Chitkara 2006). Such situations warrant the need for structural coordination mechanisms (Simon 1962, p. 42). It is therefore essential that product modularity and interaction among teams' members be matched, to a certain degree, to the product under development. Our research findings suggest that instead of looking to enhance this overlap at all costs, though, managers should think carefully about taking a balanced approach and finding an optimum between the product modularity dimensions (module standardization and reconfiguration) and team interaction in order to improve innovation at the team level.

Second, we provide evidence of the impact of this alignment on innovation at the team level. As mentioned, we contribute to the literature that studies the mirroring hypothesis (Brusoni and Prencipe 2001, Sosa et al. 2004, MacCormack et al. 2012, Furlan et al. 2014) by empirically showing that alignment can influence innovation. In particular, we highlight the importance of product modularity in innovation. Our arguments further develop the research on both the mirroring hypothesis (MacCormack et al. 2012, Furlan et al. 2014) and product modularity and innovation (Henderson and Clark 1990, Pil and Cohen 2006), arguing that there are diverse, and even opposite, effects on innovation between the two dimensions of product modularity in combination with team interaction. Our study theorized that the degree of alignment between module standardization and team interaction would have a U-shaped relationship with innovation. However, the empirical results could not confirm this hypothesis; rather, they showed a negative linear impact of alignment on innovation (with all tested datasets). One possible reason this effect was not confirmed could be the context of the single firm that was analyzed.

It is essential to contextualize this research within the framework of the mirroring hypothesis and organization design. Research in that domain tests said hypothesis under the conditions of a stable, mature, and structured organization and product line. In a stable environment in which technological dynamism and organizational change are low, firms do not face a significant risk of technological obsolescence (Uotila et al. 2009). In such a context, the theoretical statements about product modularity and innovation should hold. On the other hand, under a fast-changing, unstable technological environment, product changes will continuously need to be implemented—and not in such a predictable, stable manner (Baldwin 2008). Under those conditions, the degree of alignment between product and organizational structure is difficult to isolate and analyze. Hence, the arguments of this research might not hold. We might therefore consider that the negative effects of increasing alignment have a much greater significance than the positive ones (Sanchez and Mahoney 1996, Hoetker 2006), indicating that team members probably avoid the risk of introducing new ideas and innovating.

Furthermore, our study theorized that the degree of alignment between module reconfiguration and team interaction would have an inverted U-shaped relationship with innovation. However, the empirical results could not confirm this hypothesis either, indicating a positive linear impact on innovation (with all tested datasets). One of the possible reasons for this result, as described in the findings above, could be related to the context of the single-case scenario. In sum, however, this finding provides evidence that a modular context enables access to diverse and novel knowledge, which allows designers to break through the limits of the existing technology configuration (Pil and Cohen 2006, Tiwana 2008). Moreover, it confirms that module reconfiguration is not just a mixing and matching system that merely yields minor efficiency gains, but entails innovation, as well.

4.5.2. Managerial Contributions

From a management point of view, our work provides several substantial insights. First, in line with past research (Gokpinar et al. 2010), it underscores the necessity of looking at the degree of alignment as a management measure. We have proved that the degree of alignment is related to innovation at the team level. This measure can support managers in improving innovation outcomes by balancing the degree of "matching" between product modularity (as a multidimensional construct) and team interaction. Once a measure of alignment is available, a tool could be used to assess the degree of alignment between team interaction and product modularity (i.e., module standardization and reconfiguration). In the context of large, complex projects, these measures could increase awareness of the need for team interaction between particular team members at any point in time. Managers could focus on facilitating appropriate team interaction channels (Bano et al. 2016).

Second, our findings have important managerial implications in terms of endeavoring to improve coordination among R&D teams, especially in complex product-development projects. Our research proves that, under this specific context, a degree of overlap between team interaction and product modularity promotes innovation at the team level. Additionally, we identified conditions in which this overlapping can weaken innovation. This finding is significant, since managers generally tend to consider that a greater degree of overlap is largely positive for innovation (Cataldo et al. 2006, Olson et al. 2009).

Third, an essential element in this framework is team interaction (Sosa et al. 2004, MacCormack et al. 2012). As suggested in this research, the degree of team interaction can affect a number of organizational processes and results, obviously being significant for innovation outcomes (Baldwin and Clark 2000). The resulting frameworks have important implications for managers (i.e., organizational architects) who are interested in designing their organizations to improve organizational performance. For instance, managers could look at approaches to influence the degree of team interaction, depending on the degrees of product modularity, to achieve better innovation outcomes. Processes, workflows, or different tasks could be designed specifically for this purpose (Puranam et al. 2012). To give an example, providing a shared vocabulary of terms (Weber and Camerer 2003) facilitates communication, which would be especially valuable in uncertain conditions, and enables coordination.

Moreover, managers may often expect that, after separating out the individual tasks and modular products within a team, activities will be clarified and run independently. They assume that afterward, the integration process will support consolidation (Zirpoli and Becker 2011). However, such a process risks missing out on the dialog concerning technical tasks that so often promotes the exchange of ideas and innovation. This research advises managers to also take into consideration the contingencies identified in this study. In particular, they should carefully analyze the presence and strength of the factors identified in it and their impact on an optimal organizational design. A mismatch between product and organizational architecture can lead to transactional inefficiency (Furlan et al. 2014). In such contexts, product modularity might not be sufficient for reducing transaction costs. If managers fail to recognize this, they might develop products with high transaction costs.

Furthermore, complex and innovative product architectures require tight integration between the units developing the different modules (Sosa et al. 2004). If managers do not recognize this need and build thick boundaries between development teams, coordination is likely to suffer, and, as a result, errors or performance penalties are likely to occur. Our findings suggest that intermittent collaboration should be sufficient for balancing the overall team performance, for instance, in a context with a highly complex product and a high degree of overlap in which coordination costs across modules are also high (March 1991). It also provides a clear explanation for some empirical studies that insist that coordination still exists in modular organizations (Brusoni 2005, Tiwana 2008), implying that managers of modular firms cannot thoroughly rely on the standardized component interfaces, but must instead develop a set of common knowledge to ensure the effectiveness of outsourcing or inter-firm collaboration (Park et al. 2018).

Finally, incorporating an integrated ICT system in current team processes can have multiple benefits apart from supporting the streamlining of business processes, in terms of preventing a duplication of efforts and allowing for the succinct gathering and collating of requirements to adequately address client needs. The exchange of business information is critical, because it promotes development of a set of metrics for measuring performance against specific goals and deliverables and, more importantly, minimizes inconsistent knowledge and draws teams closer.

4.5.3. Limitations and Future Research

Despite these interesting findings, this study has a number of limitations, some of which provide opportunities for future research. First, our sample was limited to a single firm in the automotive industry. The research is primarily a single-industry, single-organization case study. The heterogeneity of the automotive industry does suggest that the research results could be generalized. Nevertheless, future studies replicating this research across other sectors, teams, and organizations could increase our understanding of the phenomena studied.

Second, apart from the factors highlighted in this research model, the mirroring relationships under study may also be influenced by other systems, such as institutional, cultural, and intra-organizational settings versus the inter-organizational setting. A further exploration of relative factors could be meaningful in developing a more systematic framework of the mirroring hypothesis.

Finally, the ultimate motivation of this study was to better adapt organization design to the products being developed in order to achieve better innovation outcomes. Our results provide an approach for identifying gaps between organizational structure and products in the context of R&D teams working with product modularity. However, to acquire a deeper understanding, it would be useful to further investigate essential R&D team organizational factors, such as knowledge diversity, and their effects on alignment in the product modularity context. Studying the performance implications of these different factors could be interesting.

The present study offers several additional avenues for future research. In particular, studies should test if the mirroring hypothesis holds in varying contexts with regard to the various factors. For example, they might test it across industries with different levels of complexity in terms of product architecture or across products. A fundamental question concerns the performance implications of the mirroring hypothesis. Past research argues that organizations that align their product architecture with their organizational architecture achieve better results.

In the context of our research, we proved that mirroring provides this superior performance for innovation under specific conditions (Cabigiosu and Camuffo 2012). All in all, though, there is a need for further empirical studies to confirm and extend that hypothesis.

In this paper, we investigated the degree of alignment between product and organization in geographically dispersed R&D teams. This form of organization has become ubiquitous and is an essential gatekeeper for innovation. Our investigation has demonstrated the importance of alignment between product and organization and the need to find the right balance in such settings to accomplish the best innovation outcomes. As summarized earlier, our results have important implications for both theory and management. Our aim with this study was to visualize an approach to research questions in the team context and on product modularity that can support future organizational research.

APPENDIX 4: Argumentation and Operationalization of Control Variables

In addition to our dependent and independent variables, we controlled for other factors that might influence the defined model. We controlled for *team size*, since prior research has suggested that this can affect group dynamics (Pelled 1996) and influence team interactions (Markham et al. 1982, Taylor and Greve 2006), as well as having an impact on teams' ability to utilize knowledge and, ultimately, innovate. Team size was measured in the survey by asking the respondents to indicate the number of people involved in the team (in line with Ancona and Caldwell 1992, Pelled 1996, Tsai 2000, Van der Vegt and Jansen 2003). Furthermore, the literature suggests that there are inevitably some designers who typically innovate and perform better than others and that this is usually attributable to differences in cognitive ability and *level of education* (Curtis et al. 1988, Moilanen et al. 2014). Consequently, a team's overall contribution to innovation will also depend on its educational background (Kafouros 2008). In addition, engineers' level of education has often been related to a cumulative knowledge base (Spanos and Voudouris 2009). This situation may have consequent effects on the degree of alignment between team interaction and product modularity, since engineers tend to become more familiar with product structure and support, easing the interactions among team members. Level of education was measured with the following survey item: "Please indicate your level of education: Mid. School / Bachelor / Master / PhD / Other (please indicate)" (Bozionelos 2008).

We controlled, as well, for *project length,* which is an integral part of teamwork, especially for team learning (McGrath 1991, Kasl et al. 1997). Kelly and McGrath (1985) concluded that having more time is linked with greater team creativity. Time is needed as an incubation mechanism to articulate ideas, provide input, identify challenges, and innovate (West 2002).

Furthermore, project length can also influence the degree of alignment between product modularity and team interaction, due to the increasing opportunities for interaction among members and the accruing knowledge on the modularity of the product (Lovelace 1986). Project length was measured with the following item: "Please indicate the project length in months (from nomination to SOP)" (adapted from Lovelace 1986, Kim and Oh 2002, Tiwana 2008).

The variable *years of experience at the company* was added as a control, since it has been frequently argued that the innovation of teams decreases with their experience (Kratzer et al. 2004). For instance, Lovelace (1986) asserts that the innovation performance of research scientists decreases in accordance with the length of time they are part of a group. We measured years of experience at the company from a survey question, using the number of years since joining the organization.

The variable *number of fields of experience* was also added as control. Research has shown that a member's different levels of experience with diverse domains and technologies play a role in their interactions with other team members (Staples et al. 1999, Kirkman et al 2004). Less technically experienced team members may be less inclined, or able, to communicate and might therefore form the kinds of relationships that diminish innovation (Patel et al. 2012). Number of fields of experience was measured with the following item: "Please indicate the number of fields in which you have gathered prior work experience: Mechanics; Software; Project Management; Systems Engineer; Hardware; PCB Layout; Testing; Other (please indicate)" (Staples et al. 1999).

Number of roles in the project was considered because having a variety of roles represented allows teams to be more adaptable and flexible in responding to problem-solving demands, which improves innovation outcomes (Ittner et al. 2002, Cavalluzzo and Ittner 2004, Salas et al. 2005a). On the other hand, team members may in such cases experience higher workloads and more pressure than when dedicating themselves to solely one role, which in turn can negatively affect their ability to commit to innovation activities (Shea and Guzzo 1987, Hackman 1990, Klein 2001). Number of roles was measured with the following question: "Your role/s in this project?: Hardware; Mechanics; Software; Testing; Systems Engineer; PCB Layout; Project Manager; Other (please indicate)" (Ittner et al. 2002).

Furthermore, *work experience in total* can also influence innovation since more experienced employees may benefit more from interactions with other coworkers or require fewer interactions to accomplish their tasks effectively and efficiently (Young-Hyman 2017). Work experience in total was measured in the questionnaire using the total number of years since the start of the respondent's professional career.

Finally, *geographical dispersion* was controlled for to capture the distribution across the three main R&D center locations (i.e., Europe, America, and Asia). Based on the main location of each team member, a team-level variable was operationalized capturing the distribution across these three regions: that is, ranging from 1 (team members are all in the same location); 2 (team members are spread across two different locations); and 3 (team members are spread across three different locations), as adapted from Magni et al. (2013).

APPENDIX 5: Robustness Checks

Table 18 Robustness Check: Without the Direct Controlling Effects of Team Interaction, Module Standardization, and Module Reconfiguration.

Variable	Innovation				
	MODEL 1	MODEL 2	MODEL 3	MODEL 4	MODEL 5
Alignment_Standard	-0.03*	-0.12t			-0.18*
	(0.01)	(0.07)			(0.08)
Alignment_Standard_SQ		0.00			0.00
		(0.00)			(0.00)
Alignment_Reconfiguration			0.02	0.08	0.18**
			(0.01)	(0.06)	(0.06)
Alignment_Reconfiguration SQ				-0.00	-0.00*
				(0.00)	(0.00)
Team Interaction	-	-	-	-	-
	-	-	-	-	-
Module Standardization	-	-	-	-	-
	-	-	-	-	-
Module Reconfiguration	-	-	-	-	-
	-	-	-	-	-
Experience at Company	0.06**	0.06**	0.07**	0.06**	0.06**
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Total Experience	-0.05*	-0.04*	-0.03t	-0.03t	-0.03t
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Team Size	0.02	0.03	0.02	0.01	0.02
	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
Project Length	-0.01	-0.01	-0.01	-0.00	-0.01
	(0.01)	(0.01)	(0.02)	(0.02)	(0.01)
Nr. Fields of Experience	0.18*	0.15t	0.08	0.08	0.11
	(0.08)	(0.09)	(0.08)	(0.08)	(0.08)
Nr. of Roles in Project	-0.33t	-0.31t	-0.35t	-0.33t	-0.34*
	(0.18)	(0.18)	(0.18)	(0.18)	(0.17)
Level of Education	0.46*	0.45*	0.44t	0.46*	0.51*
	(0.23)	(0.23)	(0.23)	(0.23)	(0.21)
Geographical dispersion	-0.28t	-0.24	-0.25	-0.28t	-0.28t
	(0.15)	(0.15)	(0.15)	(0.16)	(0.15)
Constant	4.22***	5.18***	3.04***	2.26*	3.45**
	(0.78)	(1.09)	(0.77)	(1.05)	(1.11)
Adj. R-square	16.1%	23.3%	24.3%	24.4%	26.3%
Model significance	0.00	0.00	0.00	0.00	0.00
AIC	260.62	260.84	263.21	263.90	248.95
BIC	286.77	289.61	289.36	292.66	282.95

tp<0.10; *p<0.05; **p<0.01; ***p<0.001 / Non Standardized β values / Standard errors in brackets.

Table 19 Robustness Check: Substituting Innovation by Number of Patents as the Dependent Variable

Variable	Innovation				
	MODEL 1	MODEL 2	MODEL 3	MODEL 4	MODEL 5
Alignment_Standard	-0.42*	-0.52*			-0.92**
	(0.17)	(0.22)			(0.30)
Alignment_Standard_SQ		0.00			0.01*
		(0.00)			(0.00)
Alignment_Reconfiguration			-0.23	-0.39	0.36
			(0.16)	(0.36)	(0.42)
Alignment_Reconfiguration SQ				0.00	-0.01
				(0.00)	(0.00)
Team Interaction	1.55t	1.59t	0.60	1.02	2.17t
	(0.90)	(0.91)	(0.83)	(1.21)	(1.23)
Module Standardization	2.05*	2.18*	-0.36*	-0.36*	3.26**
	(1.01)	(1.03)	(0.16)	(0.16)	(1.22)
Module Reconfiguration	0.31t	0.29	1.66t	2.17	-0.23
	(0.17)	(0.18)	(0.86)	(1.35)	(1.52)
Experience at Company	0.13***	0.13***	0.12**	0.12**	0.13***
	(0.04)	(0.04)	(0.04)	(0.04)	(0.03)
Total Experience	-0.08**	-0.08**	-0.07*	-0.07*	-0.08**
	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
Team Size	0.04	0.04	0.03	0.03	0.01
	(0.04)	(0.04)	(0.04)	(0.05)	(0.04)
Project Length	-0.01	-0.01	-0.01	-0.01	0.01
	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
Nr. Fields of Experience	0.23	0.21	0.15	0.16	0.21
	(0.14)	(0.14)	(0.14)	(0.14)	(0.14)
Nr. of Roles in Project	-0.48	-0.48	-0.40	-0.44	-0.38
	(0.29)	(0.29)	(0.30)	(0.31)	(0.30)
Level of Education	0.56	0.55	0.83*	0.84*	0.50
	(0.37)	(0.38)	(0.38)	(0.38)	(0.38)
Geographical dispersion	-0.17	-0.13	-0.31	-0.29	-0.20
	(0.24)	(0.25)	(0.25)	(0.26)	(0.25)
Constant	-6.59	-5.97	-1.64	-3.21	-9.97
	(4.87)	(4.95)	(4.54)	(5.57)	(6.11)
Adj. R-square	21%	21%	17%	16.3%	24%
Model significance	0.00	0.00	0.00	0.00	0.00
AIC	355.65	357.05	359.79	361.52	354.64
BIC	389.66	393.66	393.79	398.13	296.49

tp<0.10; *p<0.05; **p<0.01; ***p<0.001 / Non Standardized β values / Standard errors in brackets.

Table 20 Robustness Check: Substituting Team Interaction by Communication Frequency

Variable	Innovation				
	MODEL 1	MODEL 2	MODEL 3	MODEL 4	MODEL 5
Alignment_Standard	0.03	-0.06			-1.28**
	(0.04)	(0.12)			(0.41)
Alignment_Standard_SQ		0.00			0.02**
		(0.00)			(0.01)
Alignment_Reconfiguration			0.03	0.09	1.34**
			(0.04)	(0.11)	(0.44)
Alignment_Reconfiguration SQ				-0.00	-0.02**
				(0.00)	(0.01)
Team Interaction	-0.59t	-0.59t	-0.59t	-0.60t	-0.55t
	(0.31)	(0.31)	(0.31)	(0.31)	(0.30)
Module Standardization	-0.44*	-0.43*	-0.35*	-0.36*	1.70t
	(0.21)	(0.21)	(0.17)	(0.17)	(0.97)
Module Reconfiguration	0.44*	0.42*	0.33	0.33	-1.85t
	(0.17)	(0.17)	(0.22)	(0.22)	(0.99)
Experience at Company	0.13***	0.13***	0.13***	0.13***	0.13***
	(0.04)	(0.04)	(0.04)	(0.04)	(0.03)
Total Experience	-0.07*	-0.07*	-0.07*	-0.07*	-0.06*
	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
Team Size	0.04	0.04	0.04	0.03	-0.00
	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)
Project Length	-0.02	-0.01	-0.02	-0.02	0.00
	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
Nr. Fields of Experience	0.16	0.16	0.16	0.16	0.19
	(0.14)	(0.14)	(0.14)	(0.14)	(0.14)
Nr. of Roles in Project	-0.42	-0.47	-0.43	-0.39	-0.25
	(0.31)	(0.31)	(0.31)	(0.32)	(0.31)
Level of Education	0.81*	0.85*	0.79*	0.79*	0.75t
	(0.38)	(0.39)	(0.38)	(0.38)	(0.39)
Geographical dispersion	-0.28	-0.26	-0.28	-0.31	-0.37
	(0.25)	(0.26)	(0.25)	(0.26)	(0.25)
Constant	4.67*	5.06*	4.71*	4.44*	4.33*
	(1.86)	(1.93)	(1.86)	(1.93)	(1.86)
Adj. R-square	25.9%	26%	23.3%	22.4%	29.4%
Model significance	0.01	0.01	0.01	0.01	0.00
AIC	361.70	363.01	361.54	363.19	355.13
BIC	395.69	399.62	395.53	399.80	396.98

tp<0.10; *p<0.05; **p<0.01; ***p<0.001 / Non Standardized β values / Standard errors inbrackets.

Table 21 List of Interviews

Interviewee no.	Date	Position	Role	Experience in the organization (years)	Region	Telephone (TEL) Face-to-Face (FTF)	Duration (min.)
1	2014.07.29	R&D Senior Manager	Manager	22	Europe	TEL	45
2	2014.07.30	Project Manager	Project M	18	Asia	FTF	25
3	2014.07.30	Engineer	Product Design	3	Asia	FTF	30
4	2014.08.04	R&D Team Leader	Product Design	17	Europe	FTF	40
5	2014.08.04	Senior Engineer	Product Design	15	Europe	TEL	30
6	2014.08.20	R&D Team Leader	Product Design	10	Asia	FTF	35
7	2014.08.20	Project Manager	Project M	11	Europe	FTF	45
8	2014.08.25	R&D Senior Manager	Manager	18	America	TEL	50
9	2014.08.25	Senior Engineer	Tooling Design	8	America	FTF	40
10	2014.08.29	Senior Engineer	Product Design	5	Asia	FTF	35
11	2014.09.01	R&D Team Leader	Process Design	8	America	FTF	30
12	2014.09.01	Engineer	Tooling Design	2	Asia	FTF	30

CHAPTER 5
CONCLUSIONS AND DISCUSSION

5.1. INTRODUCTION

Given the fundamental importance of innovation for the survival of organizations and the extensive use and application of product modularity, the central aim of this dissertation is about the role of product modularity on innovation in the research and development (R&D) team context.

R&D teams are becoming standard practice in an increasingly complex business setting (Kratzer et al. 2004, Langfred 2005, Carnabuci and Bruggeman 2009, Sandberg et al. 2015). However, as indicated at the beginning of this dissertation and under this R&D context, collaboration in teams working with product modularity becomes paradoxical. On the one hand, product modularity provides an approach of collaborating among team members that reduce the need for coordination and communication efforts significantly. (Sanchez and Mahoney 1996, Baldwin and Clark 1997, Fine 1998, Schilling 2000), which means independent tasks following basic standards and design rules. On the other hand, collaboration in this setting involves the need for higher participation and knowledge exchange among team members (Brusoni and Prencipe 2001, Steinmueller 2003), as this is required for the integrative process of putting the various modules into one product.

Furthermore, and despite the extended use and application of product modularity, there is a low degree of agreement on its definition (Gershenson et al. 2003, Ro et al. 2007).

At the same time, various studies argue that team communication is expected to be organized in order to mirror the tasks they carry out (Sosa et al. 2007, Tiwana 2008, MacCormack et al. 2012, Cabigiosu et al. 2013, Furlan et al. 2014, Colfer and Baldwin 2016). (Henderson and Clark 1990, Brusoni and Prencipe 2001, Tiwana, 2008, Cabigiosu et al. 2013, Furlan et al. 2014). Although the insights from these studies are important and useful in improving R&D processes, they imply that a decreasing degree of alignment between team interaction and product modularity is detrimental to innovation. However, these studies could not empirically test this assumption, and it is from here where we perceive the demand for further argumentation.

Moreover, organizations aim to achieve various performance objectives simultaneously (Baum et al. 2000, Dussauge et al. 2002). However, the literature has tended to identify innovation performance indicators as unidimensional. Efficiency and effectiveness are essential conditions for estimating performance (Schmidt and Finnigan 1992, Neely 1998), with thechallenge for organizations being to balance both of them within an R&D team context (Fox

2013). There seems to be a poor fit between practical and academic research on innovation performance. Defining a multidimensional view of innovation of R&D organizations is therefore fundamental since, in practice, organizations target multiple performance objectives at the same time, balancing between strategies aiming at efficiency or effectiveness outcomes (Mouzas 2006).

Finally, communication technologies (ICT) have facilitated organizations to create and spread coordination structures, such as R&D teams, over the past years. Despite the extensive practice of R&D teams that communicate predominantly via email (Mathews et al. 1998, Tsai 2000, Muncer et al. 2000a, Frantz and Carley 2008, Bird et al. 2008, Lin 2010), little is known about the characteristics and performance of such teams.

This dissertation aimed to fill the aforementioned gaps by answering the following central research question:

What is the role of product modularity and its implications for innovation in the R&D team context?

In order to answer the research question and close the above-described gaps in the literature, this dissertation contained three empirical studies presented in the previous chapters.

The research question is composed fundamentally of three building blocks: product modularity, collaboration, and innovation.

The first empirical study (Chapter 2) explored the impact of team interaction and knowledge diversity (key collaboration factors in this context) on innovation, with the moderating effect of product modularity. The second study (Chapter 3) considered a more granulated approach to product modularity. This study investigated the concept of product modularity as a multidimensional construct composed of module standardization and reconfiguration and explored the impact of product modularity (multidimensional) on two dimensions of innovation (i.e., effectiveness and efficiency). In the third study (Chapter 4), we went one step further and looked at how firms organize themselves under this particular R&D team context. This study explored the degree of alignment between module standardization and reconfiguration with team interaction within R&D teams and, ultimately, we evaluated the impact on innovation at the team level. All three empirical studies generated an essential quantity of main conclusions that deliver answers to the central research question.

5.2. MAIN CONCLUSIONS: STUDY 1

Organizations are facing increasing business challenges in an accelerated and continuous globalized and interlinked world. In this context, innovation is essential for long-term survival. Consequently, organizations build internally R&D teams that are a challenge to manage and coordinate. Under this setting, organizations apply product modularity in order to reduce complexity and enhance innovation. Collaboration within R&D teams working with product modularity is, however, paradoxical as, on the one hand, team members need to work independently, reducing the interaction with other members and keeping a modularly defined design rule or standard. On the other hand, team members need to be participative in the consolidation process of bringing the different modules together. Furthermore, research studies in the intra-organizational collaboration context are scant. Additionally, under this R&D team context, there is no closing argument on the essential elements of team collaboration that have an impact on innovation. Drawing upon the knowledge base view of the organization, this study examined collaboration in the R&D team context by analyzing the effects of the central elements of collaboration (team interaction, knowledge diversity) on innovation, under the moderating influence of product modularity. Additionally, this research studied the moderating effect of product modularity in this relationship. The theorizing and results suggest that, in this context, there is a negative impact of team interaction on innovation, whereas knowledge diversity shows a positive impact on innovation - furthermore, product modularity moderates negatively both relationships: team interaction and innovation, and knowledge diversity and innovation.

These results lead to the conclusion that, under the R&D team context working with product modularity, innovation strongly depends on the team collaborative setting, including team interaction, and the knowledge diversity within the team.

Furthermore, an increasing degree of product modularity will decrease the need for interaction, knowledge exchange among team members, and at the same time reduce the exchange of ideas and innovate. In addition, having a high variety of knowledge among team members will make it easier for the team to innovate. In particular, targeting the corresponding adjustments in team settings could generate substantial improvements in innovation outcomes.

Finally, and due to the unexpected and somehow unusual outcomes of the moderating effect of product modularity, in the following chapter we further elaborate on the concept of product modularity and explore the potential direct influences of product modularity on innovation.

5.3. MAIN CONCLUSIONS: STUDY 2

The use and application of product modularity as a method to reduce complexity and improve efficiency is widely and extensively employed (Garud et al. 2003, Mikkola and Gassmann 2003, Pil and Cohen 2006, Cabigiosu et al. 2013). Empirical studies of the effects of product modularity on innovation, however, have been scant and ambiguous, providing divergent definitions and dimensions for product modularity. This study adopted a definition of product modularity as a multidimensional construct composed of module standardization and reconfiguration and investigated the impact of modularity on two dimensions of innovation (i.e., effectiveness and efficiency). Several conclusions can be drawn from its results, providing novel theoretical and managerial contributions to the role that product modularity (i.e., module standardization and reconfiguration) can play on innovation.

We found a U-shaped relationship between module standardization and innovation effectiveness, with a negative impact on innovation efficiency. Furthermore, reconfiguration has an inverted U-shaped relationship with innovation effectiveness and a positive effect on innovation efficiency. These findings contribute primarily to the literature on product modularity since the multidimensional approach resolves some of the ambiguity from previous studies.

For the first time, our findings provide insight into the optimum of module standardization and reconfiguration in consideration of the relevant innovation criteria. For managers of R&D teams, this means that strategic decisions on innovation objectives hold direct and nuanced implications for product modularity, such as priorities for standardization or additional efforts for reconfiguration.

Finally, this study aimed to resolve the prevailing poor fit between innovation practice and theory by adopting, empirically, effectiveness and efficiency views of innovation. We argue that the vast body of studies on innovation fundamentally describes one kind (Plessis 2007). However, organizations aim to achieve multiple objectives at once (Neely 1998, Mass 2005), and theoretical perspectives on innovation should thus be likewise multidimensional in scope (Mouzas 2006).

5.4. MAIN CONCLUSIONS: STUDY 3

Building on the insights from the second empirical study (Chapter 4), that product modularity may have contradictory effects on innovation, we conceptualize modularity as two-dimensional - module standardization and reconfiguration - and empirically investigate the mirroring hypothesis one by one. This study parts with the assumption that if two components or product modules share design interfaces, the team members that develop them need to connect (Thompson 1967). Studies related to organization theory recognize that organizations should be designed to reflect the nature of the task they perform (Mac Cormack et al. 2012). Few systematic empirical studies exist on this relationship despite the popular notion of the mirroring hypothesis in organizational design.

By pulling from recent studies (Brusoni and Prencipe 2001, Langlois 2002, Sosa et al. 2004, MacCormack et al. 2012, Furlan et al. 2014), this study aimed to empirically investigate the impact of the degree of alignment between team interaction and module standardization and reconfiguration on innovation in R&D teams. The outcomes suggest a U-shaped relationship between the alignment of team interaction and module standardization on innovation. Furthermore, the degree of alignment of team interaction and module reconfiguration propose an inverted U-shape relationship with innovation. With this study, we enhanced the understanding of the concept of alignment between task and organizational structure at the team level. We suggest that targeting for an optimized alignment between product modularity (as a multidimensional construct) and team interaction can be beneficial to innovation at the team level.

It is essential for managers to foresee where misalignment is more likely to occur - that is, to differentiate which areas of the product and team need explicit consideration to distinguishing critical design interfaces and guarantee most effective team interactions.

Finally, this study explores the email communication data among R&D teams, providing a unique source of investigation, which has been to date difficult to access other research studies.

5.5. OVERALL THEORETICAL IMPLICATIONS

This dissertation offers significant contributions to academic purposes.

First, this study unpacks our theoretical understanding of the concept of product modularity in R&D organizations by establishing the two critical dimensions of product modularity (i.e., module standardization and reconfiguration). The theoretical and empirical setting takes place at the R&D team level. As a result, we clarify earlier ambiguities from previous studies on the concept of product modularity.

Second, with this dissertation, we enriched the understanding of the concept of alignment between task and organizational structure at the team level. In this context, we provided evidence of the impact of this alignment on innovation. Our proposition that the degree of alignment can have effects on innovation outcomes contributes to the literature related the “mirroring” hypothesis (Brusoni and Prencipe 2001, Langlois, 2002, Sosa et al. 2004, MacCormack et al. 2012, Furlan et al. 2014). We suggest that, if we aim for enhancing innovation at the team level, an optimized alignment between product modularity and team interaction needs to be considered.

Third, this study provided a deeper understanding of the dynamics of the collaboration process and extends to the literature in the fields of organization science and team organizations. Specifically, we improved the understanding of collaboration in the R&D teams, developing products with a certain degree of modularity. This research inspected the effects of R&D collaboration on innovation at the team level. Moreover, this dissertation analyzed the influence of the essential collaborative features of R&D teams (team interaction, knowledge diversity) on innovation conceptually, under the moderating effect of product modularity.

Fourth, this dissertation addressed the existing poor fit between innovation theory and practice by adopting empirically, effectiveness, and efficiency views of the innovation concept.

Finally, this study investigated the communication exchange among team members via email. Despite the broad use of this media, little is known about the characteristics and performance of this form of communication in organizations.

5.6. MANAGERIAL IMPLICATIONS

From a management point of view, this work suggests several substantial insights. The practical implications of the results for the management of R&D teams confirm that, under the R&D team context working with product modularity, innovation strongly relies on the team collaborative setting, including team interaction and knowledge diversity. This situation suggests that adjustments in the team setting could produce significant improvements in innovation (Amabile 1998). If managers are aiming for enhancements on innovation under the R&D team context, it is desirable to create teams with high knowledge diversity and relatively low team interaction. In particular, there must be an extensive experience available within the R&D team members, as this experience has positive effects on innovation.

In managerial terms, in order to achieve a high level of innovation within the team context working with product modularity, it is best to keep team interaction to a relatively low or moderate level. In particular, this can entail avoiding a high frequency of contact during development, holding a few meetings and communication exchange as necessary (Amabile and Conti 1999, Kratzer et al. 2004). Following this method, the risks of sub-groups forming could be prevented. Sub-group formation is proven to be an inhibitor of innovation (Leenders et al. 2002, Kratzer et al. 2004, Ancona and Bresman 2007). It is therefore recommended that team setting is organized based on the degree of team interaction. Managers are advised to observe team communication and should be aware of the contingency influences of team interaction on innovation. Failing to address this issue could affect innovation outcomes negatively in the organization.

At the same time, R&D managers could measure a team's overall level of knowledge and perform a knowledge-gap analysis. This exercise would enable managers to evaluate the relative degree of knowledge overlap, perhaps via bibliometric analysis (Lane and Lubatkin 1998). As indicated by Hamel (1991), too much overlap would require too much unlearning, and too little overlap would require too much teaching. With such information available, managers may be able to select among diverse sources. In addition, the introduction of job rotation programs could enhance overall team knowledge diversity in the medium term.

Moreover, the results suggest that, overall, product modularity delivers a sound strategy to reach improvements in innovation (as a multidimensional construct). These results provide an excellent instrument for managers who search for enhancing innovation performance, balancing resources and efforts in R&D teams. In short, these empirical findings support our arguments that organizational decisions related to the application and use of module standardization and reconfiguration have a substantial impact on innovation. When aiming for the enhancement of innovation outcomes in organizations that work with product modularity, an optimum balance needs to be established, while also taking into consideration the opposite effects of module standardization and reconfiguration on innovation.

Furthermore, the systematic use of standardized and reconfigurable components decreases the demand of an active managerial authority across R&D team interfaces, which in turn diminishes the management of complex tasks in product development. By organizing R&D teams around the development of standardized components, managers will be able to achieve increased efficiencies that support further innovative products and technologies.

A systematic process that facilitates the implementation and use of product modularity, in turn, enables stronger links to product manufacturing processes. Since standardized components are more accessible and more quickly produced, this situation will reinforce the reuse of these components in new designs. However, managers must carefully monitor and follow when the possible tipping point of diminishing innovation, due to too much manufacturing modularity, could be reached.

In order to cope with highly complex products and be able to innovate, managers need to apply some form of product modularity. Module standardization and reconfiguration will both have a direct effect on the design-related costs. For example, if pre-designed standards are already accessible in the form of design rules or guidelines, the cost of development tends to be lower. However, if modular standards are being developed as part of the development effort, the related development costs and time may increase.

In addition, in order to improve innovation effectiveness, managers should pursue the development of products with higher degrees of module reconfiguration up to an optimal level.

Beyond this level, product modularity impacts innovation negatively. In order to achieve an optimum, a balance between product differentiation and commonality is suggested (Robertson and Ulrich 1998) by distinguishing those product components that customers value most. On the other side, managers should look for enriching module standardization with the purpose of strengthening innovation effectiveness. Developing a system that provides “off the shelf” modular solutions could reduce the number of alternatives during development (Baldwin and Clark 2000), as well as decrease the intensity of the managerial involvement within R&D teams (Sanchez and Mahoney 1996), deliver superior flexibility (Lee and Tang 1997, Fisher et al. 1999), and ultimately improve innovation.

First and foremost, a method that balances product modularity dimensions (i.e., module standardization and reconfiguration) needs to be deployed so that it can support designers to take decisions that will lead to enhanced innovation performance. All in all, methods and tools for monitoring product modularity dimensions need to be installed in order to accomplish superior innovation outcomes.

Regarding structural organizational suggestions, it is essential to deploy a measure on the degree of alignment (Gokpinar et al. 2010). We have proved that the degree of alignment is related to innovation at the team level. This specific performance measure can be used to improve innovation results, reaching an optimum balance between product modularity (as a multidimensional concept) and team interaction, measuring the degree of alignment between team interaction and product modularity (i.e., module standardization and reconfiguration). In the case of larger and more complex projects to be undertaken, these measures could improve awareness of the demand for team interaction among specific team members at a given point in time. Managers would look into smoothing suitable team interaction channels (Bano et al. 2016).

Additionally, this study provides evidence that, within this specific context, a particular level of overlapping between team interaction and product modularity stimulates innovation at the team level. Moreover, this study provides evidence identifying the circumstances when the overlapping diminishes innovation. This result is significant as, in general, it is considered that greater overlapping will be in general positive for innovation (Cataldo et al. 2006, Olson et al. 2009).

A critical component in this outline is team interaction (MacCormack et al. 2012). As earlier revealed, the degree of team interaction can affect a number of organizational processes and results, becoming substantial for innovation outcomes. (Baldwin and Clark 2000). The resulting framework has significant managerial repercussions, as they have an impact on enriching performance. For example, processes, methods or diverse activities could be conceived for this objective (Puranam et al. 2012). One practical example could be providing a shared vocabulary of terms (Weber and Camerer 2003) that would simplify interaction, itself especially valuable in uncertain situations.

Moreover, activities will be run independently after tasks and modular products are clarified and separated within the R&D team. Afterward, the integration process will confirm the modules' merging (Zirpoli and Becker 2011a). However, there is a risk of letting the technical aspects lag behind due to communication exchange limitations, which generally would decrease idea exchanges and, ultimately, innovation.

This research advises managers, in particular, to carefully analyze the presence and strength of the factors and their impacts on the optimal organizational design. A discrepancy between product and organization might cause certain inefficiencies to emerge (Furlan et al. 2014). Managers should, therefore, monitor this situation, in order to avoid any increasing transactions costs.

Furthermore, the development of complex and innovative products involves the integration process of different team members that develop diverse modules (Sosa et al. 2004). If the boundaries separating development teams are not sufficiently clarified, coordination will face challenges which may result in errors or inefficiencies. These results explain the need as well for coordination, even under modular developments and organizations (Brusoni 2005, Tiwana 2008), implying that managers cannot fully rely on standardized components. On the other side, shared knowledge needs to be developed to ensure, for instance, the effectiveness of outsourcing or inter-firm collaboration.

Finally, this dissertation confirms the benefits of the use of ICT systems under the R&D team setting. ICT technologies will help to prevent additional efforts and improve response speed, minimizing knowledge inconsistencies and bringing team members closer.

5.7. LIMITATIONS AND SUGGESTIONS FOR FUTURE RESEARCH

Despite several interesting conclusions, this dissertation has some potential limitations, some of which provide opportunities for future research.

First, the study has a relatively small sample size, although higher than in many other studies of innovation and teams (Zander and Kogut 1995, Szulanski, 1996, Lane and Lubatkin 1998, Tyler and Steensma 1998, Ancona and Bresman 2007). An even larger sample would be desirable for reasons of statistical power. Future research on the factors affecting innovation could benefit from this study's empirical setting and replicate the study.

Second, one potential limitation relates to the single industry and organization. Single group studies are limited in generalizing their findings to their particular contexts. Although the industry segment and organization chosen is characterized by a high degree of heterogeneity, innovation, and a broad range of products with a certain degree product modularity, future studies could replicate this research across other sectors and organizations in order to enhance our understanding.

Third, this study deals with relatively stable and mature products in a developed industrial context, in which the product development process consists of well-defined and established steps. The findings of our research may not generalize to teams that operate in very uncertain or rapidly changing environments, where, for instance, increasing team interaction is seen as a driving factor for innovation in teams (Leenders 1995, Kratzer et al. 2004, Borgatti and Foster 2003, Obstfeld 2005, Turner et al. 2010). Therefore, effects on innovation might be contingent on environmental dynamics (Ethiraj and Levinthal 2004, Ernst 2005, Pero et al. 2010), and our arguments may be limited to established markets and large organizations. Future studies on teams could help draw indications for the organizations involved in a more dynamic industry or context.

Fourth, due to the very nature of survey data as cross-sectional, there is a risk to miss claiming causality. However, as earlier indicated, the direction of the claimed effects is supported by similar theorizing and findings from previous studies in the team and innovation context (Lau et al. 2007, Danese and Filippini 2010, Jimenez and Sanz 2011). In addition, due to the novelty of the data and the multidimensional approach taken for the first time in this study, future research could further confirm our outcomes.

Furthermore, the current research has not differentiated between types of innovation in terms of the degree of innovativeness (e.g., incremental or radical innovation). Future studies could explore how different kinds of innovation are affected by module standardization and reconfiguration.

In addition, the "mirroring" relationships may also be influenced by other systems, in addition to the aspects underscored in this dissertation, such as institution, culture, and intra-organizational versus inter-organizational settings. Further investigation can be of value if a more systematic framework of the "mirroring" hypothesis is developed. Within the "mirroring" area of research, studies should test if the mirroring hypothesis holds in contexts that vary regarding the various factors.

Finally, past studies argue that organizations that align the architecture of products with the architecture of organizations achieve better results. In the studied context of our research, we demonstrated that the mirroring hypothesis delivers superior innovation outcomes, however, under specific conditions (Cabigiosu and Camuffo 2013).

In sum, further empirical research may be necessary to confirm and broaden our conclusions. Represents a Brief Summary of the Managerial Suggestions for this Research.

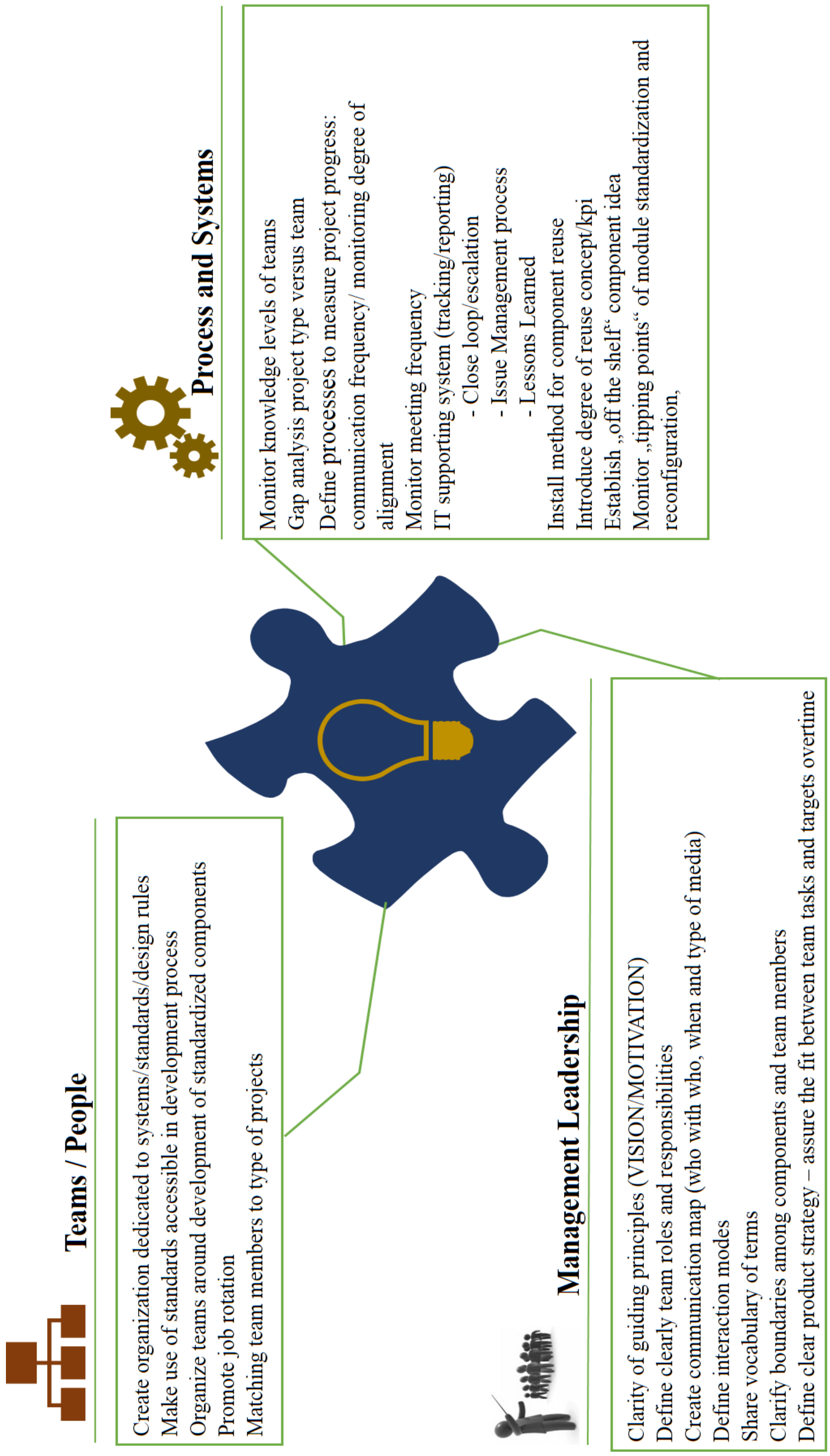


Figure 9 Suggestions for Managers of R&D Teams

5.8. FINAL STATEMENT

To date, intra-organizational team collaboration research studies have been scant (Bell and Kozlowski 2002, Hinds and Kiesler 2002, Hertel et al. 2003b, Hertel et al. 2005). Teams are an essential organizational booster for innovation. This team-level dissertation establishes a firm base on which to build a future investigation, addressing the continued evolution of organizational forms, practices, and technologies supporting innovation. The results of the present study show that team interaction and knowledge diversity can be beneficial to innovation. The general outcomes of this dissertation are important and helpful for further theoretical exploration of R&D team collaboration and for practical issues on how to manage R&D teams successfully. In particular, we investigated the impact of module standardization and reconfiguration on both innovation effectiveness and efficiency in R&D teams.

The results prove that module standardization and reconfiguration can be beneficial to innovation effectiveness and efficiency but that these benefits vary. Further research is needed since innovation is crucial for organizations' existence. Finally, we have explored the degree of alignment between product and organization in R&D teams. The investigation has the demonstrated significance of this alignment and, in order to improve innovation, the necessity to achieve a balance. These findings provide significant repercussions, both in theory, and management. With this dissertation, we have aimed to present an approach that can support future organizational research studies within the team context. In sum, this dissertation can hopefully be a source of inspiration for scholars. In the end, there is still a lot of fascinating future research work to be done.

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APPENDIX 6: Content of the Survey related to this Dissertation

Survey for PROJECT NUMBER and PROJECT NAME

PURPOSE

The purpose of this survey is to gather information on the product identified with the above-indicated Project Number, that you are currently developing in an R&D Team in which you are a member. It is important to help to understand how team members realize a technical product development in collaboration working with a certain degree of product modularity.

YOUR PARTICIPATION

We need your complete and honest participation and response. For this reason, the complete confidentiality of this survey is ensured for every respondent.

DIRECTIONS

The survey will take approximately 10-15 minutes to complete. Please follow the instructions of the survey itself and indicate your responses accordingly.

GENERAL INFORMATION

Q0. Have you filled this survey before? (Yes/No).

Q1. Your location (Subsidiary)

Q2. Your experience at this company (Years)

Q3. Your total professional experience (Years)

Q4. Your level of education (Mid. School; Bachelor; Master; Ph.D.; Other, please indicate)

Q5. In the last year, in how many projects did you participated which were or are involving more than one development location (Number of projects)?

Q6. Please indicate (cross mark) the number of fields in which you have gathered prior work experience: (Mechanics; Software; Project Management; Systems Engineer; Hardware; PCB Layout; Testing; Other, please indicate).

Q7. Your role/s in this project? (Hardware; Mechanics; Software; Testing; Systems Engineer; PCB- Layout; Project Manager; Other, please indicate)

Q8. Team size (only AE-development members' no)?

Q9. Project Length in months (from nomination to SOP)

PRODUCT MODULARITY

The following questions are related to the concept of product modularity. Product modularity refers to the use of standardized and interchangeable components or units that enable the configuration of a wide variety of end products. A product can be divided into loosely coupled/independent parts, i.e., the modules.

Please read the following statements related to the degree of product modularity in your current product in development specified in this survey. Please indicate to what extend do you agree to below statements (fully disagree=1, fully agree=7)

Q10. Product's components are standardized

Q11. Product doesn't use common assemblies and components

Q12. Components are interchangeable across different products

Q13. Product components can be reused in other products

Q14. Products can be re-configured into further end products

Q15. Product can be decomposed into separate modules

INNOVATION PERFORMANCE

The following questions are related to the concept of innovation performance. Innovation is an iterative process initiated by the perception of a new market and/or new service opportunity for a technology-based invention. In this specific technologically related context, the main focus is on innovation being a new technology that is applied in one or more final products.

Please read following statements related to the degree of innovation performance in the current product in development indicated in this survey. Please indicate to what extent the product differs from the current ones in the industry or market. (fully disagree=1, fully agree=7)

Q16. This product is new to the market or customer

Q17. The product possesses technical specifications, functionalities components or materials differing from the current ones

Q18. The product we developed is the first of its kind

Q19. Product has unique features to Market or Customer

Q20. This product has or is acquiring patents

Q21. The product has patentable innovations

How would you rate the level of achievement of the following performance items in your current product in development? (seven-point scales ranging from 1=very unsuccessful' to 7='very successful'.)

Q22. Product revenues' generation compared to the R&D expenditure

Q23. Product patentable discoveries by R&D expenditure

Q24. Compared to the innovative features developed in this product, the investment is reasonable

TEAM INTERDEPENDENCE

The following questions are related to the concept of team interdependence, which mainly relates to the degree of interaction within the team in the indicated project.

How would you rate the current statements related to the R&D Team developing the related to the above-indicated product for this survey? (strongly disagree=1 – strongly agree=7)

Q25. Friendly attitude exists in the Team

Q26. Team members feel strong ties to the team.

Q27. Team members are committed to maintaining close interpersonal relationships

Q28. Communication and intimacy of the relationship in the Team is easy

Q28. Team members are in contact with each other on a regular basis in order to conduct regular business

Q29. Team members are in contact with each other on a regular basis for social, non-business, purposes

Q30. Team members have been collaborating in projects in the past

Q31. Team members will be collaborating on further projects in the future

Q32. Within your team, how often do you communicate, on average, with regard to the above-indicated product in this survey? (ll)

(Many times a day / at least once a day / every week / every two or three of weeks / Once a month or less / Not at all)

KNOWLEDGE DIVERSITY

The following questions are related to the concept of knowledge diversity in teams.

Knowledge diversity refers to the degree to which the knowledge held by the team members is dispersed across different technological areas

How would you rate following statements regarding the degree of knowledge diversity in the current project R&D Team developing the indicated product in this survey?(strongly disagree=1 – strongly agree=7)

Q33. Team knowledge about many different technologies is combined

Q34. Team enjoys from a variety of technical knowledge areas to develop the related product.

Q35. The diversity in the knowledge within the team makes the discussions difficult. (R)

Q36. Our team possesses diverse knowledge

USE of ICT

The following questions are related the use of ICT (information and computer technologies) within the above-specified project for this survey

Q37. Please indicate the frequency of communication with the R&D team via following media (0=never, 1=once per month or less, 2=few times a month, 3=once or more times per week, 4-once per day or 5 more)

Written letter (no emails) (_) / Face to face meetings (_) / Tel calls - (no video) (_) / Video Conference calls, Skype or similar (_) / Emails (_) / Wechat/Whatsup/SMS or similar (_)

Please read following statements related to the intensity of ICT use within the Team in your current product (xxxx) in development. Please indicate to what extent do you agree with below statements (fully disagree=1, fully agree=7)

Q38. Team collaboration is achieved through email communication

Q39. The team makes use of email communication

Q40. The team makes use of ICT-based systems

Q41. Computerized systems which this team is using are easy to use and useful

Q42. In this team, electronic communication is common

Q43. Overall, the email communication systems support the team ability to innovate

Q44. Overall, the email communication systems support in the experimentation of new ideas

ABOUT THE AUTHOR

Daniel Martinez Martin was born in September 1971, in Barcelona, Spain. After finishing secondary school, he started engineering studies and obtained his Master of Engineering degree from "Universitat Politecnica of Catalunya" in 1996, Barcelona. His master's thesis was related to efficiency gains in the automotive manufacturing process. In 1999 he finalized a post-degree in Technical Sales engineering in AHK in Munich. In 2007, he obtained his Master of Business Administration from CEIBS in Shanghai.

Since 1996, he has been working in the automotive industry in diverse roles and responsibilities, mainly in the technical area. With more than 22 years of engineering and management experience in the sector, Daniel Martinez Martin has been supporting the build of R&D infrastructures and leading diverse Technical organizations, distributed in very diverse countries and locations. Daniel Martinez started in 2014 an executive PhD research in the joint program at City University of London and Tilburg University. This dissertation is the result of the PhD research.

His main areas of research interest are innovation, team collaboration, R&D organizations, and modularity.