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Two dimensions of product modularity and innovation: the case of R&D teams

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This study investigates the relationship between product modularity and innovation in 101 research and development (R&D) teams. The key contribution and the departure from prior empirical work consists in bringing into relation multidimensional operationalizations of these two concepts. Product modularity is composed of standardization and reconfigurability and innovation of novelty and efficiency. The literature provides arguments for both negative and positive relationships between standardization and the two types of innovation, while positive relationships are argued for product reconfigurability. The empirical findings corroborate most of the theorizing, although negative relationships are found for standardization. This study contributes to the literature by unpacking the understanding of the concept of product modularity in R&D organizations since the multidimensional approach resolves some of the ambiguity from previous studies. The modularity literature long called for studies to empirically investigate product modularity in more than one dimension implying a number of theoretical implications discussed here.

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1. Introduction

Many organizations face challenges with managing their research and development (R&D), since managers responsible for R&D must leverage and exploit a distributed body of knowledge in an effective manner. To this end, organizations build teams that collaborate to share knowledge and create and distribute their R&D activities, yet they are difficult to structure and integrate (Szulanski, 1996; Gassmann and Zedtwitz Von, 1999). The Covid-19 pandemic has resulted in a surge of employees working from different locations, which additionally increases complexity. These situations drive organizations to adopt different product design and development processes (Krishnan and Ulrich, 2001; Hagedoorn *et al.*, 2006), with researchers suggesting that the use of 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, tourism, sporting goods, automotive, and many other industries (Teece, 1986; Baldwin and Clark, 1997; Suzik, 1999; Avlonitis and Hsuan, 2017).

Despite the rapid increase in the use of product modularity for diverse applications, there is little consensus on its exact role in innovation as a multidimensional construct (Gershenson *et al.*, 2003; Ro *et al.*, 2007). The existing body of literature investigating relationships between product modularity and innovation has so far produced mixed and contradictory results (Langlois and Robertson, 1992; Fleming and Sorenson, 2001). Aggregating potentially different effects of two dimensions into one measurement could cause research findings to be unclear. The literature does provide arguments for different effects of two dimensions of product modularity. Studies have made an effort to bridge the different perspectives on modularity (Ulrich and Tung, 1991; Gershenson *et al*., 2003), but ambiguity in understanding the multidimensional characteristics of this concept remains. We define product modularity as a two-dimensional concept in terms of standardization and reconfigurability, following Gershenson *et al*. (2003) and Salvador (2007). Standardization refers to the extent to which something (e.g., products or software code) is constructed by combining a set of *standardized* components (also called parts) that have been made separately (Pels and Erens, 1992), while reconfigurability is the degree to which the components can be *reused* to facilitate a broad range of new product variations by mixing and matching the modules (Mikkola and Gassmann, 2003). We follow the hierarchical structure of Salvador (2007), which starts with a *product system*, for example, Tesla's car model Y, of which there are four *product variants*: rear-wheel drive, long-range rear-wheel drive, long-range all-wheel drive, and performance all-wheel drive, which in turn consist of both different and the same *modules*/subsystems like the chassis, battery, seats, and touch screen interface, which in turn consist of their underlying *components* like for the touch screen interface of glass, wires, and printed circuit board.[1] Modularity at the product (variants) level is the results of the degree of modularity of the underlying modules and components.

One key reason for adopting a two-dimensional definition of modularity is that a product system and its product variants consist of several distinct, integral modules or subsystems that can be both independent and interdependent, to some extent, at the same time (Simon, 1962). This interpretation incorporates, in other words, both standards or decomposition, as well as reconfigurability or reuse. Two different types of well-known modular LEGO elements illustrate the relevance of the distinction between these two dimensions. The first type is the basic LEGO building blocks like the two-by-two and two-by-four bricks, which have both a high degree of standardization (i.e., the way they are shaped and connected to other elements is universal) and reconfigurability (i.e., they can be reused in many compositions). However, the second type—less common and more specialized LEGO elements like car windows and car doors—also has a high degree of standardization (i.e., standardized in shape and a universal way of connecting to other elements), but a lower degree of reconfigurability (i.e., these bricks are used in fewer compositions). Hence, breaking with the last decades of work on modularity, we move beyond the empirical treatment of modularity as a single/joint construct (Salvador, 2007) for the purpose of introducing definitional clarity and structure to guide empirical research.

Regarding the first dimension, standardization, one stream of the literature suggests that it 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). On the other hand, it has also been argued that it can improve an organization's ability to innovate (Ulrich and Eppinger, 2000) 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 (Hargadon and Eisenhardt, 2000). These arguments suggest that standardization could have varying effects on innovation.

Similarly, a theory presents contrasting lines of argumentation for the second dimension of product modularity, reconfigurability. On the one hand, a high degree of reconfigurability is thought to increase the innovation of R&D teams by multiplying design options (Sanderson and Uzumeri, 1995; Ethiraj and Levinthal, 2004). On the other hand, a contrasting stream of research argues that reconfigurability could diminish innovation because reusability leads to similar product design and predictability (Sabel and Zeitlin, 2004; Ernst, 2005).

In a competitive environment, innovation is essential for the competitiveness and survival of organizations (Townsend *et al*., 1998), and organizations aim to achieve various performance

[1] As evident by Tesla cars, where model 3 and model Y not only use the same platform (chassis), but also share many other components, product modularity does not only (have to) pertain to standardized and reused components within a product system, but also across.

Moreover, modules can again contain submodules like the overall battery pack of an electric car, which in turn consists of submodules of batteries, which in turn consist of groups of battery cells, which are in the end composed of minerals.

objectives simultaneously (De Leeuw *et al*., 2014). Novelty (e.g., market newness and patent creation) as a primary innovation objective and the related efficiency (e.g., a productivity concept that relates the output to the used resources) are two central dimensions of innovation performance (Schumpeter, 1934; De Leeuw *et al*., 2014). For organizations, it could be a challenge to balance these two dimensions in their R&D teams (Fox, 2013). It is therefore important to incorporate an additional multidimensional view of the innovation performance.

Combining the two dimensions of product modularity with the two innovation dimensions results in the following research question: *what are the relationships of module standardization and reconfiguration with both innovation novelty and efficiency?*

Investigating this research question is important since innovation is crucial for organizations' survival. The challenges of a competitive environment that is becoming 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 widespread organizational form. It is therefore relevant to study the effects of product modularity on innovation in greater depth.

The principal contribution of this paper is to unpack the understanding of the concept of product modularity by theorizing and investigating the effects of standardization and reconfigurability on innovation. The focus of this study is on the level of the product (variants) and is investigated at a large international supplier in the automotive industry.[2] The level of analyses is on 101 R&D teams, where each team focused on one product. The results of analyzing the two dimensions of modularity show opposing relationships with the two dimensions of innovation. When utilizing a one-dimensional operationalization, the results become incomplete and insignificant since one dimension can obfuscate the effects of the other dimension, or the effects can cancel each other out, resulting in overall nonsignificant findings. Unpacking product modularity into the two dimensions could resolve earlier ambiguities identified in research on product modularity. On the one hand, this means that previous findings could be biased when taking a one-dimensional focus. On the other hand, this calls for future studies to incorporate the two-dimensional approach.

2. Conceptual framework

2.1 Innovation as a multidimensional construct

In the context of knowledge creation and transfer among R&D teams and team members, 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; Hansen, 2002). From a practical point of view, organizations pay attention to both the novelty (e.g., the output like market newness and patents) and the related efficiency (e.g., a productivity concept that relates the output to the used resources) (Mouzas, 2006; De Leeuw *et al*., 2014). Novelty indicates new technologies or products (Garcia and Calantone, 2002; Naranjo-Valencia *et al*., 2011), while efficiency is a concept of how the organization's resources are utilized in providing those new technologies or products (Garcia and Calantone, 2002).

For organizations, success often depends on a balance between both strategies aimed at pursuing novelty and those maximizing efficiency (Ford and Håkansson, 2006). Focusing solely on novelty can result in "unprofitable developments/growth" if the cost is higher than the resulting outcomes or profit (Mouzas, 2006). Conversely, focusing solely on efficiency can result in short-term profitability (Mouzas, 2006) but prevents organizations from achieving differentiation and innovation (Mass, 2005).

[2] Since the focus is on a supplier in the automotive industry, a product (variant) is considered not at the level of the full car (e.g., different models of Tesla's model Y), but at the level of products used in the car, like a gear shifter and a touch screen interface. This shows that, depending on the focus, the "label" on a product/module could be different (e.g., where the focus is on the full car level, a touch screen could be a module, while if the focus is one level deeper, the touch screen could be the product, in turn consisting of other modules, which in turn consist of parts/components).

2.2 Key dimensions of product modularity

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

In a comprehensive literature review on product modularity, Salvador (2007) concludes that product modularity is a set of two different constructs—component separability (primarily associated with a separation of standards) and component combinability (mainly related to reconfigurability of components). In addition to the literature incorporated in that review, other literature can be identified which reflect a similar multidimensional view with minor variances. By one definition, product modularity refers to the use of standardized and exchangeable components (i.e., standardization) that allow the configuration of a wide variety of products (i.e., reconfigurability) (Schilling, 2000). Similarly, Danese and Filippini (2010: 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 or product can be separated (decomposition in standard components) and recombined (reconfigurability of components). As such, both standardization and reconfigurability are a characteristic of the system/product (e.g., a LEGO car), while this is the result of the characteristics of the underlying modules and in turn the parts/components used (e.g., the LEGO bricks example in the introduction) including their interfaces that facilitate interactions/communications between two or more parts/components.

In addition to the differences, both standardization and reconfigurability can have varying degrees (i.e., low to high), which underscores the relevance of theorizing and investigating both. To illustrate this, one can think of a two-by-two matrix of low and high degrees of both standardization and reconfigurability, resulting in four products. First, a low degree of standardization and a low degree of reconfigurability could be a product that uses no or a very limited number of standardized components but, for example, would each time be (mostly) tailor made with different and unique components due to unique requirements of clients. An example is historically grown software code (known as spaghetti code).

Second, and contrastingly, a high degree of standardization and a high degree of reconfigurability could be a product that uses multiple underlying standardized components as the core of the product (e.g., following a prescribed industry standard), while at the same time, the product facilitates additions and modifications beyond the standardized core, which makes it useful for many clients. An example would be the standardized and widely reused 2×2 and 2×4 LEGO bricks.

Third, a high degree of standardization and a low degree of reconfigurability could be a product that uses multiple standardized components and/or follows prescribed industry standards but, for example, would each time be (mostly) tailor made due to unique requirements of clients. Two examples include the LEGO car windows and the LEGO car door elements.

Fourth, we would observe a low degree of standardization and a high degree of reconfigurability in a basic/simple product that uses no or a very limited number of standardized components and, for example, is useful for multiple applications and clients. An example could be the limited standardized near-field communication (which has many degrees of freedom), which is utilized in many different products (e.g., contact payment, product anti-theft labels, and car keys). Another example is a 3D-pen that heats a plastic filling that melts and can be used to "draw" in 3D, of which there are many different forms and shapes and can be used to make all kinds of 2D and 3D designs. Appendix 1 describes four products in detail, one in each quadrant, which are taken from the empirical setting.

Importantly, modularity or modularization occurs within the context of a wider system of technologies and their life cycles, within and across firms (Tee, 2019). In other words, characterizing (and measuring) modularity builds upon existing (historical) systems and context and the fresh start or dramatic re-organization represents an exception rather than the rule of modularization (MacCormack *et al*., 2006). As such, the focus in the remainder of this study is on a mature and stable setting as well as within R&D teams (not across teams or in the interaction with the larger system/organizational level). Moreover, the focus is on the product level that is an aggregation of their underling components.

2.2.1 Module standardization

The first dimension of product modularity, 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). Standardization has been regarded as an essential element for innovation and performance in organizations (Langlois, 2002; Pil and Cohen, 2006). The literature relates 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 and Evans 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 thus refers to the use of common components, in which one of the critical elements is the interface (Lampel and Mintzberg, 1996; Sanchez and Mahoney, 1996; Lee and Tang, 1997), which can be used to combine components (analogous to connecting LEGO bricks).

Impact of module standardization on innovation novelty

This section describes the theorizing on the negative relationship between the degree of standardization and innovation novelty (Uotila *et al*., 2009). Researchers and developers develop new concepts and need to understand existing standards as well as be knowledgeable about compatible boundaries with other components before they are able to apply these standards (Ulrich, 1995; Schilling, 2000), requiring cognitive investments in existing structures. This process of understanding and learning comes at the downside of increasing dedicated development time and raises the effort to acquire the related knowledge. This situation, in turn, reduces the possibilities for the team members to dedicate themselves more deeply to the creation of new ideas, in turn decreasing innovation novelty (Shapiro and Varian, 1999).

Additionally, 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). Given the high complexity of technology development, some argue that it is no longer possible to freeze interface standards as an operationalization of standardization (Ernst, 2005). Since standardization results in frozen interface standards, this means that it is necessary to continuously negotiate adjustments, which takes the focus away from new product development and thus lowers innovation novelty.

Furthermore, R&D processes are to some extent serendipitous, intrinsically unstructured, and consist 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, 1997: 208), which are the very premise of standardization. As a form of centralized control, standardization impedes the novelty of innovative activities (Shalley *et al*., 2004), since it can, for example, result in a thinking-within-the-box mindset, which in turn hampers the development of new concepts and products. A thinking-within-the-box mindset can cause organizations to miss out on value-creating opportunities because it cannot escape the limits of the existing standardization strategies (Brusoni *et al*., 2007) and requires new ideas/products to be compatible with current ones (Ulrich, 1995; Prencipe *et al*., 2003). As such, in a stable and mature setting, standardization could lower an organization's ability to create novel innovations.

Hypothesis 1a: The degree of module standardization has a negative relationship with innovation novelty.

Impact of module standardization on innovation efficiency

Regarding the impact of standardization on innovation efficiency, modularity has traditionally been seen as beneficial based on arguments around efficiency gains in the innovation process. When the degree of standardization increases, the costs of knowledge sharing go down due to the capacity for information hiding inherent in modular designs (Parnas, 1972) as well as obtained knowledge and experience. As such, in addition to the required investments and costs, various positive effects of standardization come into play regarding innovation efficiency.

Increasing levels of 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 standardization accelerates autonomous innovation, that is, innovation efficiency through requiring little (cognitive) coordination among teams (Langlois, 2002).

In line with this, a reduction in complexity through increasing levels of 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 solve problems more quickly and reliably (i.e., lower costs) and thus enhances innovation efficiency (Baldwin and Clark, 2000).

Additionally, increasing levels of standardization allow a product to be independently and synchronously deconstructed into a set of smaller, de-coupled subsystems, different team designs, and test modules. This approach reduces the time and cognitive effort that needs to be dedicated to designing products (Sanchez and Mahoney, 1996; Sanchez, 1999) as well as the need to spend time coordinating with other parties, and thus innovation efficiency is increased. In summary, in a stable and mature setting, standardization could improve an organization's innovation efficiency.

Hypothesis 1b: The degree of module standardization has a positive relationship with innovation efficiency.

2.2.2 Module reconfigurability

The second dimension of product modularity, reconfigurability, is one of the most commonly understood aspects of product modularity and refers to the degree of reuse of product components/parts for forming new product variations. Products are modular when diverse product configurations can be obtained from mixing and matching components or modules (as a collection of 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 reconfigurability 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 products/lines or use them for future product development projects (Mikkola and Gassmann, 2003).

Impact of module reconfigurability on innovation novelty

With regard to the relationship between the degree of reconfigurability and innovation novelty, numerous studies have argued that reconfigurability in R&D promotes innovation novelty (Shapiro and Varian, 1999; Ethiraj and Levinthal, 2004; Mikkola, 2006). The number of design options that developers need to consider is reduced when they are working with reconfigurability since the workload involved in finding design solutions or solving problems is correspondingly lower (Pil and Cohen, 2006). Consequently, organizations can create innovation through rapid trial-and-error learning (Langlois and Robertson, 1992; Sanchez, 1999; Baldwin and Clark, 2000). Trail-and-error learning is useful to develop new concepts and products, which in turn suggests that reconfigurability enhances an organization's ability to find a suitable product design, leading to better product innovation performance (Pil and Cohen, 2006). This trial-and-error process helps create new product ideas for more innovative modules, enhancing innovation novelty.

In line with the above, by recombining different components and/or modules, additional "combinatorial innovation" can be realized (Shapiro and Varian, 1999; Ethiraj and Levinthal, 2004). This means that developers can try many configurations of existing components and/or modules, while at the same time developing innovative new ones (Mikkola, 2006). This, in turn, results in more creative products being built on the available components and/or modules, increasing the level of innovation novelty.

Additionally, engineers can reconfigure modules or components of prior solutions and due to modularity rely on analogical reasoning to generate new design alternatives, accelerating the rate at which (incremental) innovation improvements are made (Usher, 1954; Clark, 1985). As such, in a stable and mature setting, reconfigurability could improve an organization's innovation novelty.

Hypothesis 2a: The degree of module reconfigurability has a positive relationship with innovation novelty.

Impact of module reconfigurability on innovation efficiency

Related to the above and building upon three lines of argumentation, a positive relationship is also expected between the degree of reconfigurability and innovation efficiency. First, since reconfigurability allows product variety to be managed without an explosion of costs, the literature often associates reconfigurability with decreasing innovation costs and increasing flexibility in resource allocation (Jacobs *et al.*, 2007; Lau *et al.*, 2007). Without such reconfigurability, more intense collaboration across design interfaces would be necessary (Eppinger and Chitkara, 2006), and this would result in increased R&D team collaboration costs. Utilizing reconfigurability could thus reduce R&D collaboration 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 the overall innovation life-cycle costs (Newcomb *et al.*, 1998; Gershenson and Stauffer, 1999) and, in turn, supporting innovation efficiency. For example, reconfigurability can facilitate collaboration among team members as well as guide design and implementation choices. At least when it comes to achieving incremental novelty in the innovation life cycle, reconfigurability can reduce coordination and development costs.

Third, when product variety is required, reconfigurability becomes useful for innovation-related cost-saving activities (Hillstrom, 1994). Numerous of these advantages of reconfigurability have been reported, such as increasing reuse and remanufacturing in both product development and retirement (Graedel and Allenby, 1996) as well as achieving reductions in innovation investment costs (Fisher *et al.*, 1999). Thus, reconfigurability leads to greater flexibility in terms of responding to changes and a reduction of development costs and, ultimately, innovation efficiency (Hopwood, 1995; Sosale *et al.*, 1997). In summary, in a stable and mature setting, reconfigurability could improve an organization's innovation efficiency.

Hypothesis 2b: The degree of module reconfigurability has a positive relationship with innovation efficiency.

3. Research design

3.1 Context and data

The empirical testing was conducted (pre-Covid) in a leading large multinational organization that produces products for the automotive industry (e.g., driver-assist cameras, gear shifters, steering columns, headlights, switch panels, touch screen interfaces, and rain sensors). The organization has R&D teams distributed across three global regions (i.e., Europe, America, and Asia). Previous innovation and organization studies have used a similar strategy of focusing on leading organizations in an industry (Gulati and Gargiulo, 1999; De Leeuw *et al.*, 2019) as it allows the exploration of organizations in a favorable innovation context and ensures the availability of data. 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 innovations/patents, and broadly applies the modularity concept (Fixson *et al.*, 2005; Ro *et al.*, 2007; Schulze *et al.*, 2015; Jacobides *et al.*, 2016).

The unit of analysis was the product innovation being developed by different R&D teams that develop different kinds of technical products with a different degree of product modularity. 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). Within the organization, each R&D team was working dedicated to one product (i.e., a one-to-one relationship between the team and the product).[3] The R&D teams are working on complex products, which, on average, take almost 20 months to develop. This type of team setting is very common in the automotive supplier industry. Team members enjoy a high degree of specialization (e.g., software or hardware specialist) (Carnabuci and Bruggeman, 2009), work on one product development aspect, and will collaborate solely within the team on the development of a defined product during the period of development.

To test the hypotheses, a structured questionnaire (Appendix 4) was sent to the R&D team members. Participants are 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 heterogeneous. The questionnaire was pretested with team members from different regions, whereupon the questionnaire was slightly modified to prevent ambiguity in the questions used.

In an effort to select the most representative sample, a list of all the projects that have passed the initiation phases (i.e., technical orientation, idea generation, multiple rounds of first concept designs, market research, and initial idea selection) was made.[4] From that list, very small projects and projects that were not related to team activities were excluded. To prevent an overrepresentation of successful projects, projects in all three phases beyond the initiation phases of development (i.e., detail design, validation, and start of production) were included. This resulted in a list of 140 projects, and the organization provided the contact details of all team members per project.

It was 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 questionnaire collection took 6 weeks. A reminder was sent to respondents who had not answered after 3 weeks. There were no significant differences between early and late respondents (comparing the average response values on the key variables of interest, i.e., innovation novelty, innovation efficiency, standardization, and reconfigurability), which might suggest 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 49.93%. For 101 teams, one or more useful responses were received, with an average number of three to four respondents per R&D team. These 101 projects were relatively equally distributed across the three latest phases of development (i.e., 34 in the further description phase, 36 in the validation phase, and 31 in the start of production phase), which increases the representativeness by incorporating products in the final production phase. Comparing the means and variances of the two innovation variables also shows comparable numbers across these three phases, which does not seem to indicate systematic differences across the different stages regarding the assessment ability of the employees.

[3] The focus of this study is on teams working on independent products and not on the relationships of these products to the larger system. As such, the measurements relate to internal aspects of each product, and not to the interface between the products and the larger system or with other products.

[4] After a successful initiation phase, the project is awarded/given a go, meaning that the organization would move forward with the next phases of development, which consist of further detailing the product, a validation phase, and finally the start of production. Together, this would take, on average, about 20 months. As such, the R&D team members are able to make and proper estimation of the expected novelty, efficiency, and levels of standardization and reconfigurability. The more toward the latest phases of development, the more the data would evolve from estimations toward real figures.

3.1.1 Level of analysis

The literature 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; Carnabuci and Operti, 2013; Sandberg *et al*., 2015). This is also the focus of this study (Gershenson *et al*., 2003; Pil and Cohen, 2006).[5] As described, the data were collected from R&D teams that are working on developing product innovations with different degrees of standardization and reconfigurability. See Appendix 4 for the full questionnaire.

To prevent potential issues with regard to data aggregation to the team level, multiple recommendations and checks for allowing such aggregation were fulfilled (i.e., product and team-level focus in a questionnaire, inter-rater agreement of >0.8, intra-class correlation (ICC) of 0.75, averaging scores, and a low Harman's single factor score), which are described in detail in Appendix 2.

3.2 Research variables and measures

This study relied on existing scales from the literature to operationalize the variables, described in more detail below. The questions were mostly rated on a seven-point Likert scale.

3.2.1 Dependent variables

Innovation novelty was operationalized as the combination of two elements: market newness and patent creation (Griliches, 1990; Katila, 2000; Wang and Ellinger, 2011). Regarding the first element, market newness assesses whether, during the product development period, the product contains any new technologies for that particular market (Schwartz *et al*., 2011; Yin *et al*., 2011). Four questions were used: (i) "This product is new to the market or customer" (Jansen *et al*., 2006); (ii) "The product possesses technical specifications, functionalities, components, or materials differing from the current ones" (Gunday *et al*., 2011); (iii) "The product we developed is the first of its kind" (Darroch, 2005); and (iv) "The product has unique features to the market or customer" (Garcia and Calantone, 2002).

The second element, patent creation, refers to the number of patents applied for or current and potential innovation patents during the product development time (start of project until start of mass production) (Werner and Souder, 1997; Chiesa *et al*., 2009; Jalles, 2010). Two questions were used: (i) "This product has or is acquiring patents" (Wang and Ellinger, 2011) and (ii) "The product has patentable innovations" (Lau *et al*., 2007). The overall measure was constructed by taking the average value of the total six questions, which were all measured at a seven-point Likert scale ranging from strongly disagree (1) to strongly agree (7).

Innovation efficiency was operationalized based on three questions, adapted from Garcia and Calantone (2002), designed to quantify new product revenues and/or patentable discoveries both related to R&D costs: how would you rate the level of achievement of the following performance items in your current product in development?—(i) the product's revenue generation compared to the R&D expenditure; (ii) the product's patentable discoveries by R&D expenditure (Naranjo-Valencia *et al*., 2011); and (iii) 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 theaverage of these three questions, which were all measured on a seven-point Likert scale ranging from very unsuccessful (1) to very successful (7). See Appendix 4 for the full questionnaire.

The construct validity of the two dependent variables was verified through factor analysis and a two-factor solution provided the best results. All question factor loadings were above 0.719 and confirmed that the six questions used to measure innovation novelty and the three used for innovation efficiency had convergent and discriminant validity (i.e., the answers to these questions belong together within one factor/variable and do not belong to the other). This means that the

[5] Under the collaborative R&D team context, considering innovations at the component or module level would not affect our hypothesis and results differently, since this study investigates an innovation context that does not (rapidly) change the system architecture. Innovation at the component or module level can eventually result in changes within the system architecture without altering its overall design (Henderson and Clark, 1990). Changes at the system architecture level are beyond the scope of this study and the cross-sectional nature of the data matches with this.

answers to the related questions fell into the related factor, confirming the theoretical intended structure (i.e., two distinct dependent variables). Reliability was evaluated through both the composite reliability score for each variable and Cronbach's alpha. Cronbach's alpha values for the two dependent variables, innovation novelty and innovation efficiency, were 0.826 and 0.763, respectively, indicating that the items were internally consistent and therefore the constructs were reliable (Streiner, 2003; Hair *et al.*, 2006).

3.2.2 Independent variables

The two dimensions of product modularity, standardization and reconfigurability, were measured using existing and adapted questions. Product modularity was defined in 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). Here, the components or units are synonyms and subparts of the larger overall product.

Module standardization was measured at the product level using three questions adopted from previous studies (Jacobs *et al.*, 2007; Lau *et al.*, 2007; Danese and Filippini, 2010): (i) "Product in design uses common component modules" (Danese and Filippini, 2010); (ii) "Product components are standardized" (Lau *et al.*, 2007); and (iii) "Product can be decomposed into separate standard modules" (Lau *et al.*, 2007). The overall measure was constructed by taking the average value of the three questions, which were all measured at a seven-point Likert scale ranging from strongly disagree (1) to strongly agree (7).

Module reconfigurability was measured in line with Lau *et al.*, (2011) and Jacobs *et al.*, (2007) through three adapted questions: (i) "Components are interchangeable across different products" (Jacobs *et al.*, 2007); (ii) "Product components can be reused in other products" (Lau *et al.*, 2007); and (iii) "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, which were all measured at a seven-point Likert scale ranging from strongly disagree (1) to strongly agree (7).

The construct validity of the two independent variables was verified through factor analysis and a two-factor solution provided the best results, supporting the two-dimensional approach. All question factor loadings were above 0.702 and confirmed that the three questions used to measure standardization as well as the three used for reconfigurability had convergent and discriminant validity (i.e., the answers to these questions belong together within one factor/variable and do not belong to the other). This means that the answers to the related questions fell into the related factor, confirming the theoretical intended structure (i.e., two distinct independent variables). Regarding reliability, Cronbach's alpha values for the two constructs, standardization and reconfigurability, were 0.618 and 0.805, respectively, indicating that the items were internally consistent and that the constructs were reliable (Streiner, 2003; Hair *et al.*, 2006).

3.2.3 Control variables

The analyses incorporated eight control variables based on the literature. See Appendix 4 for the full questionnaire. First, *experience at the company*, as it is often argued that the level of innovation outcomes of teams decreases with their experience (Kratzer *et al.*, 2004). It was measured by asking the number of years since joining the organization.

Second, *total experience* may influence innovation because more experienced employees may benefit more from interactions with other coworkers or may require fewer interactions to accomplish their tasks effectively and efficiently (Young-Hyman, 2017). Total experience was measured by asking the total number of years since the start of their professional career.

Third, *team size*, since team size may affect group dynamics (Pelled, 1996) and influence team interaction and communication (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 by asking the number of people involved in the team (in line with Ancona and Caldwell, 1992; Pelled, 1996; Tsai, 2000; Van Der Vegt and Janssen, 2003).

Fourth, *project length*, which is an essential 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, which can result in higher degrees of novelty. Time is needed as an incubation mechanism to articulate ideas, provide input, identify challenges, and innovate (West, 2002). Project length was measured by asking the project length in months (from nomination to standard operating procedure), adapted from Lovelace (1986), Kim and Oh (2002), and Tiwana (2008).

Fifth, the *number of fields of experience*, since different levels of experience with diverse domains and technologies play roles in the interactions with team members (Staples *et al*., 1999; Kirkman *et al*., 2004). Less technically experienced team members may be less inclined or able to communicate and form useful relationships, which could diminish innovation (Patel *et al*., 2012). It was measured by asking the number of fields in which the employee has gathered prior work experience: mechanics; software; project management; systems engineer; hardware; PCB layout; testing; other, please indicate (Staples *et al*., 1999).

Six, the *number of roles* in the project, since, on the one hand, the variety of roles allows teams to be more adaptable and flexible to respond to problem-solving demands, which improves innovation outcomes (Cavalluzzo and Ittner, 2004; Salas *et al*., 2005a). On the other hand, team members may experience higher workloads and pressure than when dedicating themselves to only one role, which in turn can negatively affect their ability to dedicate themselves to innovation activities (Shea and Guzzo, 1987; Hackman, 1990; Klein, 2001). It was measured by asking the role(s) in this project: hardware; mechanics; software; testing; systems engineer; PCB layout; project manager; other, please indicate.

Seventh, the *level of education*, since the literature suggests that the best researchers/developers typically innovate and perform better than others, which is usually attributed to differences in cognitive abilities (Moilanen *et al*., 2014). Consequently, the degree of contribution to innovation is likely to depend on the level of education (Kafouros, 2008). It was measured by asking the level of education: (i) mid. school, (ii) bachelor, (iii) master, and (iv) PhD (Bozionelos, 2008). Dummy variables were created for these four levels, with a value of 1 if one or more team members obtained that level (0 otherwise).

Eighth, *geographical dispersion*, to capture the distribution across the three main R&D center locations within the organization (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 locations, i.e., ranging from 1 (team members are all in the same location), 2 (team members are across two different locations), and 3 (team members are across three different locations [adapted from Magni *et al*., 2013]).

4. Analysis and results

4.1 Descriptive statistics and checks

Table 1 reports the descriptive statistics of and correlations between the variables. Regarding the descriptive statistics, for example, the averages of the dependent and independent variables were all between 3.65 and 4.89 on a seven-point Likert scale, the average team size was seven members, and the average total team experience was over 15 years.

Some significant correlations are to be expected like the correlations between the bachelor level of education and the master level (−0.30), between project length and team size (0.42), and total experience and experience within the company (0.39). However, a number of potentially important correlations are also presented: a correlation of 0.44 between the two innovation outcomes and a correlation of 0.43 between standardization and reconfigurability, which could raise potential issues of common method bias and/or interdependence between these variables. Although the two described factor analyses clearly show two distinct variables for both the two innovation outcomes (Section 3.2.1) and the two modularity measures (Section 3.2.2), multiple analyses have been conducted to investigate the potential issues of common method bias and the relatedness between the variables (i.e., multicollinearity).

Regarding the potential impact of common method bias, the design of the data collection limits the potential biases of individual respondents (e.g., answering based on an agreement bias) since the final measures were aggregated from the individuals to the team level (Section 3.1). This aggregation (i.e., taking the mean of the individual team members) mitigates the potential biases from some individuals. Additionally, Harman's single factor score was calculated to assess

Table 1. Descriptive statistics and correlations

Variable	Min.	Max.	Mean	Std. dev.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. Innovation novelty	1.25	7.00	3.65	1.23	1														
2. Innovation efficiency	1.00	7.00	4.57	0.86	0.44*	1													
3. Standardization	1.00	7.00	4.78	0.98	−0.16	−0.14	1												
4. Reconfigurability	2.00	7.00	4.89	1.04	0.15	0.22*	0.43*	1											
5. Experience at company	1.00	21.75	9.81	4.33	0.24*	0.08	−0.08	−0.05	1										
6. Total experience	5.00	34.00	15.17	5.54	−0.08	−0.20*	−0.04	−0.16	0.39*	1									
7. Team size	1.00	22.00	7.06	4.07	0.12	0.04	0.08	0.03	0.32*	0.25*	1								
8. Project length	3.00	37.00	19.65	7.06	−0.02	0.09	−0.25*	−0.12	0.17	0.18	0.42*	1							
9. Number of fields of experience	1.00	6.00	2.27	1.08	0.08	0.20*	0.25*	0.25*	0.07	0.06	0.09	−0.11	1						
10. Number of roles in project	1.00	4.00	1.37	0.54	−0.01	−0.28*	0.21*	0.22*	0.16	0.13	0.21*	−0.26*	0.17	1					
11. Education: mid. school	0.00	1.00	0.66	0.47	0.04	−0.06	−0.10	−0.10	0.12	0.04	0.09	0.12	−0.08	−0.09	1				
12. Education: bachelor	0.00	1.00	0.94	0.24	−0.22*	−0.19	−0.14	−0.10	−0.03	0.05	0.02	0.08	−0.08	−0.04	0.15	1			
13. Education: master	0.00	1.00	0.88	0.32	0.10	0.17	0.06	−0.07	0.08	0.07	−0.01	−0.11	−0.01	−0.10	0.17	−0.30*	1		
14. Education: PhD	0.00	1.00	0.66	0.48	0.05	0.02	−0.14	−0.19	0.03	0.03	0.07	0.18	0.01	0.02	0.11	0.04	0.06	1	
15. Geographical dispersion	1.00	3.00	1.55	0.57	−0.16	−0.15	−0.11	−0.14	0.08	0.15	−0.08	0.09	−0.03	0.03	0.16	0.18	0.36*	0.18	1

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

Table 2. Main regression results with module standardization, reconfigurability, innovation novelty, and innovation efficiency

	Innovation novelty				Innovation efficiency			
Variables	**M1**	**M2**	**M3**	**M4**	**M5**	**M6**	**M7**	**M8**
Standardization		−0.30*		−0.41**		−0.17*		−0.27**
		(0.13)		(0.14)		(0.09)		(0.09)
Reconfigurability			0.16	0.29*			0.19*	0.28***
			(0.13)	(0.13)			(0.08)	(0.08)
Experience at company	0.08**	0.08*	0.08**	0.07*	0.04 t	0.03	0.04 t	0.03
	(0.03)	(0.03)	(0.03)	(0.03)	(0.02)	(0.02)	(0.02)	(0.02)
Total experience	−0.04	−0.04 t	−0.03	−0.03	−0.04*	−0.04**	−0.03*	−0.03*
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.01)
Team size	0.03	0.04	0.03	0.04	0.01	0.02	0.01	0.02
	(0.04)	(0.04)	(0.04)	(0.04)	(0.02)	(0.02)	(0.02)	(0.02)
Project length	−0.01	−0.02	−0.01	−0.03	0.01	0.01	0.01	0.00
	(0.02)	(0.02)	(0.02)	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)
Number of fields of experience	0.06	0.11	0.03	0.07	0.19*	0.22**	0.15*	0.18*
	(0.11)	(0.11)	(0.12)	(0.11)	(0.07)	(0.07)	(0.07)	(0.07)
Number of roles in project	−0.16	−0.10	−0.23	−0.20	−0.45**	−0.42*	−0.53**	−0.51**
	(0.26)	(0.25)	(0.26)	(0.25)	(0.17)	(0.17)	(0.17)	(0.16)
Education: mid. school	0.12	0.09	0.13	0.10	−0.26	−0.28	−0.25	−0.27
	(0.40)	(0.39)	(0.40)	(0.38)	(0.26)	(0.26)	(0.25)	(0.24)
Education: bachelor	−0.50	−0.55	−0.48	−0.54	−0.16	−0.20	−0.14	−0.18
	(0.37)	(0.36)	(0.37)	(0.35)	(0.24)	(0.24)	(0.23)	(0.22)
Education: master	0.22	0.27	0.22	0.29	0.40 t	0.42*	0.40*	0.44*
	(0.32)	(0.31)	(0.32)	(0.30)	(0.21)	(0.20)	(0.20)	(0.19)
Education: PhD	0.37	0.27	0.47	0.42	0.13	0.07	0.26	0.22
	(0.43)	(0.42)	(0.43)	(0.42)	(0.28)	(0.27)	(0.28)	(0.26)
Geographical dispersion	−0.36	−0.39	−0.34	−0.36	−0.25	−0.27 t	−0.23	−0.25
	(0.25)	(0.24)	(0.25)	(0.24)	(0.16)	(0.16)	(0.16)	(0.15)
Constant	4.32***	5.78***	3.57***	4.95***	5.03***	5.87***	4.15***	5.09***
	(0.77)	(0.99)	(0.96)	(1.03)	(0.50)	(0.65)	(0.61)	(0.65)
Observations	101	101	101	101	101	101	101	101
R^2	0.17	0.22	0.19	0.27	0.29	0.32	0.33	0.40
$P > F$	0.08	0.03	0.08	0.01	<0.001	<0.001	<0.001	<0.001
Adj R^2	0.07	0.11	0.08	0.16	0.20	0.23	0.24	0.31
AIC	332	328	332	324	244	242	240	231
BIC	363	362	366	361	276	276	274	267

t = $p < 0.10$; *$p < 0.05$; **$p < 0.01$; and***$p < 0.001$
nonstandardized β values for all variables standard errors in parentheses two-sided test.

a potential common method bias. Results indicate that the total variance for a single factor was 25.81% (less than the commonly used threshold of 50%), which suggests that the data and results were not largely affected by common method bias (Podsakoff *et al.*, 2012).

When it comes to the relatedness between the two dependent and two independent variables (i.e., multicollinearity), the effects of standardization and reconfigurability were first analyzed separately (models 2, 3, 6, and 7 in Table 2) and then simultaneously, i.e., controlling for the other dimension (models 4 and 8 in Table 2). The results of the models, which simultaneously incorporate the two independent variables (i.e., models 4 and 8), are corroborated by three of the four models in which only the individual variables are incorporated (i.e., models 2, 6, and 7). A potential explication (i.e., a nonlinear relationship) for the individually insignificant relationship between reconfigurability and innovation novelty (i.e., model 3) is presented in Section 4.3. Further relatedness between the two independent modularity variables is investigated through mediation analyses, which are described in Section 4.3.

In a similar vein, additional analyses were conducted, which incorporated the other dependent innovation variable as a control variable in the analysis. Those results (Appendix Tables A1 and A2) confirm the main findings.[6]

Additionally, to further check the results and potential issues due to correlations between both the two independent and two dependent variable analyses were conducted, which used principal component analysis (PCA) to operationalize the two dimensions of product modularity and the two innovation variables. The PCA with varimax rotation results in orthogonal dimensions, which limits the correlations, and draws out independent aspects. Those results (Appendix Table A3) also confirm the main findings.

Moreover, analyses (Appendix Table A4), where the two dimensions of product modularity are combined into one overall product modularity measure (i.e., a one-dimensional operationalization), show nonsignificant findings, which reinforce the added value of the two-dimensional operationalization (i.e., combining these two distinct dimensions into one obfuscates the relationships). Additionally, analyses (Appendix Table A5), where the two innovation outcome variables are combined into one overall innovation measure, show similar findings in comparison to the separate models, which confirms the found relationships.

Figure 1 shows the detailed distribution of the data regarding the degrees of standardization and reconfigurability and shows that most data fall in the quadrant high-high degrees, while data are also present in the other quadrants, confirming the added value to the focus on the two dimensions. However, the figure also highlights potential outliers like the observation in the upper left quadrant. To investigate the potential impact of these outliers, all observations with a value of 1 or 7 (i.e., the lowest/highest values of standardization and or reconfiguration) were removed. The results (Appendix Table A6) show similar findings, which suggest that the relationships are not strongly influenced by those potential outliers.

4.2 Regression results

Ordinary least squares (OLS) regression analysis was performed to investigate the relationships between standardization and reconfigurability (the two independent variables) and innovation novelty and efficiency (the two dependent variables). Since the innovation measures could theoretically be considered to not be a fully continuous variable (Section 3.2.1), the analyses were reanalyzed with ordered logistical regressions. The results are presented in Appendix Table A7 and show similar findings.

Moreover, the assumptions of OLS regression were checked and showed no major issues. First, Shapiro–Wilk tests for normal data conducted on the residuals were insignificant (e.g., model 4: $P = 0.73$; model 8: $P = 0.91$), indicating that the residuals are normally distributed. This is confirmed by both the Q–Q plots, which show that the plotted residuals are on or very close to a straight line at a 45° angle, and histograms (including a normal distribution overlay) of the residuals, which appear normally distributed. Second, RF plots, visualizing the residuals against fitted values, show random values, which indicate independency of the residuals. Third, Breusch–Pagan/Cook–Weisberg tests for heteroskedasticity, however, are insignificant for the models with innovation novelty as the dependent variable (e.g., model 4: $P = 0.04$;) but nonsignificant for the models with innovation efficiency (e.g., model 8: $P = 0.89$). The assumption of homoscedasticity (the opposite of heteroskedasticity) is less critical than the previously checked assumptions because regression is fairly robust to this violation (Zeith, 2006). Moreover, the OLS beta coefficients are not affected (i.e., remain unbiased) when heteroskedasticity is present (i.e., in the innovation novelty models), but the standard errors might be wrong (Zeith, 2006). Therefore, those models were reanalyzed with robust standard errors and the results are comparable, i.e., in model 4, the effect of standardization remains negative and significant (β standardization = −0.41, $P = 0.005$), while reconfigurability remains positive and significant (β reconfigurability = 0.29,

[6] The relationships between standardization and both innovation novelty and innovation efficiency as well as between reconfigurability and innovation efficiency are confirmed. However, the relationship between reconfigurability and innovation novelty becomes insignificant (see model 6). Further investigation revealed that this might be due to a potential nonlinear relationship (see model 7). This potential curvilinear relationship is further investigated and elaborated on in Section 4.3.2.

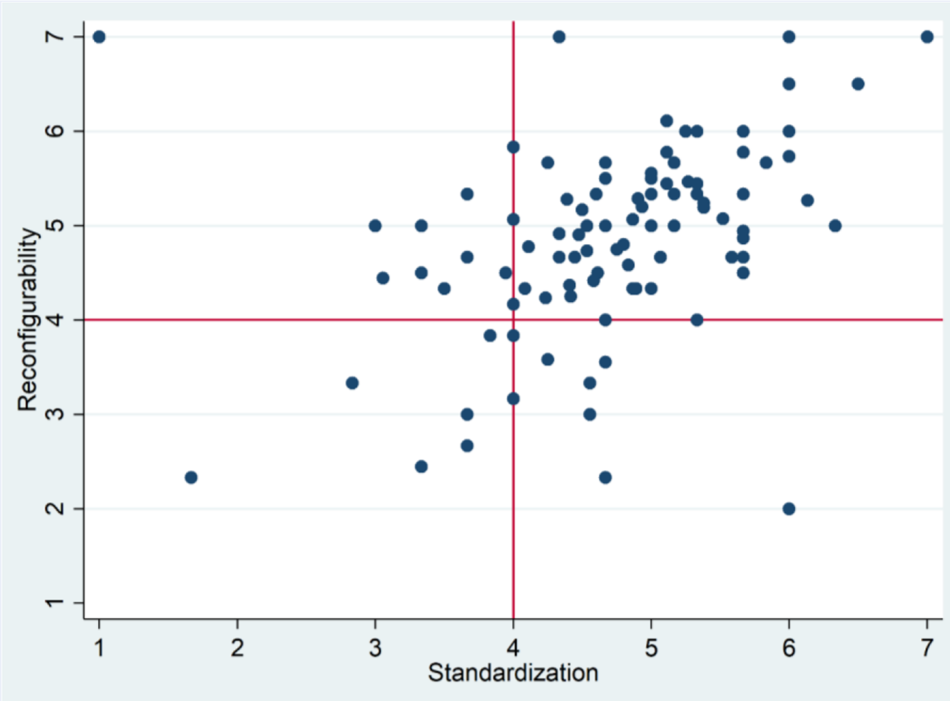

Figure 1. Empirical degrees of module standardization and reconfigurability

$P = 0.025$)., which indicates that the results are not influenced by heteroscedasticity. Fourth, the Ramsey (1969) regression specification-error tests were not significant, which indicates that there are no omitted important variables. Fifth, the variance inflation factors are calculated after each regressions model. The Variance Inflation Factors of all variables are below 1.76 (with a mean of 1.38), suggesting limited concerns of multicollinearity, as indicated by Zeith (2006), which noted no issues regarding potential multicollinearity.

Table 2 presents the main results of the regression analyses for both innovation novelty (models 1–4) and efficiency (models 5–8). With the exception of modules 1 and 3, all other models are significant. Models 1 and 5 are the baseline modes with only the control variables to facilitate the comparison of stability of their relationships with the other models, which are stable (i.e., checking that no variable coefficients "switch signs" in the models, given the potential correlations between control and predictor variables).

As was mentioned in Section 4.1, standardization and reconfigurability are first investigated individually and then simultaneously. The model sequence thus started with the individual incorporation of standardization (models 2 and 6) and reconfigurability (models 3 and 7). In models 4 and 8, standardization and reconfigurability were simultaneously incorporated.

Regarding the control variables, it is interesting to observe that there are differences between their relationships with the two innovation variables. Experience at the company has a positive relation with novelty, but a nonsignificant one with efficiency, while total experience has a nonsignificant relation with novelty, but a negative one with efficiency. Moreover, the number of fields of experience (positive), number of roles in the project (negative), and master level of education (positive) have a significant relationship with efficiency, but all are nonsignificant for novelty. These differences highlight the added value of the incorporation of these control variables as well as the relevance of differentiating between innovation novelty and efficiency.

Focusing on innovation novelty (models 1–4), model 4 is the model with the highest adjusted R^2 (16%) as well as the best relative quality based on the lowest value of both the Akaike information criterion (AIC) (AIC: 324) and Bayesian information criterion (BIC) (BIC: 361). With

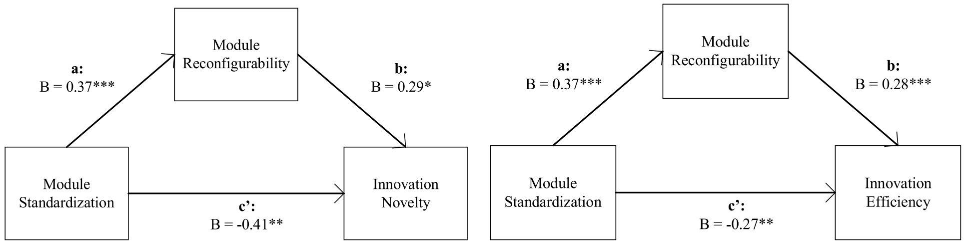

Figure 2. Mediation analyses: Standardization through Reconfigurability

regard to innovation efficiency (models 5–8), model 8 has the highest adjusted R^2 (31%) as well as the best relative quality based on the lowest value of both the AIC (AIC: 231) and BIC (BIC: 267).

Focusing on the degree of standardization in these two models, the results confirm Hypothesis 1a, which theorized a negative relation with innovation novelty (model 4: β standardization = –0.41, $P = 0.004$), but rejects Hypothesis 1b, which theorized a positive relation with innovation efficiency (model 8: β standardization = –0.27, $P = 0.002$).

Focusing on the degree of reconfigurability, these two models confirm Hypotheses 2a and 2b, which both theorized a positive relation with innovation novelty (model 4: β reconfigurability = 0.29, $P = 0.024$) and innovation efficiency (model 8: β reconfigurability = 0.28, $P = 0.001$).

4.3 Other post hoc analyses: mediation, curvilinear, and relative effects

The results reveal a puzzle; in contrast to the theorizing leading to hypothesis 1b, why is the relationship between standardization and innovation efficiency negative? In addition, when investigating reconfigurability in isolation, model 3, in Table 2, shows a nonsignificant coefficient. Although this is to be expected in models where the variables are related, analyses to explore curvilinear relationships do provide an additional explanation. Therefore, in addition to the post hoc analyses already described in Section 4.1, three additional post hoc analyses were conducted (i.e., mediation analyses, curvilinear relationships, and relative effects), which are described below.

4.3.1 Mediation analyses: standardization → reconfigurability → innovation

One could argue that without standardization there is no reconfigurability. As such, it is interesting to investigate if there is a positive indirect effect of standardization through reconfigurability on innovation. If this would be the case, it could offer a partial explanation for the negative direct effect, as standardization is then a cost to make, before the benefits of reconfigurability can be utilized. Figure 2 shows the results of two mediation analyses: on the left on innovation novelty and on the right on innovation efficiency. The coefficients of the paths b and c' can also be observed in model 4 (innovation novelty) and model 8 (innovation efficiency), shown in Table 2.

Following Baron and Kenny (1986), the total effect (c) consists of a direct effect (see above path: c') and a potential indirect effect. This indirect effect can be calculated by multiplying the relationships to and from the mediator (i.e., reconfigurability), see above paths a and b.

For innovation novelty (the figure on the left), the indirect effects is $a \times b$: $0.37 \times 0.29 = 0.11$. The Sobel, Delta, and Monte Carlo tests (Goodman, 1960; Sobel, 1982; MacKinnon *et al.*, 1995) all show that the indirect effect of 0.11 with a standard error of 0.05 (and a 95% confidence interval: 0.01–0.21) is significant with $P = 0.04$. Following Sobel (1982), calculating the ratio between the indirect effect and the direct effect (i.e., 0.11/0.41 = 0.27) reveals that the mediated/indirect effect is smaller than the direct effect (i.e., about 0.3 times the size of the direct effect). The total effect is then as follows: the direct effect (–0.41) + the indirect effect (0.11) = –0.3, which can also be observed in model 2, shown in Table 2.

For innovation efficiency (the figure on the right), the indirect effects is $a \times b$: $0.37 \times 0.28 = 0.10$. The Sobel, Delta, and Monte Carlo tests (Goodman, 1960; Sobel, 1982; MacKinnon *et al.*,

1995) all show that the indirect effect of 0.10 with a standard error of 0.04 (and a 95% confidence interval: 0.03–0.18) is significant with $P = 0.008$. Following Sobel (1982), calculating the ratio between the indirect effect and the direct effect (i.e., 0.10/0.27 = 0.37) reveals that the mediated/indirect effect is smaller than the direct effect (i.e., about 0.4 times the size of the direct effect). The total effect is then as follows: the direct effect (–0.27) + the indirect effect (0.10) = –0.17, which can also be observed in model 6, shown in Table 2.

Combined these mediation analyses reveal that the positive mediated/indirect effect through reconfigurability offers a partial explanation for the negative relationship of standardization on the two performance dimensions, although a larger part of the negative direct effect remains. As such, the standardization could partly be seen as an investment or cost to enable or facilitate the positive effects of reconfigurability.

4.3.2 Curvilinear relations

Curvilinear relationships could offer an (partial) explanation for the puzzling negative relation between standardization and innovation efficiency, as well as for the less surprising nonsignificant coefficient of reconfigurability in isolation with innovation novelty. As indicated in the introduction, the literature does provide some arguments of why (high degrees of) standardization might also have negative effects (in addition to the theorized positive effect) and (high degrees of) reconfigurability negative effects (in addition to the theorized positive effects). When those arguments are combined with the linear theorizing, one could argue for potential curvilinear relationships. To investigate this, squared variables of both standardization and reconfigurability have been incorporated, respectively, in models 4b and 8b (Table 3).

For standardization, there does not appear to be a curvilinear relationship since the squared coefficients are nonsignificant. Also the relationship between reconfigurability and innovation efficiency is nonsignificant; however, the relationship with innovation novelty might be curvilinear based on the significant coefficients in model 4b: β reconfigurability linear = 2.18, $P = 0.01$; β reconfigurability squared = –0.21, $P = 0.03$.

To test for the presence of a curvilinear relationship, two more steps, as described in Lind and Mehlum (2010), were followed. First, testing the significance of the lower and upper bound slopes of the potential shape as well as their joint significance. The lower bound slope has a positive significant coefficient of 1.33 ($P \leq 0.01$) and the upper bound slope had a negative but marginally nonsignificant coefficient of –0.79 ($P = 0.056$). The overall test of the presence of an inverted U-shape reveals a P-value of 0.056, which is marginally nonsignificant. Second, checking whether the tipping point (i.e., optimum) falls within the data range. The tipping point lies at 5.14 with a 90% confidence interval, also based on the Fieller calculation, between 4.62 and 7.25, which just falls outside the data range (1–7).

Figure 3 visualizes the relationship of the degree of reconfigurability with innovation novelty. The small gray squares present the bivariate data points at the team level based on the questionnaire. The black curve shows the relationship based on the coefficients. The dashed start and end of the black curve include the slopes of the lower and upper bounds. The dotted lines at the start and end of the curve present the predicted slopes (also based on the coefficients) just before and beyond the data range. The maximum/extreme point with its 90% confidence interval is also incorporated. Overall, these results offer some indication of a potential curvilinear relationship.

These post hoc analyses confirm the linear results of three of the four hypotheses but do not add to the understanding of the puzzling negative relation between module standardization and innovation effectiveness. For Hypothesis 2a, however, the findings might indicate an inverted U-shaped relationship between the degree of module reconfigurability and innovation novelty. This could indicate that a too high degree of module reconfigurability might negatively impact innovation novelty, which offers a potential additional explanation of the nonsignificant linear relationship of module reconfigurability in isolation with innovation novelty. These findings are further discussed in the discussion section.

Table 3. Curvilinear: regression results

	Innovation novelty		Innovation efficiency	
Variables	**M4**	**M4b**	**M8**	**M8b**
Standardization	−0.41**	−1.45 t	−0.27**	−0.44
	(0.14)	(0.77)	(0.09)	(0.50)
Standardization squared		0.13		0.02
		(0.09)		(0.06)
Reconfigurability	0.29*	2.18*	0.28***	0.42
	(0.13)	(0.84)	(0.08)	(0.54)
Reconfigurability squared		−0.21*		−0.02
		(0.09)		(0.06)
Experience at company	0.07*	0.07*	0.03	0.03
	(0.03)	(0.03)	(0.02)	(0.02)
Total experience	−0.03	−0.03	−0.03*	−0.03*
	(0.02)	(0.02)	(0.01)	(0.01)
Team size	0.04	0.02	0.02	0.02
	(0.04)	(0.04)	(0.02)	(0.02)
Project length	−0.03	−0.01	0.00	0.00
	(0.02)	(0.02)	(0.01)	(0.01)
Number of fields of	0.07	0.06	0.18*	0.18*
experience	(0.11)	(0.11)	(0.07)	(0.07)
Number of roles in project	−0.20	−0.09	−0.51**	−0.51**
	(0.25)	(0.25)	(0.16)	(0.16)
Education: mid. school	0.10	0.09	−0.27	−0.27
	(0.38)	(0.38)	(0.24)	(0.24)
Education: bachelor	−0.54	−0.52	−0.18	−0.17
	(0.35)	(0.35)	(0.22)	(0.23)
Education: master	0.29	0.20	0.44*	0.44*
	(0.30)	(0.30)	(0.19)	(0.19)
Education: PhD	0.42	0.41	0.22	0.22
	(0.42)	(0.41)	(0.26)	(0.27)
Geographical dispersion	−0.36	−0.40 t	−0.25	−0.24
	(0.24)	(0.24)	(0.15)	(0.16)
Constant	4.95***	2.88	5.09***	5.08***
	(1.03)	(1.81)	(0.65)	(1.17)
Observations	101	101	101	101
R^2	0.27	0.31	0.40	0.40
$P > F$	0.01	<0.01	<0.001	<0.001
Adj R^2	0.16	0.19	0.31	0.30
AIC	324	322	231	235
BIC	361	364	267	276

t = $p < 0.10$; *$p < 0.05$; **$p < 0.01$; and ***$p < 0.001$
nonstandardized β values for all variables standard errors in parentheses two-sided test.

4.3.3 Relative effects of standardization and reconfigurability

To facilitate a relative comparison of the impact of the independent and control variables on the dependent variable, the analyses were reproduced with standardized beta regression coefficients, see Appendix Table A8. Note that in that table the P values are presented in the parentheses instead of the standard errors. Regarding the relative impact on innovation novelty, model 4 shows that standardization has the largest effect (β standardized = −0.32), followed by the control variable experience at the company (β standardized = 0.26), and reconfigurability (β standardized = 0.25). In contrast and regarding the impact on innovation efficiency, model 8 shows that reconfigurability has the largest effect (β standardized = 0.34), followed by the control variable the number of roles (β standardized = −0.32), and standardization (β standardized = −0.31).

Overall, the results thus confirm the relevance for the two dimensions of product modularity over almost all control variables and show that for innovation efficiency the positive effect of

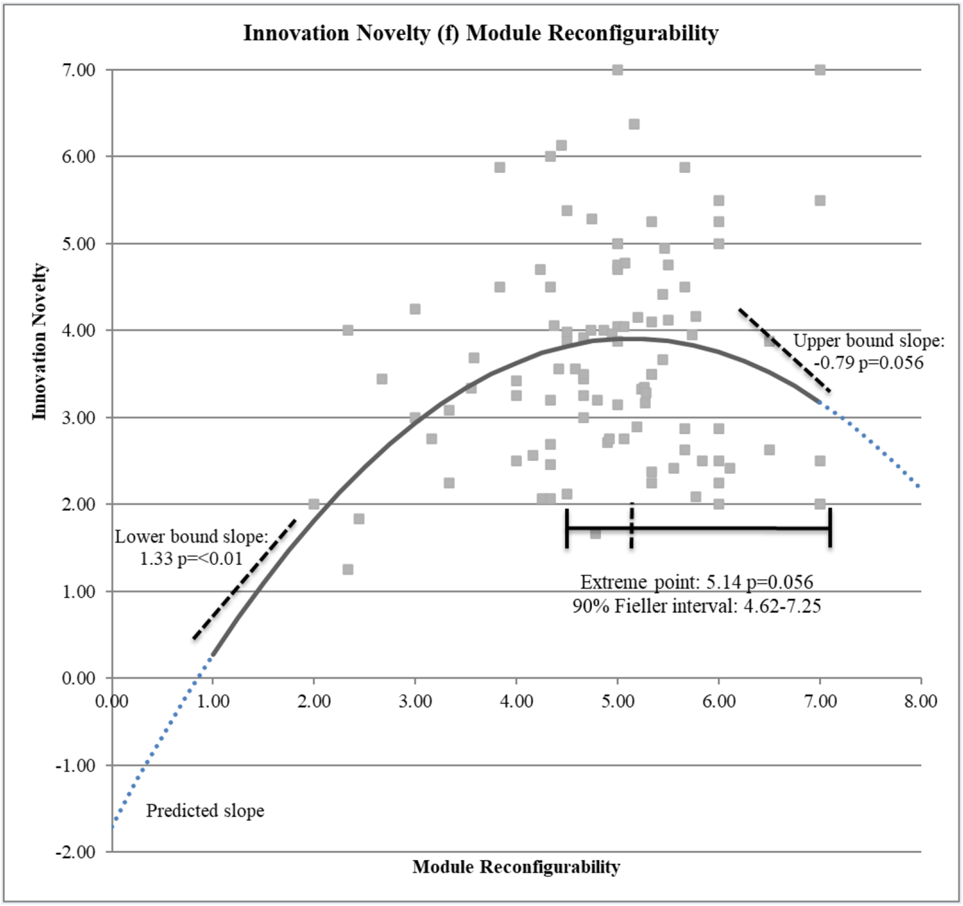

Figure 3. Curvilinear relations of Reconfigurability and Innovation Novelty

reconfigurability is larger than the negative effect of standardization, which could provide a partly explanation for this puzzling negative relation.

5. Discussion and conclusions

This study aimed to unpack product modularity into standardization and reconfigurability and investigated the relationships with innovation novelty and efficiency. The results are in line with the following three theorized relationships: Hypothesis 1a: "The degree of module standardization has a negative relationship with innovation novelty," Hypothesis 2a: "The degree of module reconfigurability has a positive relationship with innovation novelty," while the results of the post hoc analyses indicate that this relationship could be curvilinear (Figure 3), and Hypothesis 2b: "The degree of module reconfigurability has a positive relationship with innovation efficiency." However, for Hypothesis 1b: "The degree of module standardization has a positive relationship with innovation efficiency," the opposite relationship was found (i.e., negative).

The main results in Table 2 confirm the added value of differentiating product modularity into the two dimensions since these seem to have opposing effects. The two-dimensional approach is further corroborated by the factor analyses in Section 3.2.3, which showed two distinct factors. Moreover, the findings are replicated multiple times in the post hoc analyses presented in Appendix 3: Tables A1 and A2, controlling for the other dependent variable; Table A3, dependent and independent variables via PCA; Table A5, combined innovation as one dependent variable;

Table A6, analyses without the outliers; Table A7: ordered logistical regression; and Table A8, which shows the relative importance of these two dimensions over almost all other control variables. Additionally, the post hoc analyses presented in Appendix Table A4 show that if the two dimensions are combined into one variable no significant relationships are found, which shows a risk of obfuscation if the two dimensions are not separated.

Despite this strong support for the two-dimensional approach to product modularity, the negative relationship found between the degree of standardization and innovation efficiency (in contrast to Hypothesis 1b) is puzzling. Although some research has argued that standardization has a negative impact on innovation novelty as well as efficiency (Kaplan and Haenlein, 2006), the negative finding raises the question why there are *no direct benefits of standardization on innovation efficiency*? There are four potential explanations for this puzzle, two based on the post hoc analyses, one related to the operationalization of the innovation efficiency variable, and one related to the empirical setting.[7]

The first partial explanation can be found in the post hoc mediation analyses (Section 4.3.1.), which shoes an indirect positive effect of standardization via reconfigurability. Part of the total effect of standardization runs through reconfigurability and this indirect effect is positive, although the direct negative effect is larger. Since standardization is a prerequisite for reconfigurability, it could be seen as an investment. The costs of standardization (in the form of the negative effect on innovation efficiency) might be needed to enable benefits of reconfigurability (in the form of positive effects on innovation efficiency).

The second partial explanation can be found in the post hoc relative effect analyses (Table A8). Comparing the standardized coefficients of standardization and reconfigurability shows that for innovation efficiency the positive reconfigurability effect is larger in comparison to the smaller negative effect of standardization.

The third potential partial explanation for this puzzling finding might be found in the operationalization of the innovation efficiency variable. As described in Section 3.2.1, the questionnaire contained three questions to operationalize innovation efficiency, which at once captures the ratio between the two aspects: (i) the innovation output and (ii) the related costs in combined questions (e.g., product's patentable discoveries by R&D expenditure). Following the theorization leading to Hypothesis 1a and results (Table 2), an increase in the degree of standardization results in a decrease of innovation novelty, which is the first aspect of the operationalization. The theorizing that also argues for a decrease is the R&D costs (which should lead to an increase of innovation efficiency in line with Hypothesis 1b), which is the second aspect of the operationalization. If in the majority of the R&D projects the decrease of the first aspect would be larger than the decrease of the second aspect, the ratio measure would go down/become lower. This would be in line with the negative relationship found. The operationalization of the two aspects at once limits the possibility for further empirical investigation into this potential partial explanation.

The fourth partial explanation for the puzzling negative finding might be found in the empirical setting, which is a large international supplier in the automotive industry. With the exception of additional features like climate control and automatic windshield wipers, developments have been relatively incremental, and incorporation of radical new technologies has been relatively slow. The literature confirms that 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). This is also confirmed by the average project length of almost 20 months, which is close to 2 years (Table 1). However, in the more recent years this has started to change, and more radical products are being developed and implemented (e.g., automated parking, lane keeping, adaptive cruise control, summoning of the car, and (partial) self-driving).

Therefore, a possible hypothesis is that current standards in the auto industry were designed for a very mature industry, with a defined dominant design, and well-established modules. But recent changes in industry architecture, structure, new technologies, etc., have meant that such standards are now partly becoming outdated and, potentially, even disadvantageous. So, electric cars, digital

[7] The curvilinear post hoc analyses do not contribute to solving the puzzle, since these analyses confirm the linear relationship between standardization and innovation efficiency.

technologies, etc., are forcing changes in standards, which require additional investments since the widespread use of standards brings with it a lengthy and very costly search for new and better architecture (Ernst, 2005). These additional costs and related higher levels of effort might be greater than the innovation benefits (e.g., patents). Since innovation efficiency is influenced by innovation expenditures such as cost, time, and resources (Wheelwright and Clark, 1992), this could result in negative effects on innovation efficiency. In other words, and in line with the third explanation, the ratio of the operationalization of innovation efficiency would become worse.

Together these four explanations offer partial and potential explanations for the puzzling negative relationship between standardization and innovation efficiency, although the results could benefit from a future study to further investigate the relationships (Section 5.3).

5.1 Theoretical implications

The study makes three contributions toward advancing the literature, enhancing the understanding of intra-organizational collaboration in particular for R&D organizations by establishing the effects of standardization and reconfigurability on innovation (i.e., novelty and efficiency) at the team level.

The first and main theoretical contribution is that this is the first empirically tested study to adopt a multidimensional view of product modularity, suggesting that both standardization and reconfigurability matter for innovation and exert distinct and even opposite effects. The multidimensional approach has been identified in theory (Gershenson *et al*., 2003; Salvador, 2007), but (to our knowledge) not previously tested empirically. The existing body of literature investigating relationships between product modularity and innovation has so far produced mixed and contradictory results (Langlois and Robertson, 1992; Fleming and Sorenson, 2001). As mentioned, the additional analyses in Appendix Table A4 show that missing a two-dimensional operationalization results in nonsignificant findings. For both innovation dimensions, the negative (standardization) and positive (reconfigurability) effects seem to cancel each other out, resulting in overall nonsignificant findings. On the one hand, this means that previous findings could be biased when relying on a one-dimensional operationalization of modularity. On the other hand, this clearly shows that future studies would benefit from incorporating the two-dimensional approach.

Second, this study adds to the literature by providing empirical evidence that the degree of reconfigurability has a positive relation with innovation novelty as well as efficiency (Langlois and Robertson, 1992). This result is consistent with the stream of research that supports the adoption of product modularity as an important driver in enhancing, for example, efficiencies (Ulrich, 1994; Gershenson *et al*., 2003; Pil and Cohen, 2006). Specifically, the 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 innovation costs (Newcomb *et al*., 1998; Gershenson and Stauffer, 1999) and supporting innovation.

Moreover, another stream of the literature has claimed that reconfigurability also has adverse effects (Clark, 1985; Fleming and Sorenson, 2001). This research extends and combines the literature by empirically showing that the degree of reconfigurability has a potential inverted U-shaped relationship with innovation novelty. Theoretically, this relationship is the result of simultaneous positive and negative effects. With regard to the positive effects, when the number of design alternatives is increased through reconfigurability (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, and with regard to the negative effects, too much reconfigurability can increase predictability and product similarity (Sabel and Zeitlin, 2004; Ernst, 2005), by reducing the degrees of freedom, which limits product differentiation (Ulrich and Tung, 1991; Robertson and Ulrich, 1998). This lowers the options for new and specifically different opportunities (Fleming and Sorenson, 2001), which negatively affects the generation of new ideas and innovation novelty. The empirical findings indicate, therefore, the need for a potential optimum in the relationship between reconfigurability and innovation novelty. For higher levels of innovation, new products should be developed with a degree of reconfigurability, but only up to a certain optimal level. Beyond this level, reconfigurability becomes counterproductive to innovation novelty. The optimum level in this study was 5.14 (on a seven-point Likert scale). Future studies could examine contingencies and factors influencing the optimum.

The third theoretical contribution relates to the concept of innovation. An argument could be made that innovation research fundamentally describes two kinds of innovation: novelty and efficiency (Plessis, 2007) but that many studies investigate these dimensions separately. Yet, organizations aim to achieve multiple objectives at once (Neely, 1998; Mass, 2005; De Leeuw *et al.*, 2014), and theoretical perspectives on innovation should thus be likewise multidimensional in scope (Mouzas, 2006). This study has fruitfully applied such a perspective to extend the theory of modularity.

5.2 Managerial implications

The arguments and findings presented here can support management practice, although they are quite nuanced. Individually, standardization seems to have a negative relationship with both novelty and efficiency, while reconfigurability has a positive relationship with efficiency and a potential inverted U-shaped relationship with novelty. When looking at a combined effect, some levels of standardization are required to be able to work with reconfigurability. Indeed, there is an indirect positive effect of standardization on both innovation outcomes, which runs (i.e., mediation) through reconfigurability. Together, this shows that organizations should be careful in the way they think about and use modularity to avoid potential pitfalls. Some aspects of modularity have negative effects, while for others, there is a balance to be found, and managers must strive to find the "optimal levels" both for the required level of standardization to facilitate reconfigurability and for an upper level of reconfigurability (to prevent the potential downward slope of the inverted U-shape).

These results suggest to managers that 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, but at the same time this comes at a cost (i.e., the negative effect of standardization). As such, managers should carefully organize their R&D teams around developing standardized components to facilitate reconfigurability.

In addition, for better innovation novelty, new products should be developed with higher degrees of reconfigurability 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 reconfigurability, 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. However, and most importantly, they need to develop a method of balancing the product modularity dimensions (i.e., standardization and reconfigurability) 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 to subsequently improve innovation outcomes.

5.3 Limitations and future research

Despite the interesting findings and contributions, this study has some potential limitations. In hindside, it would have been better to measure the two parts of the innovation efficiency (innovation and costs) separately, which would enable the investigation of the potential different effects on these two parts. This might contribute to further teasing out the puzzling negative relationship between standardization and innovation efficiency, providing an avenue for future research to explore further.

Additionally, due to the cross-sectional survey, there is a risk to miss claiming causality. However, the direction of the 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; Naranjo-Valencia *et al.*, 2011). Longitudinal research assessing the influence of standardization and reconfigurability over time would provide additional and even stronger support for the effects reported here. Additionally, this would provide the opportunity to investigate the interplay between changes in the degree of modularity at the product level and developments at other levels (Sosa *et al.*, 2003) like the system or organizational level. Moreover, it would be interesting to investigate the relationships in other industries while incorporating potentially interesting moderating variables like product characteristics, which could influence these relationships like technological factors (e.g., weight or size limitations of products), which could influence/limit the degree of the product modularity dimensions (Hölttä-Otto and de Weck, 2007).

Moreover, the emergence of modularity (the creation of standards and use of reconfigurability) depends on the maturity and organization of the research setting regarding working with product modularity. In other words, both the creation of standards and reuse (or design rules) depends on how product development is organized (Brusoni and Prencipe, 2006; MacCormack *et al.*, 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 significant impact on modularity (MacCormack *et al.*, 2006). A fascinating question in the research agenda is about what comes first: reconfigurability 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 relates to modularity along both dimensions.

Finally, there are organizational implications outside 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. Another interesting research direction would be the investigation of the potential moderating influence of the level of uncertainty and complexity. This could provide fodder for the design and development of organizational structure and settings that help promote innovation in new R&D teams.

To conclude, this study investigated the impact of two dimensions of product modularity: standardization and reconfigurability on both innovation novelty and efficiency in R&D teams. The results of this study conclude that standardization (as costs) has a negative effect, while reconfigurability (as benefits) can be beneficial to innovation novelty and efficiency. 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 further study the effects of product modularity on innovation in the R&D team context, and the multidimensional approach to modularity that we pilot here empirically should provide a promising research agenda.

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Appendix 1

Four examples of different degrees of product modularity and reconfigurability

To illustrate the importance of the distinction between these two dimensions, as well as an illustration of different degrees of both dimensions, Figure A1 shows four R&D products taken from the empirical setting of this study (i.e., a supplier in the automotive industry), which show varying degrees of standardization and reconfigurability (i.e., low or high). The usage of a questionnaire to measure the degree of both standardization and reconfigurability at the product level, enabled us to select these four products based on the answers provided by the respondents. Below elaboration focusses on the degrees of standardization and reconfigurability of the underlying modules and components which collectively result in a degree of standardization and reconfigurability at the aggregated product level. The degree of standardization and reconfigurability of the modules and components as well as the overall product are elaborated on for both these modules and components as well as the overall product, both regarding other products as well as other products for different car models and brands of cars.

First, the lower-left quadrant in Figure A1 (low-low) shows a tailor-made "3D freeform design surfaces touch screen interface product," which can, for example, be positioned on the arm-rest in the car door on the driver's side and is used to open/close the window(s), adjust the seat(s) position, adjust the seat(s) heating/cooling, and adjust the alignment of the mirrors. Different car models and brands of cars use different applications, i.e., in the positioning of the product (i.e., seamless integrated curved surfaces enable full freedom for car designers), colors, materials used, illumination techniques, sensors, shielding features, the functionalities offered, and in the way the components and the product interface communicates with the other parts of the car (non-standardized interfaces across different car models and brands). As such, this product was rated to have a relatively low level of standardization. Due to the uniqueness of the components and the product for each car model and different brands, there are also limited degrees of combinations that can be reused to create new products for other car brands and models. For each car model and different brands, the product is mostly designed from scratch using relatively unique components. As such, the "3D freeform design surfaces touch screen interface" was rated as a relatively low degree of reconfigurability.

Second, the upper-right quadrant in Figure A1 (high-high) shows a "steering column product," which is positioned behind the steering wheel of a car and, for example, holds the steering wheel and levers for multiple functions like putting the car in different drive modes (e.g., drive, neutral/park, or reverse), turning on/off and/or changing the speed of the windshield wipers, spraying cleaning fluid on the front or back windshield, turning on/off the adaptive cruise control (including changing the distance kept between the car and the car in front of it), and turning on/off lane keeping/driver assistance. The lever modules are highly standardized regarding their movement options (i.e., move up/down and/or forward/backward, with a potential additional button that can turn or be pushed), their positioning (i.e., the levers can be on the left and right side of the steering wheel), and their interfacing/communication (i.e., signals for moving a lever up or down are comparable/the same for both different levers and for different car models and brands of cars). Because this steering column product is composed of highly standardized components (e.g., each lever is technically comparable and can be made from off-the-shelf parts, i.e., limited uniqueness), this product was rated to have a relatively high level of standardization. At the same time, the underlying components like the levers and the overall steering column can be reused in multiple car models and even across different brands, since many reconfigurations can easily be made by adding multiple levers and varying the specific functions. As such, the steering column was rated as a relatively high degree of reconfigurability.

Figure A1. Two-by-two matrix of degrees of standardization and reconfigurability

Third, the lower-right quadrant in Figure A1 (high standardization-low reconfigurability) shows a "steering angle sensor," which is fixed onto the steering wheel shaft in a car and determines both the angle and the position of the steering wheel. It is used as a technology for many driver assistance systems and automated driving (e.g., parking assistant/auto parking, adaptive cruise control, and driver fatigue detection). This is a high-safety product that consists of highly standardized components (i.e., receiver, sender, connector, and rotary wheel), positioned in a fixed geometry with the steering column based on proven safety tests and developed standards, and includes multiple internal checks and tests (e.g., sensor-internal plausibility tests and special self-diagnostic functions). Due to the safety requirements, the highly standardized components of the steering angle sensor have limited possibilities for reconfigurability. This is because the sensors include embedded specific safety checks and tests, which have very limited or no other use in other products. Moreover, the interface/communication of the sensor toward other parts of the car differs across different car models and brands. This means that for each car model and brand, this sensor needs to be tailor made. In other words, even though the sensor consists of standardized components, it needs to be customized for each model and brand, so it cannot be reused without substantial modifications. As such, the steering angle sensor was rated at a relatively high degree of standardization and a low degree of reconfigurability.

Fourth, the upper-left quadrant in Figure A1 (low standardization-high reconfigurability) shows "remote car keys," which are among others used to unlock and lock cars. To communicate with the car, a key uses Near-Field Communication (NFC) and authentication like Radio-Frequency IDentification (RFID), which is realized through the utilization of a relatively basic coil. This coil is to a limited extent standardized through norms that prescribe the used communication frequency as well as the supported data rates, in line with underlying patents of Sony and Philips as well as an ISO-/IEC-approved standard. This has resulted in a global certification and testing standard to ensure global interoperability of NFC services. However, beyond this basic standardization, there are multiple degrees of freedom like the utilized materials and the shape (e.g., round or squared) of these coils. As such, differently shaped coils are also utilized in other applications like contactless payments with banking cards, mobile phones, smartwatches, and smart jewelry, but also in the domain of logistical product tracking, shopping product security, and even self-payment terminals in shops (e.g., an RFID coil with a unique code is attached to each product, and the payment terminals detect the different products). In addition to this relatively basic coil with variation options, the other components of the remote car keys vary widely. Most car brands have physical buttons on the car key to open or close the doors (e.g., Opel and Ford), while some other brands do not (e.g., Tesla's key card), see the picture in Figure A1. Moreover, there are also variations regarding the incorporation of a physical metal key to insert into the ignition to start the car, where there are also car keys without a metal key where the cars are started with a button. Beyond this, there is also a wide variation in the materials used. As such, the overall remote car key was rated as a relatively low degree of standardization.

At the same time and regarding reconfigurability, some brands will use the RFID coil in the key to identify the user and adjust multiple car settings to the preferences of that user (e.g., seat positions, steering wheel positions, mirror positions, air conditioning settings, and audio settings), while other brands do not have this functionality. Additionally, the physical (off-the-shelf) buttons on the key offer opportunities for reconfiguration across different models of cars and different brands. For example, a press and hold of the "open doors key" does nothing for some brands, while for others it will open up all side windows (to ventilate the car before getting in). Also, from a design and material usage point of view, many different reconfigurations can be made. As such, the car keys are rated as a relatively low degree of standardization and a high degree of reconfigurability.

Altogether, Figure A1 illustrates both dimensions and degrees of product modularity. These examples capture the importance of the multidimensional view of product modularity (i.e., standardization and reconfigurability) and show nuance in the dimensions as well as differences in the degrees.

Appendix 2

Recommendations and checks for team-level data aggregation

The following five recommendations and checks were followed and conducted to ensure that the data aggregation toward the team level was valid. First, and most importantly, related 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 and/or the product being developed.

Second, the degree of inter-rater agreement within the teams was assessed (i.e., comparing pairs of multiple respondents per team) as an indication of the homogeneity of team members' perceptions (James *et al*., 1984). This indicated satisfying agreement across the individuals within the teams (inter-rater agreement of greater than 0.8 in more than 80% of the cases), which is a precondition for group-level aggregation. These results are consistent with recent studies and support aggregation to the group level.

Third, to compare the answers of all team members simultaneously, the ICC was calculated for every team (101 teams), which enabled the estimate of the inter-rater reliability for these key variables: innovation novelty, innovation efficiency, standardization, and reconfigurability, as well as knowledge diversity and team interaction. The average ICC between measures was 0.75, with a 95% confidence interval, indicating a high degree of reliability (Campion *et al*., 1993).

Fourth, after recoding the data to the same data range (if needed), the scores of multiple team members were averaged at the team level. This averaging can, to some extent, lower the impact of potential common method bias from some respondents.

Fifth, a Harman's single factor score was calculated to assess a potential common method bias. Results indicate that the total variance for a single factor was 25.81% (less than the commonly used threshold of 50%), which further suggests that the data and results were not largely affected by common method bias (Podsakoff et al., 2012).

Appendix 3:
Robustness checks and additional analyses

Table A1. *Other dependent variables as control*: curvilinear regression results with module standardization, reconfigurability, and innovation novelty

	Innovation novelty						
Variables	**M1**	**M2**	**M3**	**M4**	**M5**	**M6**	**M7**
Standardization		−0.21	−0.38			−0.28*	−1.26
		(0.13)	(0.61)			(0.14)	(0.75)
Standardization squared			0.02				0.12
			(0.07)				(0.09)
Reconfigurability				0.06	1.33 t	0.17	2.00*
				(0.12)	(0.69)	(0.13)	(0.81)
Reconfigurability squared					−0.14 t		−0.20*
					(0.07)		(0.09)
Innovation novelty							
Innovation efficiency	0.57***	0.52**	0.51**	0.56***	0.55***	0.45**	0.44**
	(0.15)	(0.15)	(0.16)	(0.16)	(0.16)	(0.16)	(0.16)
Experience at company	0.06*	0.06*	0.06*	0.06*	0.06*	0.06*	0.06*
	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
Total experience	−0.02	−0.02	−0.02	−0.01	−0.01	−0.02	−0.01
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Team size	0.02	0.03	0.03	0.02	0.01	0.03	0.01
	(0.03)	(0.03)	(0.03)	(0.03)	(0.04)	(0.03)	(0.04)
Project length	−0.02	−0.02	−0.02	−0.02	−0.01	−0.03	−0.01
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Number of fields of experience	−0.05	−0.00	−0.00	−0.06	−0.05	−0.01	−0.01
	(0.11)	(0.11)	(0.11)	(0.11)	(0.11)	(0.11)	(0.11)
Number of roles in project	0.10	0.12	0.11	0.07	0.15	0.03	0.13
	(0.25)	(0.25)	(0.25)	(0.26)	(0.26)	(0.26)	(0.26)
Education: mid. school	0.27	0.23	0.23	0.27	0.26	0.22	0.21
	(0.38)	(0.37)	(0.38)	(0.38)	(0.37)	(0.37)	(0.37)
Education: bachelor	−0.40	−0.45	−0.43	−0.40	−0.47	−0.46	−0.44
	(0.34)	(0.34)	(0.35)	(0.35)	(0.34)	(0.34)	(0.34)
Education: master	−0.01	0.05	0.05	0.00	−0.07	0.09	0.01
	(0.30)	(0.30)	(0.30)	(0.30)	(0.30)	(0.30)	(0.30)
Education: PhD	0.29	0.23	0.23	0.33	0.32	0.32	0.31
	(0.40)	(0.40)	(0.40)	(0.41)	(0.41)	(0.40)	(0.40)
Geographical dispersion	−0.21	−0.25	−0.23	−0.21	−0.29	−0.25	−0.30
	(0.24)	(0.23)	(0.24)	(0.24)	(0.24)	(0.23)	(0.23)
Constant	1.43	2.72*	3.05 t	1.26	−1.35	2.68*	0.67
	(1.05)	(1.31)	(1.74)	(1.12)	(1.77)	(1.30)	(1.93)
Observations	101	101	101	101	101	101	101
R^2	0.29	0.31	0.31	0.29	0.32	0.32	0.36
$P > F$	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Adj R^2	0.19	0.21	0.20	0.19	0.21	0.21	0.24
AIC	319	318	320	320	318	318	316
BIC	353	354	359	357	358	357	360

t = $p < 0.10$; * $p < 0.05$; ** $p < 0.01$; and *** $p < 0.001$
nonstandardized β values for all variables standard errors in parentheses two-sided test.

Table A2. *Other dependent variables as control*: curvilinear regression results with module standardization, reconfigurability, and innovation efficiency

	Innovation efficiency						
Variables	**M8**	**M9**	**M10**	**M11**	**M12**	**M13**	**M14**
Standardization		−0.11	−0.47			−0.20*	−0.17
		(0.08)	(0.40)			(0.09)	(0.49)
Standardization squared			0.04				−0.00
			(0.04)				(0.06)
Reconfigurability				0.15*	−0.04	0.23**	0.03
				(0.08)	(0.45)	(0.08)	(0.55)
Reconfigurability squared					0.02		0.02
					(0.05)		(0.06)
Innovation novelty	0.24***	0.22**	0.22**	0.22***	0.23***	0.18**	0.18**
	(0.06)	(0.07)	(0.07)	(0.06)	(0.07)	(0.07)	(0.07)
Innovation efficiency							
Experience at company	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)
Total experience	−0.03*	−0.03*	−0.03*	−0.03 t	−0.03 t	−0.03 t	−0.03 t
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Team size	0.00	0.01	0.01	0.00	0.00	0.01	0.01
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Project length	0.01	0.01	0.01	0.01	0.01	0.01	0.01
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Number of fields of experience	0.18*	0.19**	0.19**	0.14*	0.14*	0.17*	0.16*
	(0.07)	(0.07)	(0.07)	(0.07)	(0.07)	(0.07)	(0.07)
Number of roles in project	−0.42**	−0.40*	−0.41*	−0.48**	−0.49**	−0.48**	−0.49**
	(0.16)	(0.16)	(0.16)	(0.16)	(0.16)	(0.15)	(0.16)
Education: mid. school	−0.29	−0.30	−0.30	−0.27	−0.27	−0.28	−0.28
	(0.24)	(0.24)	(0.24)	(0.24)	(0.24)	(0.23)	(0.24)
Education: bachelor	−0.04	−0.07	−0.03	−0.03	−0.02	−0.09	−0.08
	(0.23)	(0.23)	(0.23)	(0.22)	(0.22)	(0.22)	(0.22)
Education: master	0.34 t	0.37 t	0.38 t	0.35 t	0.36 t	0.39*	0.40*
	(0.19)	(0.19)	(0.19)	(0.19)	(0.19)	(0.19)	(0.19)
Education: PhD	0.04	0.02	0.03	0.15	0.15	0.15	0.15
	(0.26)	(0.26)	(0.26)	(0.26)	(0.26)	(0.26)	(0.26)
Geographical dispersion	−0.17	−0.18	−0.16	−0.16	−0.14	−0.18	−0.17
	(0.15)	(0.15)	(0.16)	(0.15)	(0.15)	(0.15)	(0.15)
Constant	3.99***	4.59***	5.24***	3.35***	3.74***	4.21***	4.55***
	(0.54)	(0.72)	(1.00)	(0.62)	(1.08)	(0.71)	(1.15)
Observations	101	101	101	101	101	101	101
R^2	0.39	0.40	0.40	0.41	0.41	0.45	0.45
$P > F$	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Adj R^2	0.30	0.31	0.31	0.33	0.32	0.36	0.35
AIC	231	231	232	229	230	224	228
BIC	265	268	272	265	270	264	273

t = $p < 0.10$; *$p < 0.05$; **$p < 0.01$; and ***$p < 0.001$
nonstandardized β values for all variables standard errors in parentheses two-sided test.

Table A3. *Dependent and independent variables via PCA*: results with module standardization, reconfigurability, innovation novelty, and innovation efficiency

	PCA innovation novelty				PCA innovation efficiency			
Variables	**M1**	**M2**	**M3**	**M4**	**M5**	**M6**	**M7**	**M8**
PCA standardization		−0.35*		−0.49**		−0.22 t		−0.36**
		(0.15)		(0.16)		(0.11)		(0.11)
PCA reconfigurability			0.19	0.34*			0.24*	0.35***
			(0.14)	(0.14)			(0.10)	(0.10)
Experience at company	0.09 t	0.08	0.09 t	0.07	0.04 t	0.07 t	0.08*	0.06 t
	(0.05)	(0.05)	(0.05)	(0.05)	(0.02)	(0.04)	(0.03)	(0.03)
Total experience	−0.05	−0.05	−0.04	−0.04	−0.04*	−0.06*	−0.05 t	−0.05 t
	(0.04)	(0.04)	(0.04)	(0.04)	(0.02)	(0.03)	(0.03)	(0.03)
Team size	0.03	0.05	0.03	0.06	0.01	0.02	0.01	0.03
	(0.06)	(0.06)	(0.06)	(0.06)	(0.02)	(0.04)	(0.04)	(0.04)
Project length	−0.02	−0.03	−0.02	−0.04	0.01	0.00	0.01	−0.01
	(0.03)	(0.03)	(0.03)	(0.03)	(0.01)	(0.03)	(0.02)	(0.02)
Number of fields of experience	0.05	0.13	−0.01	0.04	0.19*	0.39**	0.26 t	0.30*
	(0.18)	(0.18)	(0.18)	(0.18)	(0.07)	(0.13)	(0.13)	(0.12)
Number of roles in project	−0.26	−0.16	−0.37	−0.31	−0.45**	−0.78*	−0.98**	−0.93**
	(0.41)	(0.40)	(0.41)	(0.40)	(0.17)	(0.30)	(0.30)	(0.28)
Education: mid. school	0.36	0.33	0.37	0.34	−0.26	−0.46	−0.43	−0.45
	(0.63)	(0.62)	(0.63)	(0.60)	(0.26)	(0.46)	(0.45)	(0.43)
Education: bachelor	−0.59	−0.72	−0.57	−0.73	−0.16	−0.43	−0.32	−0.44
	(0.58)	(0.57)	(0.58)	(0.56)	(0.24)	(0.42)	(0.41)	(0.40)
Education: master	0.23	0.31	0.24	0.37	0.40 t	0.70 t	0.67 t	0.76*
	(0.50)	(0.49)	(0.50)	(0.48)	(0.21)	(0.36)	(0.36)	(0.34)
Education: PhD	0.64	0.46	0.82	0.72	0.13	0.14	0.48	0.40
	(0.68)	(0.67)	(0.69)	(0.66)	(0.28)	(0.49)	(0.49)	(0.47)
Geographical dispersion	−0.56	−0.58	−0.52	−0.51	−0.25	−0.38	−0.31	−0.31
	(0.40)	(0.39)	(0.39)	(0.38)	(0.16)	(0.28)	(0.28)	(0.27)
Constant	1.36	1.43	1.44	1.59	5.03***	0.82	0.87	0.98
	(1.22)	(1.20)	(1.22)	(1.17)	(0.50)	(0.88)	(0.87)	(0.83)
Observations	101	101	101	101	101	101	101	101
R^2	0.12	0.17	0.13	0.22	0.29	0.31	0.32	0.39
$P > F$	0.40	0.15	0.34	0.04	0.00	0.00	0.00	0.00
Adj R^2	0.01	0.05	0.02	0.10	0.20	0.21	0.23	0.30
AIC	425	421	425	416	244	359	356	347
BIC	456	455	459	453	276	393	390	384

t = $p < 0.10$; *$p < 0.05$; **$p < 0.01$; and ***$P < 0.001$
nonstandardized β values for all variables standard errors in parentheses two-sided test.

Table A4. *Combined modularity (standardization and reconfigurability combined)*: regression results with combined modularity, innovation novelty, and innovation efficiency

	Innovation novelty		Innovation efficiency	
Variables	**M1**	**M2**	**M5**	**M6**
Combined modularity (standardization and reconfigurability combined)		−0.08		0.03
		(0.16)		(0.10)
Experience at company	0.08**	0.08**	0.04 t	0.04 t
	(0.03)	(0.03)	(0.02)	(0.02)
Total experience	−0.04	−0.04	−0.04*	−0.04*
	(0.02)	(0.02)	(0.02)	(0.02)
Team size	0.03	0.03	0.01	0.01
	(0.04)	(0.04)	(0.02)	(0.02)
Project length	−0.01	−0.01	0.01	0.01
	(0.02)	(0.02)	(0.01)	(0.01)

(continued)

Table A4. (Continued)

	Innovation novelty		Innovation efficiency	
Variables	M1	M2	M5	M6
Number of fields of experience	0.06	0.08	0.19*	0.18*
	(0.11)	(0.12)	(0.07)	(0.08)
Number of roles in project	−0.16	−0.14	−0.45**	−0.46**
	(0.26)	(0.26)	(0.17)	(0.17)
Education: mid. school	0.12	0.11	−0.26	−0.26
	(0.40)	(0.40)	(0.26)	(0.26)
Education: bachelor	−0.50	−0.51	−0.16	−0.16
	(0.37)	(0.37)	(0.24)	(0.24)
Education: master	0.22	0.23	0.40 t	0.40 t
	(0.32)	(0.32)	(0.21)	(0.21)
Education: PhD	0.37	0.33	0.13	0.15
	(0.43)	(0.44)	(0.28)	(0.28)
Geographical dispersion	−0.36	−0.37	−0.25	−0.25
	(0.25)	(0.25)	(0.16)	(0.16)
Constant	4.32***	4.69***	5.03***	4.89***
	(0.77)	(1.08)	(0.50)	(0.70)
Observations	101	101	101	101
R^2	0.17	0.18	0.29	0.29
$P > F$	0.08	0.11	0.00	0.00
Adj R^2	0.07	0.07	0.20	0.19
AIC	332	333	244	246
BIC	363	367	276	280

t = $p < 0.10$; *$p < 0.05$; **$p < 0.01$; and ***$p < 0.001$
nonstandardized β values for all variables standard errors in parentheses two-sided test.

Table A5. *Combined innovation (novelty and efficiency combined)*: regression results with module standardization, reconfigurability, and innovation combined

	Combined innovation (novelty and efficiency combined)			
Variables	M1	M2	M3	M4
Standardization		−0.47*		−0.68***
		(0.18)		(0.18)
Reconfigurability			0.35*	0.57**
			(0.17)	(0.17)
Experience at company	0.12**	0.11*	0.12**	0.10**
	(0.04)	(0.04)	(0.04)	(0.04)
Total experience	−0.08*	−0.08*	−0.07*	−0.06*
	(0.03)	(0.03)	(0.03)	(0.03)
Team size	0.04	0.06	0.03	0.06
	(0.05)	(0.05)	(0.05)	(0.05)
Project length	−0.00	−0.02	−0.00	−0.02
	(0.03)	(0.03)	(0.03)	(0.03)
Number of fields of experience	0.25	0.33*	0.18	0.24
	(0.15)	(0.15)	(0.16)	(0.15)
Number of roles in project	−0.62 t	−0.52	−0.76*	−0.71*
	(0.36)	(0.35)	(0.36)	(0.33)
Education: mid. school	−0.14	−0.19	−0.11	−0.16
	(0.55)	(0.54)	(0.54)	(0.51)
Education: bachelor	−0.66	−0.75	−0.62	−0.72
	(0.51)	(0.49)	(0.50)	(0.47)
Education: master	0.62	0.69	0.62	0.73 t
	(0.44)	(0.42)	(0.43)	(0.40)
Education: PhD	0.50	0.34	0.73	0.65

(continued)

Table A5. (Continued)

Variables	Combined innovation (novelty and efficiency combined)			
	M1	M2	M3	M4
	(0.59)	(0.58)	(0.59)	(0.55)
Geographical dispersion	−0.61 t	−0.65 t	−0.57 t	−0.61 t
	(0.34)	(0.33)	(0.34)	(0.32)
Constant	9.34***	11.64***	7.72***	10.03***
	(1.07)	(1.36)	(1.31)	(1.37)
Observations	101	101	101	101
R^2	0.25	0.31	0.29	0.39
$P > F$	0.00	0.00	0.00	0.00
Adj R^2	0.16	0.21	0.19	0.30
AIC	397	391	394	381
BIC	428	425	428	417

t = $p < 0.10$; *$P < 0.05$; **$P < 0.01$; and ***$P < 0.001$
nonstandardized β values for all variables standard errors in parentheses two-sided test.

Table A6. *Outliers removed*: regression results with module standardization, reconfigurability, innovation novelty, and innovation efficiency

Variables	Innovation novelty				Innovation efficiency			
	M1	M2	M3	M4	M5	M6	M7	M8
Standardization		−0.22		−0.42*		−0.05		−0.23*
		(0.15)		(0.16)		(0.10)		(0.10)
Reconfigurability			0.19	0.36*			0.23**	0.32***
			(0.13)	(0.14)			(0.08)	(0.09)
Experience at company	0.07*	0.07*	0.07*	0.06*	0.04*	0.04*	0.04*	0.03 t
	(0.03)	(0.03)	(0.03)	(0.03)	(0.02)	(0.02)	(0.02)	(0.02)
Total experience	−0.04	−0.04 t	−0.03	−0.03	−0.04**	−0.04**	−0.03*	−0.03*
	(0.02)	(0.02)	(0.02)	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)
Team size	0.03	0.04	0.03	0.04	0.02	0.02	0.02	0.02
	(0.04)	(0.04)	(0.04)	(0.03)	(0.02)	(0.02)	(0.02)	(0.02)
Project length	−0.02	−0.02	−0.02	−0.02	0.01	0.00	0.00	0.00
	(0.02)	(0.02)	(0.02)	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)
Number of fields of experience	0.19	0.23 t	0.16	0.19	0.11	0.12	0.07	0.09
	(0.12)	(0.12)	(0.12)	(0.12)	(0.07)	(0.08)	(0.07)	(0.07)
Number of roles in project	−0.51 t	−0.49 t	−0.58*	−0.60*	−0.17	−0.16	−0.25	−0.26
	(0.28)	(0.28)	(0.28)	(0.27)	(0.18)	(0.18)	(0.17)	(0.17)
Education: mid. school	0.12	0.10	0.14	0.11	−0.25	−0.26	−0.23	−0.25
	(0.38)	(0.38)	(0.38)	(0.37)	(0.24)	(0.24)	(0.23)	(0.22)
Education: bachelor	−0.36	−0.46	−0.35	−0.53	−0.01	−0.04	0.00	−0.10
	(0.35)	(0.36)	(0.35)	(0.35)	(0.22)	(0.23)	(0.21)	(0.21)
Education: master	0.08	0.16	0.05	0.17	0.35 t	0.36 t	0.31	0.38*
	(0.31)	(0.31)	(0.31)	(0.30)	(0.20)	(0.20)	(0.19)	(0.19)
Education: PhD	0.38	0.30	0.50	0.45	0.13	0.11	0.27	0.25
	(0.41)	(0.41)	(0.41)	(0.40)	(0.26)	(0.26)	(0.25)	(0.25)
Geographical dispersion	−0.29	−0.32	−0.28	−0.34	−0.27 t	−0.28 t	−0.27 t	−0.30*
	(0.24)	(0.24)	(0.24)	(0.23)	(0.15)	(0.15)	(0.14)	(0.14)
Constant	4.51***	5.63***	3.75***	5.14***	4.72***	4.97***	3.79***	4.54***
	(0.76)	(1.07)	(0.93)	(1.05)	(0.48)	(0.68)	(0.57)	(0.65)
Observations	96	96	96	96	96	96	96	96
R^2	0.19	0.21	0.21	0.27	0.22	0.22	0.29	0.33
$P > F$	0.07	0.05	0.06	0.01	0.03	0.04	0.00	0.00
Adj R^2	0.08	0.10	0.09	0.15	0.11	0.1	0.18	0.22
AIC	305	304	305	299	217	218	209	206
BIC	336	338	338	335	247	252	243	242

t = $p < 0.10$; *$p < 0.05$; **$p < 0.01$; and ***$p < 0.001$
nonstandardized β values for all variables standard errors in parentheses two-sided test.

Table A7. *Ordered logistical*: regression results with module standardization, reconfigurability, innovation novelty, and innovation efficiency

	Innovation novelty				Innovation efficiency			
Variables	**M1**	**M2**	**M3**	**M4**	**M5**	**M6**	**M7**	**M8**
Standardization		−0.61**		−0.78**		−0.31		−0.64**
		(0.24)		(0.24)		(0.23)		(0.24)
Reconfigurability			0.21	0.45*			0.54*	0.79***
			(0.20)	(0.21)			(0.21)	(0.24)
Experience at company	0.13**	0.13**	0.13**	0.12**	0.10*	0.10*	0.10*	0.10*
	(0.05)	(0.05)	(0.05)	(0.04)	(0.05)	(0.05)	(0.05)	(0.05)
Total experience	−0.06	−0.07 t	−0.05	−0.05	−0.11**	−0.12**	−0.09*	−0.09*
	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)
Team size	0.04	0.06	0.04	0.06	0.01	0.02	0.02	0.03
	(0.06)	(0.06)	(0.06)	(0.06)	(0.05)	(0.05)	(0.05)	(0.05)
Project length	−0.03	−0.05	−0.03	−0.05	0.01	0.00	−0.00	−0.01
	(0.03)	(0.03)	(0.04)	(0.04)	(0.03)	(0.03)	(0.03)	(0.03)
Number of fields of experience	0.16	0.26	0.13	0.20	0.43*	0.51*	0.28	0.38 t
	(0.17)	(0.18)	(0.17)	(0.18)	(0.19)	(0.20)	(0.19)	(0.20)
Number of roles in project	−0.28	−0.25	−0.34	−0.34	−0.95*	−0.88*	−1.19**	−1.17**
	(0.45)	(0.44)	(0.45)	(0.45)	(0.39)	(0.39)	(0.41)	(0.41)
Education: mid. school	0.12	0.04	0.13	0.07	−0.62	−0.69	−0.63	−0.74
	(0.55)	(0.54)	(0.55)	(0.54)	(0.54)	(0.54)	(0.55)	(0.56)
Education: bachelor	−0.62	−0.87	−0.60	−0.90 t	−0.27	−0.31	−0.19	−0.33
	(0.56)	(0.55)	(0.55)	(0.54)	(0.59)	(0.58)	(0.57)	(0.56)
Education: master	0.49	0.65	0.47	0.66	1.04*	1.13*	1.04*	1.16*
	(0.48)	(0.47)	(0.48)	(0.48)	(0.47)	(0.48)	(0.48)	(0.49)
Education: PhD	0.57	0.32	0.72	0.57	0.64	0.50	0.99	0.86
	(0.58)	(0.59)	(0.59)	(0.59)	(0.63)	(0.64)	(0.66)	(0.67)
Geographical dispersion	−0.40	−0.50	−0.39	−0.52	−0.52	−0.56	−0.49	−0.57
	(0.36)	(0.36)	(0.36)	(0.35)	(0.37)	(0.37)	(0.38)	(0.39)
Observations	101	101	101	101	101	101	101	101
$P > F$	0.05	0.01	0.06	0.00	0.00	0.00	0.00	0.00
Pseudo R^2	0.02	0.03	0.02	0.04	0.04	0.04	0.05	0.06
Log-likelihood	−406	−403	−406	−401	−364	−363	−361	−357
AIC	970	966	971	963	863	863	858	852
BIC	1177	1175	1180	1175	1038	1041	1036	1033

t = $p < 0.10$; *$p < 0.05$; **$p < 0.01$; and ***$p < 0.001$
nonstandardized β values for all variables standard errors in parentheses two-sided test.

Table A8. *Standardized beta coefficients*: regression results with module standardization, reconfigurability, innovation novelty, and innovation efficiency

	Innovation novelty				Innovation efficiency			
Variables	**M1**	**M2**	**M3**	**M4**	**M5**	**M6**	**M7**	**M8**
Standardization		−0.24*		−0.32**		−0.20*		−0.31**
		(0.03)		(0.00)		(0.05)		(0.00)
Reconfigurability			0.14	0.25*			0.23*	0.34***
			(0.20)	(0.02)			(0.02)	(0.00)
Experience at company	0.30**	0.27*	0.30**	0.26*	0.19 t	0.16	0.19 t	0.15
	(0.01)	(0.02)	(0.01)	(0.01)	(0.07)	(0.11)	(0.06)	(0.11)
Total experience	−0.17	−0.18 t	−0.15	−0.13	−0.26*	−0.27**	−0.22*	−0.21*
	(0.11)	(0.10)	(0.18)	(0.20)	(0.01)	(0.01)	(0.03)	(0.03)
Team size	0.09	0.13	0.09	0.14	0.04	0.08	0.04	0.09
	(0.47)	(0.28)	(0.47)	(0.22)	(0.72)	(0.51)	(0.73)	(0.38)

(continued)

Table A8. (Continued)

	Innovation novelty				Innovation efficiency			
Variables	**M1**	**M2**	**M3**	**M4**	**M5**	**M6**	**M7**	**M8**
Project length	−0.07 (0.58)	−0.12 (0.34)	−0.07 (0.55)	−0.15 (0.23)	0.09 (0.45)	0.05 (0.68)	0.08 (0.48)	0.01 (0.92)
Number of fields of experience	0.05 (0.59)	0.10 (0.33)	0.02 (0.82)	0.06 (0.55)	0.24* (0.01)	0.28** (0.00)	0.19* (0.04)	0.22* (0.01)
Number of roles in project	−0.07 (0.53)	−0.04 (0.69)	−0.10 (0.39)	−0.09 (0.43)	−0.29** (0.01)	−0.26* (0.01)	−0.34** (0.00)	−0.32* (0.00)
Education: mid. school	0.03 (0.77)	0.02 (0.82)	0.03 (0.74)	0.03 (0.79)	−0.09 (0.32)	−0.10 (0.28)	−0.09 (0.33)	−0.10 (0.27)
Education: bachelor	−0.15 (0.18)	−0.17 (0.13)	−0.14 (0.20)	−0.16 (0.13)	−0.07 (0.50)	−0.08 (0.41)	−0.06 (0.55)	−0.08 (0.41)
Education: master	0.08 (0.49)	0.10 (0.39)	0.08 (0.48)	0.11 (0.35)	0.22 t (0.06)	0.23* (0.04)	0.22* (0.05)	0.24* (0.02)
Education: PhD	0.09 (0.40)	0.06 (0.53)	0.11 (0.28)	0.10 (0.31)	0.04 (0.64)	0.02 (0.79)	0.09 (0.35)	0.07 (0.40)
Geographical dispersion	−0.17 (0.15)	−0.18 (0.12)	−0.16 (0.17)	−0.17 (0.13)	−0.17 (0.12)	−0.18 (0.10)	−0.15 (0.15)	−0.16 (0.11)
Constant	. (0.00)	. (0.00)	. (0.00)	. (0.00)	. (0.00)	. (0.00)	. (0.00)	. (0.00)
Observations	101	101	101	101	101	101	101	101
R^2	0.17	0.22	0.19	0.27	0.29	0.32	0.33	0.4
$P > F$	0.08	0.03	0.08	0.01	0.00	0.00	0.00	0.00
Adj R^2	0.07	0.11	0.08	0.16	0.20	0.23	0.24	0.31
AIC	332	328	332	324	244	242	240	231
BIC	363	362	366	361	276	276	274	267

t = $p < 0.10$; *$p < 0.05$; **$p < 0.01$; and ***$p < 0.001$
standardized β values for all variables P-values in parentheses two-sided test.

Appendix 4:

The full questionnaire/survey

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? (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

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