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A survey of Swedish development practices

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Contrasting platform thinking and product modularization: A survey of Swedish product development practices

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1. Introduction

In many industries, the ability to offer a broad spectrum of product choices to heterogeneous customer segments has constituted a longstanding source of competitive advantage (Ramdas, 2003; Scavarda, 2009, Elmaraghy *et al.,* 2013). The importance of providing product variety and customization possibilities has increased even more during the last decades (Pine, 1993; da Silveira, 1998; Scavarda, 2009). However, without proper management, responding to the external requirements for product variety and customization can have dire consequences for the efficiency of the manufacturing operations in the company (Ramdas, 2003; Scavarda, 2009) as well as for the R&D function in the company (Halman *et al*., 2003). Not only can product variety negatively impact performance, e.g. decreasing manufacturing efficiency by increasing manufacturing costs, delivery times and inventory levels (Salvador *et al*., 2002), it can also have adverse effects across organizational boundaries, and requires management both before and after product launch (Ramdas, 2003). Variety management aims to ensure that firms can deliver the requisite end-product variety while improving the impact of product and part variety on operational performance (da Silveira, 1998). As such, the purpose of variety management is to cope with or even mitigate the trade-off between product variety and operational performance (Salvador *et al.,* 2002).

Two solutions for alleviating the negative impact of variety on internal operations are product modularization and platform thinking (Pil and Holweg, 2004). Moving away from the logic of waiting for the customers to decide what they want, these variety management practices build upon the principle of designing products and product families that can support a large range of current and future end-product variants, while still utilizing a standardized and common pool of components and subsystems. In line with Magnusson and Pasche (2013), we view platform thinking and product modularization as similar, yet distinct concepts. Even though both concepts promote component commonality, product modularization focuses on creating interchangeable modules that can be mixed-and-matched according to customer demand (Schilling, 2000; Starr, 1965), whereas platform thinking has the ambition to develop a standard base of subsystems and interfaces, whereupon many derivative products can be based (Meyer and Lehnerd, 1997).

There is a general lack of research addressing the contingency factors influencing the use of product modularization and platform thinking and their appropriateness in different contexts (Magnusson and Pasche, 2013). Moreover, only recently, authors have begun to examine the effects of product modularization quantitatively (e.g. Jacobs *et al*., 2007; 2011; Lau *et al.*, 2007; 2009), and quantitative research on the effects of platform thinking is even scarcer – notable exceptions are Pasche *et al.* (2011) and Koufteros *et al.,* (2014). To our knowledge, no large-scale empirical research has been reported in which the two concepts, contextual influences and organizational effects are considered together.

This paper is based on the proposition that, although product modularization and platform thinking can be used together, their differences influence 1) the context in which the combined or separate use of the concepts is appropriate, and 2) the types of product development practices complimenting these approaches. Based on data from 138 Swedish firms, the purpose of this paper is twofold. First, to examine in which environmental and organizational contexts the individual or combined use of the two design approaches is appropriate and secondly, to investigate which practices are complementary to product modularization and/or platform thinking. Thus, this paper aims to develop a contingency perspective by contributing to our understanding of the effects of similarities and differences between product modularization and platform thinking.

2. Theoretical background

2.1. Product modularization and platform thinking

The overall aim of product modularization is to decompose products into smaller units (modules) that can be managed independently and used interchangeably in different configurations without compromising system integrity (Baldwin and Clark, 1997; Sanchez and Mahoney, 1996). The concept of product modularization goes as far back as the 1960s, when Starr (1965, p. 138) noted: "*It is the essence of the modular concept to design, develop, and produce those parts, which can be combined in the maximum number of ways*". Thus, central to product modularization is breaking up the product into subsystems, i.e. modules, which can be used in multiple product variants (Baldwin and Clark, 1997). To facilitate the use and reuse of modules in multiple product variants requires both standardization of interfaces and dedication of functions. Defining and standardizing the interactions and physical interfaces between modules creates a loosely coupled system of components allowing the mixing and matching of components to create different product configurations (Ulrich, 1995; Sanchez, 1995). To facilitate the mixing and matching of component requires modules to also have specific and distinctive functions, which means that the main functional interactions should be within rather than between modules (Marshall *et al.,* 1998). If key functions, on the other hand, were to be shared between multiple modules, the task of standardizing subsystems for use in multiple applications would be gravely complicated (Boer, 2014). As a result, modularization is a function of several product characteristics: the degree to which modules and module interfaces are standardized and how functions are allocated to the components (Boer, 2014). The use of standard interfaces and modules allows these modules to be used in current and future products for the same functional purposes. The relative independence between modules created by these standardized interfaces and dedicated functions, facilitates the design and re-design of modules without having to change other parts of the design (Baldwin and Clark, 1997). But most importantly, product modularization creates the opportunity for firms and customers to mix and match different sets of modules to create a great variety of customized end products (Baldwin and Clark, 1997; Schilling, 2000).

In its broadest sense, a platform can be defined "*as the collection of assets that are shared by a set of products*" (Robertson and Ulrich, 1998, p. 20). From this perspective, platform thinking can refer to the identification and exploitation of a wide range of assets, including process, customer, brand, knowledge, distribution, and supply assets (Sawhney, 1998; Robertson and Ulrich, 1998; Halman *et al*., 2003). We have a more limited view on platform thinking and interpret it as the creation and management of "*a set of subsystems and interfaces that form a common structure from which a stream of derivative products can be efficiently developed and produced"* (Meyer and Lehnerd, 1997, p. 39). This means that we consider a product platform to be a set of physical elements (i.e. components, subsystems and interfaces) that are common to a variety of different end products (Muffatto, 1999, Sköld and Karlsson, 2007). Managing on the basis of product platforms is a shift from the traditional single-product focus in product development to the development of a common set of physical elements whereupon a related set of current and future products can be based (Meyer and Lehnerd, 1997; Pasche *et al.,* 2011) Platform thinking requires the decoupling of the core platform components and interfaces that are to remain fixed over the life of the platform, from the differentiating, variable non-platform elements that are allowed to change over time (Halman *et al.*, 2003; Baldwin and Woodard, 2009). Deciding which components and interfaces are to constitute the core platform involves both managing the trade-off between distinctiveness and commonality (Robertson and Ulrich, 1998; Ulrich and Eppinger, 2012) and requires the firm to determine how the platform system as a whole becomes evolvable (Baldwin and Woodard, 2009). Understanding which components constitute differentiating attributes for the customer and which components can be physically shared "below-the-skin" without compromising distinctiveness, can become a powerful tool in deciding which components to include in the core platform (Robertson and Ulrich, 1998, Sawhney, 1998). By promoting the reuse of common platform elements that have little influence on product distinctiveness, the whole system does not have to be invented or rebuilt from scratch to generate a new product variant (Baldwin and Woodard, 2009). To ensure that a system becomes evolvable, i.e. that the core platform accommodates not only current product variants but also derivative products and successive generations, the subsystem interfaces and linkages are essential (Meyer and Lehnerd, 1997; Baldwin and Woodard, 2009). Creating standardized interfaces between the core platform elements and the variable, non-platform components, ensures that product designers can develop differentiating products efficiently (Meyer and Lehnerd, 1997; Robertson and Ulrich, 1998).

Product modularization and platform thinking both emphasize standardized components and interfaces for the use in multiple product variants. As a consequence, both approaches rely on economies of substitution, where technological progress is accomplished "*by substituting only certain components of the multi-component system while retaining others*" (Garud and Kumaraswamy, 1993, p. 362). However, where product modularization focuses on creating building blocks, i.e. modules with standardized interfaces and distinctive functions, that can be mixed and matched to create product variants, product platforms have an even stronger emphasis on standardization, using the same pool of core platform components and interfaces over the life of the platform and relying on distinctive variable components to create product variants. In comparison to product modularization, platform thinking reuses components and interfaces to a higher degree. This means that even though product modularization and platform thinking both rely on economies of substitution, product modularization relies on economies of scale and scope to a lesser extent than platform thinking does (Sköld and Karlsson 2007; Magnusson and Pasche, 2013). That the two principles are highly similar, yet different is best captured by Baldwin and Woodard (2009), who propose that "*a platform architecture displays a special type of modularity, in which a product or system is split into a set of components with low variety and high reusability"* (the platform)*, "and another set with high variety and low reusability"* (the complements) (p. 25). They view the platform and the compliments as distinct modules, whose interoperability is made possible via shared interface specifications.

2.2. Organizational and environmental contingencies

Product modularization and platform thinking are not one-size-fits-all solutions. In fact, the appropriateness of these practices is contingent on market-related issues, such as demand for differentiation and market dynamics, and company characteristics, such as product characteristics and the organizational structure (Pasche *et al*., 2011). Two important contingencies that influence the appropriateness of platform thinking and/or product modularization are the characteristics of the respective firm's marketplace as well as its organization of the product development function and processes.

2.2.1 Marketplace conditions

A firm's marketplace can create forces that draw the firm to a particular state, but the firm can also shapes its marketplace in significant ways (Schilling, 2000). Similarly, product modularization and platform thinking are often stated to be a response or even a solution the 'new paradigm' for product competition and manufacturing (Pine, 1993; Worren *et al.*, 2002). In this 'new paradigm', globalization fuels competitive intensity, which in turn puts pressure on firms to keep product prices down, while still adhering to increasingly sophisticated customers that are demanding a greater degree of customization and variety than ever before (Marshall, 1993; Pine, 1993; Sawhney, 1998; Worren *et al*., 2002). Platform thinking and/or product modularization are proposed to be solutions to this environmental change, as they enable the firm to remain cost competitive by exploiting commonalities among product variants and generations, while offering the customer a high degree of customization and variety by recombining modules or adding customer specific features to a standard base of components. Some authors even argue that product modularization has been a fundamental part of shaping these new patterns of product competition (Sanchez, 1995; Baldwin and Clark, 1997). Regardless of whether platform thinking and product modularization are responses to or one of the reasons for the transformation of product competition, the transformation has not affected all firms, markets and industries in the same way. As a result, marketplaces today still differ from each other. The degree and way marketplaces differ can be explained by looking at two fundamental dimensions, the nature and intensity of competition and the degree and source of uncertainty in the marketplace (Roth *et al*., 2008). Within these dimension, this paper looks at five specific environmental characteristics, that is, the degree of competitive rivalry, price pressure, variation in demand, demand for product customization, and rapid technological change, and seeks to determine whether these environmental characteristics influence the adoption of product modularization and/or platform thinking.

2.2.2 Product development organization

A central theme in the product modularization and platform thinking literature is a discussion of how these practices influence and are influenced by the organization of work. In particular, many authors discuss how product modularization and platform thinking influences the organization of product development. In the modularity literature, some authors state that product modularization enables firms to employ a 'modular' organization of product development, where design teams can function autonomously and concurrently (e.g. Sanchez, 1995; Sanchez and Mahoney, 1996; Baldwin and Clark, 1997; Schilling, 20000; Kamrad *et al*., 2013). However, others state that firms employing product modularization still require coordination (Ernst, 2005; Persson and Åhlström, 2006), due to, for instance, unmatched design interfaces (Sosa *et al*., 2004) or preventing that increased time is spent in testing and integration phases of product development (Ethiraj and Levinthal, 2004). Platform thinking also influences how product development work should be organized (Pasche *et al*., 2011). For instance, platform development requires the use multifunctional groups, especially during concept or system-level design (Robertson and Ulrich, 1998; Halman *et al*., 2003). The successful management of these groups is critical for the success of the product platform. Unfortunately, multi-functional groups can struggle with a range of problems, created by differences in time frames, goals, assumptions etc. (Halman *et al*., 2003). Therefore, it is still pertinent to understand to what degree the entire platform development process requires cross-functional work groups as well as how the work of these groups should be managed. It is, thus, safe to say that there is still a need for more research into how the development of modular products and product platforms should be organized. Therefore, this paper examines if and how the use of platform thinking and/or product modularization influences the organization of product development work.

2.3 Complementary product development practices

Product modularization and platform thinking are often pooled within the same group of practices, so-called variety management practices or design-for-variety practices. These practices attempt to reduce variety-induced complexity and associated costs (Elmaraghy *et al.*, 2013, Scavarda 2009). Design-for-variety or variety management practices cover a wide range of organizational areas and include process practices (e.g. postponement, flexible manufacturing, production leveling, pull production), supply chain practices (e.g. outsourcing, networking), technological practices (e.g. tracking and tracing, process automation, 3D printing), organizational practices (e.g. multi-skilling, temporary workers, empowerment) and design practices (Scavarda, 2009). Within domain of product design and development, these practices can include everything from platform thinking, modularization, standardization, rapid prototyping, quality function deployment (QFD), design for assembly (DFA) etc. (Elmaraghy *et al.*, 2013). This paper explores whether product modularization and platform thinking influences the adoption of additional design-for-variety practices (i.e. design for assembly, quality function deployment, rapid prototyping and agile work procedures) as well as the adoption other well-known product development practices (i.e. failure mode and effects analysis (FMEA), technology readiness level (TRL) classification and the stage-gate method).

3. Research method

3.1. Sample and data collection

This paper uses data collected during November 2014 to February 2015 through an online questionnaire aimed at studying the product development practices in the Swedish manufacturing industry. In particular, the survey targeted individual business units and addressed the management and organization of their product development processes, as well as their use of practices such as product portfolio planning, lean product development, product platforms and modularization. The target respondents of the questionnaire were R&D managers or people with similar roles within the business unit. The population for the survey was the Swedish manufacturing industry, more specifically, Swedish firms with more than a 100 employees. The original sampling frame of 478 firms was derived from the Swedish Postal Address Register. The population consisted of firms classified as:

- Rubber and plastic industry
- Steel and metal industry
- Metal products industry
- Computer, electronics and optics industry
- Electrical appliance industry
- Other machine hardware industry
- Engine and trailer industry
- Other vehicle industry

Of these, 148 companies (31 percent) fell outside the sampling frame, as these companies did not have any internal R&D. From the resulting 330 business units, we managed to contact 262 business units by phone, in order to verify the name of the respondent and to secure participation. In addition, we sent out the survey to 53 business units without any initial telephone contact. So, in total, the survey was sent out to 315 business units. From these 315 business units, 160 responded, giving an initial response rate of 51 percent. However, 15 firms were excluded from the sample, as they did not complete more than 70 percent of the questionnaire. Moreover, 7 additional firms were excluded that did not answer at least 5 out of the 7 questions needed for the independent research variables. The final sample was a total of 138 manufacturers, resulting in a final response rate of 44 percent. The firm, product development and product platform characteristics are summarized in Table 1. The bold figures represent the number of firms in each category

Table 1. Sample characteristics

Firm characteristics								
Production			*Product type*			*Product type*		
Production	**131**	96%	Semi-manufacture	**36**	26%	Consumer	**28**	20%
No production	**6**	4%	End-products	**101**	74%	Industrial	**109**	80%
Product development characteristics								
% of sales allocated to R&D budget			*No. of permanent employees*			*No. of non-permanent employees*		
1-2%	**47**	39%	1-10	**59**	43%	0	**38**	28%
3-5%	**42**	35%	11-25	**34**	25%	1-5	**67**	50%
6-10%	**21**	18%	26-100	**25**	18%	6-10	**14**	10%
10-25%	**9**	8%	100-200	**13**	10%	10-25	**7**	5%
> 25 %	**1**	1%	>200	**5**	4%	>25	**8**	6%
Product platform characteristics								
Changes in product platforms during last 5 years			*Changes in product variants per product platform during last 5 years*			*Years of experience working with platforms*		
Mean	4.49*		Mean	4.85*		5 or less	**29**	29%
						6-10	**30**	25%
Decreased	**13**		Decreased	**8**		11-20	**31**	25%
Unchanged	**52**		Unchanged	**40**		20-50	**26**	21%
Increased	**72**		Increased	**89**		50 or more	**6**	5%

**Measured using a 7 point scale (1: decreased considerably, 4: unchanged, 7: increased considerably)*

3.2 Research variables

We developed 7-point bipolar measurement scales for most of the variables of interest in this research. To ensure construct validity, existing scales or well-know definitions of the respective variables were used as much as possible. As it was a key priority to keep the survey short, the dependent variables are single-item constructs, displayed in Table 2. The dependent variables are grouped into three categories: marketplace conditions, product development organization and product development practices. Measuring the marketplace conditions often includes measures reflecting the competition faced by firms and uncertainty measures (Roth *et al*., 2008). Similarly, to capture the external environment the firms operate in, we included two measures of competitiveness, i.e. competitive rivalry and price pressures, and two uncertainty measures evaluating the degree to which the firm experiences variation in demand and rapid technological change. In addition, we asked the firms to assess the degree to which customers require customization. This measure was included, as both modularization and the use of product platforms often are linked to the (mass) customization of products (da Silveira *et al*., 2001; Fogliatto *et al*., 2012). To assess how product development is organized, we measured the degree to which the product development process is formalized, co-located and handled by cross-functional teams, all reflecting different ways to achieve integration within and between functions (Child, 2005). In addition, we also measured the degree to which the company has used outsourcing, which is a popular mode of organizational restructuring (Child, 2005). To identify which product development practices are used within the organization, we asked the respondents to identify the degree to which their firm uses 1) techniques and methods for approaching product development work (e.g. FMEA, DFA, QFD, Rapid Prototyping, and TRL classification) and 2) managerial practices for product development (e.g. agile work procedures and defined stages and/or goals).

The independent research variables, product modularization and platform thinking, are measured using the items displayed in Table 3. The degree of modularization of the business unit's product portfolio was measured using three underlying items, that is, separateness, independence, and combinability. These items are previously used in research (see Table 3 for references) and highly consistent with Schilling's (2000) view on modularity being a "*continuum describing the degree to which a system's components can be separated and recombined, and it refers both to the tightness of coupling between components and the degree to which the "rules" of the system architecture enable (or prohibit) the mixing and matching of components"* (p. 312). The second independent research variable, platform thinking, refers to the use of product platforms. A product platform not only encompasses the reuse and sharing of components across products, but also constitutes an underlying architecture that accommodates variety and evolvability (Meyer and Lehnerd, 1997; Baldwin and Woodard, 2009). In a similar vein, we measured the degree to which platform thinking is used in the business unit by determining which amount of products are based on platforms and the degree to which these products share components (cf. Pasche *et al.,* 2011). In addition, we also assessed whether the platforms support variety and are evolvable by determining the degree to which they are used as a base for product variants and generations (cf. Koufteros *et al.*, 2014).

3.3 Reliability and validity

Cronbach's alpha α was used to assess the scale reliability of the independent variables (Table 3). Both independent variables had high α-values, above the normally accepted value 0.7, and item-total correlations above 0.3. In addition, none of the values would increase reliability if deleted, indicating that all values positively contribute to overall reliability.

To ensure validity of the product modularization and platform thinking measures, factor analyses were conducted. The results of the factor analyses are reported in the appendix. A principal component analysis with direct oblimin rotation was used for the preliminary evaluation of variables. The exploratory factor analysis had overall Kaiser-Meyer-Olkin measure of sampling adequacy was 0.85, above the commonly recommended value of 0.6 and the Bartlett's test of sphericity was significant ($p < 0.005$), indicating that the items were appropriate for factor analysis. The Kaiser rule (eigenvalues > 1) was employed in combination with evaluation of scree plots. Based on these criteria, a two-factor solution consistent with our theoretically based operationalization of platform thinking and product modularization was chosen. The solution showed convergent validity as the items within each factors were highly correlated.

Table 2. Dependent research variables

Categories and items
Marketplace condition *(1: not at all, 7: to a very high degree)*
Variation in demand
Demand for product customization
Price pressure
Competitive rivalry
Rapid technological change
Product development organization
How large a portion of product development a cross-functional team conducts *(1: no amount, 7: entirely)*
How often project management is physically collocated *(1: never, 7: always)*
The degree of use of formal product development process in projects *(1: very low degree, 7: very high degree)*
Use of outsourcing of product development work *(Percentage outsourced)*
Product development practices *(1: not important, 7: very important)*
Failure mode and effects analysis (FMEA)
Design for Assembly (DFA)
Quality function deployment (QFD)
Rapid prototyping (e.g. SLA/SLS etc.)
Agile work procedures (e.g. Scrum)
Defined gates and/or goals (e.g. Stage-gate)
TRL classification (Technology Readiness Level)

Table 3. Independent research variables

Item	References	α if deleted	Item-total correlation
Product modularization **(α = 0.90)**			
Separate modules: Our products are divided into separate modules	*(Worren et al., 2002; Lau et al., 2007; 2009)*	0.86	0.81
Combinable modules: Our modules can be combined in several ways to create product variants	*(Duray, 2004; Jacobs et al., 2007; 2011)*	0.83	0.84
Independent modules: We can make changes to a module without other modules need to be reconstructed	*(Worren et al., 2002; Lau et al., 2007; 2009)*	0.89	0.78
Platform thinking **(α = 0.80)**			
Product generations: We develop product platforms that constitute the base for multiple future product generations	*(Koufteros et al., 2014)*	0.74	0.62
Product variants: We develop a great number of product variants based on respective platforms		0.75	0.62
Platform Products:* What amount of your products is based on product platforms?	*(Pasche et al., 2011)*	0.73	0.66
*Common components *:* What amount of common components do the product variants based on a platform do you have?	*(Pasche et al., 2011*	0.78	0.56

**These items are translated from percentage (1% to 100%) to a 7-point scale*

In addition, the items showed high discriminant validity, as each item loaded considerably better on one factor than the other. The only exception was the item "product variants", which cross-loaded on both factors. However, due to the wording of the question, we decided that "product variants" should be retained as an item within the "platform thinking" factor. Confirmatory factor analysis was subsequently constructed on the previous two-factor solution, as well as on a one-factor solution. The two-factor solution showed high overall fit ($\chi^2/df = 2.48$, RSMEA = 0.06, NFI = 0.96, CFI = 0.99), whereas the one-factor solution showed a poor fit ($\chi^2/df = 4.60$, RSMEA = 0.15, NFI = 0.88, CFI = 0.90). This indicates that a two-factor solution with the proposed items does indeed fit the underlying data best. In addition, the AVE and composite reliability measures indicated the two-factor solution to be reliable, too.

4. Findings and Discussion

The data was analyzed using independent sample t-tests, where the total sample was divided into independent subsamples dependent on their average score in the independent research variables. Three different groups of t-tests were done, comparing firms with:

- Low versus high use of modularization (column 1, Tables 4-6).
- Low versus high use of platform thinking (column 2, Tables 4-6), and
- Low versus high use of both modularization and platform thinking (column 3, Tables 4-6)

The firms that had an average score larger than 5 in the relevant independent research variable were categorized as having a high degree of product modularization or a high degree of platform thinking. The firms that had an average score equal or higher than 5 both in terms of platform thinking and product modularization were categorized as having a high combined use of product modularization and platform thinking.

4.1 Marketplace conditions (Table 4)

Firms with a high use of product modularization or a high use of both product modularization and platform thinking simultaneously experience a significant higher demand for product customization than other firms ($p = 0.00$; $p = 0.08$). When it comes to platform thinking, however, there is no difference in the degree to which customers demand product customization between firms employing platform thinking and those that do not. These findings concur with the arguments of Magnusson and Pasche (2013), who reason that when customers specifically value a high degree of customization, a modularization strategy is fruitful as it enables firm to quickly incorporate module changes, and that, under the same circumstances, a platform strategy would be hindering as this strategy promotes a high degree of stability within significant parts of the product. The combination of modularization and platform thinking in situations with a high demand for product modularization has been proven successful in certain industries, such as the computer and car industries (Magnusson and Pasche, 2013). However, a well-known drawback of platform thinking is that it, if not managed properly, can lead to the firm not being able to efficiently differentiate product offers (Sköld and Karlsson, 2007) and the "*overdesign of low-end variants in the firm's product family to enable subsystem sharing with high-end products*" (Halman *et al*., 2003, p. 152). Even though the customer demand for product customization is significantly different between firms that adopt a high versus a low degree of product modularization, it should be noted that in areas where customers demand a very high degree of customization, modularization and platform thinking may not be appropriate as they do not support the design and manufacture of a single fully customized product that adheres only to the wishes of a solitary customer (da Silveira, 2001).

The results indicate that firms with a high use of platform thinking experience a significantly lower degree of technological change than firms with no or low use of platform thinking (p = 0.07). The upfront investment costs and time needed for developing platforms are considerably higher compared to the development of a single product (Halman *et al*., 2003; Pasche *et al.,* 2011). In addition, standardization can act as an internal force, introducing rigidity to the organization that prevents firm from adopting newer and better technology (Ulrich, 1995; Ernst, 2005). As a result, the use of platform thinking might not be appropriate for firms that experience a higher degree of technological change, as firms with a high degree of platform thinking will not able the reap the benefits of reuse and may not be equipped to accommodate new technology. The same logic may be applied to the design of modular components, as modular systems are more demanding to design than comparable interconnected systems (Baldwin and Clark, 1997) and also rely on the principle of component reuse. However, product modularization as a strategy can better handle higher speeds of change compared to platform thinking (Magnusson and Pasche, 2013), as these firms with this strategy are less bound to a technological trajectory, have lower levels of standardization, and can better accommodate heterogeneous inputs through reconfiguration (Eom, 2008).

It is surprising to find that there is no significant difference between firms with a high versus low use of product modularization and/or platform thinking when it comes to variation in demand. Both practices are often said to give the firm the ability contain the impact of changes. This means that desired changes can be accommodated through making the needed alterations by revising old components or even creating new components, without having to change the underlying product structure and platform (Sanchez, 1995). However, the finding that market dynamics are not necessarily related to the adoption of platform thinking and modularization is concurrent with the findings of Worren *et al*. (2002), who did not find support for the suggestion that increased uncertainty encourages the company to adopt a modular product architecture.

Table 4. Marketplace conditions

		PM			PT			PM and PT		
		N	Mean	Sig	N	Mean	Sig	N	Mean	Sig
Variation in demand	Lo	*84*	4.65	0.63	*82*	4.76	0.57	*93*	4.77	0.37
	Hi	*53*	4.77		*55*	4.62		*44*	4.55	
Demand for product customization	Lo	***83***	**4.89**	**0.00**	*81*	5.20	0.93	***92***	**5.07**	**0.08**
	Hi	***53***	**5.70**		*55*	5.22		***44***	**5.50**	
Price pressure	Lo	*84*	5.62	0.64	*83*	5.65	0.41	*94*	5.66	0.27
	Hi	*54*	5.52		*55*	5.47		*44*	5.41	
Competitive rivalry	Lo	*83*	5.49	0.95	*82*	5.45	0.63	*93*	5.45	0.57
	Hi	*54*	5.48		*55*	5.55		*44*	5.57	
Rapid technological change	Lo	*81*	3.14	0.56	***82***	**3.37**	**0.07**	*93*	3.25	0.52
	Hi	*54*	3.28		***55***	**2.95**		*44*	3.09	

4.2 Product development organization (Table 5)

There is no significant difference between firms that have a high degree of platform thinking and those that do not when it comes to the use of cross-functional teams. This is unexpected, as platforms cut among several product lines and divisional boundaries and thus require the use of cross-function teams to resolve organizational conflicts (Robertson and Ulrich, 1998; Halman *et al*., 2003) Though, given this finding, it is not surprising that there also is no significant difference in terms of the physical co-location of management, as co-location is used to strengthen the typical advantages of cross-functional teams (Muffatto and Roveda, 2000).

The results of the t-tests indicate that firms with a high degree of platform thinking use a more formalized approach to their product development process, compared to firms with no or little platform thinking ($p = 0.03$). This is consistent with the arguments put forward by Magnusson and Pasche (2013), who argue that a higher degree of formalization supports coordination in and between the teams responsible for platform thinking, as formalization helps keeping the platform and its interfaces stable and well understood. Likewise, Muffatto and Roveda (2000) find that, in order to enable technical solutions to be repeated and standardization objectives to be met, common leadership or formalized teams are the best way to disseminate information. The reason why product modularization to a lesser extent is reliant on formalization might be explained by the fact that modularization reduces the need for interaction among design teams by decomposing the system into components that can be developed by independent autonomous teams (Schilling, 2000; Kamrad *et al.*, 2013)

In terms of outsourcing, the findings suggest that firms with a high use of platform thinking or a high use of both product modularization and platform thinking simultaneously conduct a significantly lower amount of outsourcing of development work than other firms ($p = 0.00$; $p = 0.00$). This might be explained due to the fact that firms with a high degree of platform thinking strategically prioritize product development and, consequently, spend a lot more effort and resources internally to create and manage product platforms. As a result, the relative amount of work (compared to the total amount of product development work) outsourced by these companies is lower. Another explanation could be that the development and management of product development work becomes an internal, implicit competence for the firm, where it becomes difficult to incorporate other external players in product development. In the product modularization literature, it is suggested that product modularization enables black box sourcing, where suppliers develop and design a module according to the functional requirements and interfaces within the final product (Bouttellier and Wagner, 2003). However, our findings do not suggest the firms with a higher degree of product modularization employ a higher amount of outsourcing.

Table 5. Product development organization

		PM			PT			PM and PT		
		N	Mean	Sig	N	Mean	Sig	N	Mean	Sig
Use of cross-functional teams	Lo	*84*	5.05	0.19	*83*	5.10	0.43	*94*	5.07	0.24
	Hi	*54*	5.39		*55*	5.31		*44*	5.41	
Physical co-location of project management	Lo	*84*	3.56	0.48	*83*	3.60	0.71	*94*	3.64	0.90
	Hi	*54*	3.80		*55*	3.73		*44*	3.68	
Use of formal product development process	Lo	*84*	5.07	0.49	***83***	**4.89**	**0.03**	*94*	5.01	0.15
	Hi	*54*	5.28		***55***	**5.55**		*44*	5.45	
Degree of outsourcing of development work	Lo	*81*	12.54	0.39	***79***	**15.43**	**0.00**	***90***	**14.48**	**0.00**
	Hi	*49*	9.90		***51***	**5.53**		***40***	**4.95**	

4.3 Product development practices (Table 6)

Firms with a high degree of product modularization, as compared to firms with a low degree of product modularization, employ a higher degree of FMEA ($p = 0.07$), DFA ($p = 0.07$), QFD ($p = 0.01$) and TRL classification ($p = 0.01$). Firms with a high degree of platform thinking employ a higher degree of defined gates and/or goals ($p = 0.03$) and TRL classification ($p = 0.02$). Firms combining both product modularization and platform thinking employ FMEA ($p = 0.07$), DFA ($p = 0.08$) and TRL classification ($p = 0.01$) to a larger extent.

TRL classification is used in all three groups of firms, i.e. firms with a high degree of product modularization, firms with a high use of platform thinking, and firms that use these practices in combination. This is understandable, as these firms have to respond to or lead technological change by integrating new technology into an already existing product structure and architecture (Sanchez, 1995). Without having an assessment of the risks and manufacturing readiness of the new technology and an approximation of the time and costs it takes to fully mature this technology (Britt *et al*., 2008), the firm can risk a disruption in their platform plan or risk including immature technology into core platform or product architecture.

Both QFD and DFA are design-for-variety practices. That firms with high product modularization also implement these practices seems reasonable, since both QFD and DFA are tightly connected to the development of modules. In fact, QFD is even the first step in a popular product modularization technique, Modular Function Deployment, to make sure that the right design requirements are derived from market needs (Erixon, 1996). DFA has the purpose to ease assembly by improving the assembly procedure and through the integration and standardization of components (Kuo *et al*., 2001). Not only is the design of a low-cost assembly system an important problem in modularity design (Kuo *et al*., 2001), DFA can even facilitate in the creation of standardized modules, making it a promising complement to product modularization. The focus of FMEA is on the potential failure modes of every system component (Sankar and Prabhu, 2000). Therefore, the heightened use of FMEA in firms employing product modularization and those employing both product modularization and platform thinking may be a result of these firms acknowledging the fact that, if one of the standard components or modules fail, the failure would not only affect one or a couple of products, it would have a negative impact on a wide range of product variants.

Table 6. Product development practices

		PM			PT			PM and PT		
		N	Mean	Sig	N	Mean	Sig	N	Mean	Sig
Failure mode and effects analysis (FMEA)	Lo	***83***	**4.05**	**0.07**	*82*	4.12	0.22	***93***	**4.09**	**0.07**
	Hi	***54***	**4.65**		*55*	4.53		***44***	**4.70**	
Design for Assembly (DFA)	Lo	***83***	**3.67**	**0.07**	*82*	3.84	0.64	***93***	**3.71**	**0.08**
	Hi	***53***	**4.26**		*54*	4.00		***43***	**4.33**	
Quality function deployment (QFD)	Lo	***82***	**3.06**	**0.01**	*81*	3.33	0.66	*92*	3.25	0.18
	Hi	***50***	**3.92**		*51*	3.47		*40*	3.70	
Rapid prototyping (e.g. SLA/SLS etc.)	Lo	*82*	3.62	0.45	*81*	3.62	0.44	*92*	3.55	0.14
	Hi	*52*	3.88		*53*	3.89		*42*	4.10	
Agile work procedures (e.g. Scrum)	Lo	*79*	3.33	0.56	*77*	3.34	0.53	*87*	3.31	0.62
	Hi	*45*	3.13		*47*	3.13		*37*	3.14	
Defined gates and/or goals (e.g. Stage-gate)	Lo	*83*	5.02	0.13	***81***	**4.95**	**0.03**	*91*	5.04	0.13
	Hi	*52*	5.44		***54***	**5.54**		*44*	5.48	
TRL classification	Lo	***78***	**2.82**	**0.01**	***75***	**2.81**	**0.02**	***85***	**2.85**	**0.01**
	Hi	***47***	**3.62**		***50***	**3.58**		***40***	**3.70**	

The results indicate that firms with a high degree of platform thinking tend to use defined gates and/or goals. This is closely related to the fact that these firms also adopt a higher degree of formalization. Similar to the formalization of the product development processes and projects, gates and goals can provide a means for teams to coordinate and ensure a stable and well-understood product platform. In addition, gates and goals can help firms to manage the platform planning process, a process that is inherently complex and requires the firm to plan for both current and future product variants and successive generations of products (Meyer and Lehnerd, 1997).

5. Conclusions and further research

Product modularization and platform thinking are both practices that seek to alleviate the negative impact of product customization and variety on internal operations by relying on economies of substitution (Garud and Kumaraswamy, 1993). Through the use of a standardized pool of components and interfaces, these practices aim to create a broad spectrum of product choices. At first sight, product modularization and platform thinking are very similar. The difference between these practices can, however, be found in the manner in which they employ standardization. Where product modularization focuses on creating building blocks, i.e. modules with standardized interfaces and distinctive functions, that can be mixed and matched to create product variants, product platforms have an even stronger emphasis on standardization, using the same pool of core platform components and interfaces over the life of the platform and relying on distinctive variable components to create product variants. This paper is based on the proposition that these differences between product modularization and platform thinking influence 1) the context in which the combined or separate use of the concepts is appropriate, and 2) the types of product development practices complimenting these approaches.

5.1 Organizational and environmental contingencies

The external context plays an important role in the adoption of product modularization and platform thinking. Actually, the practices are often stated to be a response to and/or even a driver behind a new paradigm in product competition, where firms have to adhere to increasingly sophisticated customers that are demanding a greater degree of customization and variety than ever before (Pine, 1993; Sawhney, 1998; Worren *et al*., 2002). The internal context of the firm also plays an important role in determining the appropriateness of product modularization and platform thinking. In particular, the organization of product development work heavily influences and is influenced by the manner of and degree to which these practices are implemented and adopted within the organization (Baldwin and Clark, 1997; Pasche *et al*., 2011; Pasche and Skold, 2012; Magnusson and Pasche, 2013). Therefore, this paper examines which organizational and environmental contingencies influence the adoption of product modularization and/or platform thinking.

As modularization and the use of product platforms often are linked to the (mass) customization of products (da Silveira *et al*., 2001; Fogliatto *et al*., 2012), one environmental contingency included in this paper is the degree to which customers require customization. The results indicate that firms employing product modularization solely or combined with platform thinking have customers that specifically value customization. This implies that a modularization strategy is beneficial in these settings, possibly due to the fact that this strategy enables firms to quickly respond to customer demands by changing or personalizing modules. Another important environmental contingency is the rate to which technology changes. Since product modularization and the design of platforms are costly and resource intensive exercises, these strategies may not be applicable in environments with high technological change, where firms are not capable of reaping the benefits of module and component reuse. However, the findings indicate that only firms that employ high degrees of platform thinking experience lower rates of technological change. This might imply that product modularization as a strategy better can handle technological change, as firms employing this strategy are less bound to a technological trajectory than compared to firms using platform thinking.

An important organizational contingency to the use of platforms is the degree to which the product development process is formalized. Literature suggests that platform thinking is best supported through formalization, as a formalized product development process helps keeping the platform and its interfaces stable and also enables technical solutions to be repeated (Muffatto and Roveda, 2000; Magnusson and Pasche, 2013). The empirical results in this paper support this suggestion, as firms employing high degrees of platform thinking also have a higher degree of formalization. The sole use of platform thinking or combined with product modularization is found to be related to a lower degree of outsourcing of product development work. This might indicate that it is difficult to incorporate external suppliers in the work with immature product platforms, as platform thinking is a highly complex task and may constitute an implicit competence for the firm.

5.2 Complementary product development practices

In addition exploring contingencies, this paper also looks at which product development practices often are implemented in unison with product modularization and/or platform thinking, something that has, to the knowledge of the authors, not been empirically tested before. It is found that firms that employ product modularization also use a wide range of complementary practices, including QFD, DFA, FMEA and TRL classification. DFA can prove to be a very useful complementary practice to product modularization, as it can help the firm design modules according to assembly needs and also can help decrease the cost of assembly, a process that is all-important for modular systems (Kuo *et al*., 2011). In a similar vein, QFD can also help during module design, as it enables the firm to interpret and translate customer requirements. Last but not least, using TRL classification and FMEA can help firms with high modularization prevent very costly misfortunes, as adding a defective module or immature technology to a base of interchangeable modules would not only affect one or a couple of products, but have a negative impact on a wide range of product variants.

Platform thinking has a fewer amount of complementary practices, however, the findings do indicate that TRL classification and the use of defined gates and goals in product development supplement the use of platforms. Firms using product platforms have to respond to or lead technological change by integrating new technology into an already existing product structure. Without using TRL classification and defined goals and gates, these firms can risk that immature technology is incorporated in their core platform and that their long-term platform-based plan for future product variants and successive generations is disrupted.

5.3 Further research

A major exclusion in this study is the missing link with performance. Although firms with high levels of platform thinking and modularization exist in different market conditions and prefer certain product development structures and practices, it cannot stated whether these firms reap the performance benefits of using complementary practices or adhering to the stated contingencies.

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Appendix A. Results from the exploratory factor analysis.

Factor loadings, individual KMO measures of sampling adequacy and communalities. Factor loadings in bold indicate which factor the item is part if, product modularization (PM) or platform thinking (PT).

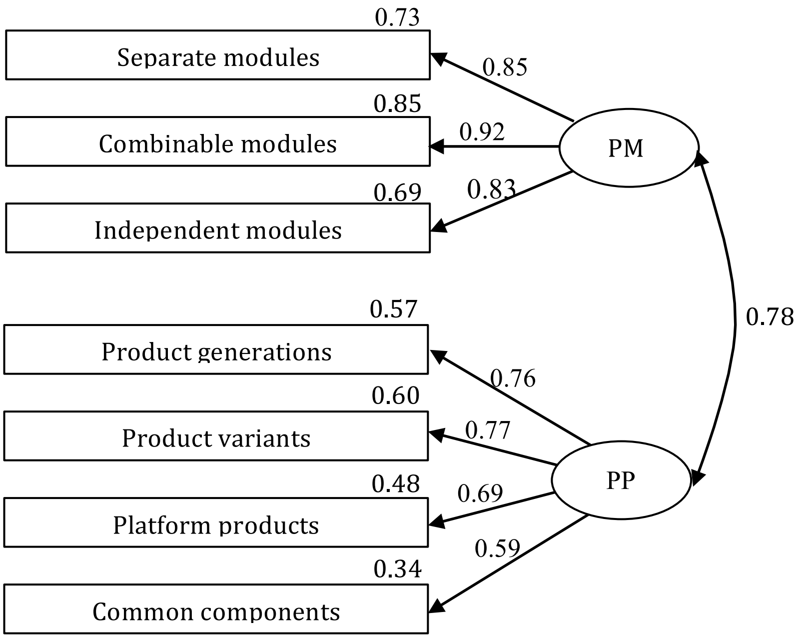
	Factor Loadings		KMO measure of sampling adequacy	Communalities
	PM	PT		
Combinable modules	**0.93**	0.47	0.87	0.80
Separate modules	**0.91**	0.42	0.83	0.84
Independent modules	**0.88**	0.49	0.77	0.89
Product variants	0.71	**0.69**	0.64	0.89
Platform products	0.48	**0.84**	0.71	0.86
Common components	0.31	**0.83**	0.70	0.84
Product generations	0.58	**0.77**	0.63	0.86

Appendix B. Results from the confirmatory factor analysis

Goodness of fit indices of two factor-solution and one-factor solution

	Goals	Two-factor solution	One-factor solution
Absolute fit indices			
Chi-Square		19.81	64.44
Chi-Square (*p* value)	*> 0.05*	0.10	0.00
Normed Chi-square (X^2/df)	*< 3*	2.48	4.60
Root mean square of error of approximation (RSMEA)	*< 0.07*	0.06	0.15
Incremental fit indices			
Normed fit index (NFI)	*> 0.90*	0.96	0.88
Relative fit index (RFI)	*> 0.90*	0.92	0.76
Incremental fit index (IFI)	*> 0.90*	0.99	0.90
Comparative fit index (CFI)	*> 0.90*	0.99	0.90

Model of two-factor solution with factor loadings, squared multiple correlation coefficients and factor correlation



Factor loadings, average variance extracted (AVE) and composite reliability for two-factor solution

	Standardized factor loadings	R^2	AVE	Composite Reliability
Product modularization (PM)				
Combinable modules	0.92	0.85		
Separate modules	0.85	0.73	0.75	0.90
Independent modules	0.83	0.69		
Platform thinking (PT)				
Product variants	0.77	0.60		
Platform product	0.69	0.48	0.50	0.80
Common components	0.59	0.34		
Product generations	0.76	0.57		