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MODULARIZATION, INTER-FUNCTIONAL INTEGRATION AND OPERATIONAL PERFORMANCE

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ABSTRACT

Many publications have contributed to create the widely held belief that product modularity is "good", i.e. holds many performance benefits. However, few of these publications are based on rigorous empirically based research. The focus of this paper is on some of the conditions considered necessary for firms to indeed use product modularity beneficially, in particular inter-functional integration between manufacturing and purchasing, design and sales, respectively. The purpose of the paper is to investigate the direct performance effects of modularization, as well as the mediating effects of the three forms of integration in the modularization-performance relationship.

***Keywords**: Modularization, Inter-functional Integration, Operational Performance, Mediated Regression, Survey*

1. INTRODUCTION

One of the purposes of organizational research is to discover and propose practices and structures that help firms perform better. One of the practices of recent interest is product modularization, which has been claimed to enable firms to produce a greater variety of products based on a smaller set of common components (Ulrich and Tung, 1991), and thereby help them to overcome product variety-operational performance trade-offs (Salvador *et al.*, 2002).

Older articles examining the concept seek to 1) define modularity, 2) explore the effects of modularity on the firm, its processes and performance and 3) propose methodologies for implementing and creating modularity (e.g. Starr, 1965; Karmarkar and Kubat, 1987; Ulrich and Tung, 1991; He and Kusiak, 1996; Kusiak and Huang, 1996; Newcomb *et al.*, 1996; Rosen, 1996; Sanchez and Mahoney, 1996; Baldwin and Clark, 1997; Gershenson and Prasad, 1997; Gu *et al.*, 1997; Huang and Kusiak, 1998). Common to the majority of these articles is that they are largely theoretical rather than based on original empirical research. After the turn of the century, authors started conducting more empirical studies to explore product modularity and its effects. Among these was a group of authors conducting survey-based research aimed at exploring the relationship between modularity and performance, and mediating or moderating effects of, amongst others, inter-functional integration and supplier integration (Worren *et al.,* 2002; Lau *et al.*, 2007; 2009; Jacobs *et al.*, 2007; 2011; Danese and Filippini, 2010; 2013).

This paper contributes to this research agenda and aims to empirically examine:

1) The direct effects of modularization on operational performance, and
2) Indirect effects by establishing whether the relationship between product modularization and operational performance is partially or fully mediated by

purchasing, design and/or sales integration.

The overall research model is shown in Figure 1.

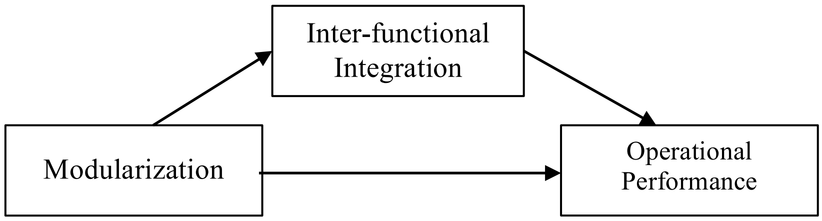

Figure 1. The research model

2. THEORETICAL BACKGROUND

2.1 PRODUCT MODULARITY AND RELATED CONCEPTS

Product modularity has been treated from different angles, including philosophical approaches to modularization, i.e. *modularity thinking*, operational approaches to creating modular products, i.e. the modular product *design process*, or the result, modularity as a *design property*.

The development of modularity theory started at the level of *modularity thinking*. Examples include Starr (1965) and Sanchez (1995), articles that sought to introduce and promote the concept. An example of *design process* is Baldwin and Clark (2000, p. 52) who define modularization as "*a procedure that uses knowledge of design structure and design parameter interdependencies to create design rules*". This knowledge of the design structure is created through the use of the design structure matrix. Others take a more holistic approach to the design process, assessing for instance the appropriateness and degree of modularity, or the links between modularity and functional strategies (Asan *et al.,* 2004). Campagnolo and Camuffo (2010) refer to "modularity as a *design property*" as the functional perspective, which focuses on the modules, functions and links between modules. One of the most cited definitions of product modularity takes this perspective: "a *modular architecture includes a one-to-one mapping from functional elements in the function structure to the physical components of the product, and specifies decoupled interfaces between components*" (Ulrich, 1995, p. 422).

We focus on the extent to which a firm has implemented and actually uses product modularity, i.e. *modularization degree*, which affects the extent to which a firm is able to (Boer, 2014; based on for the product modularity measures used by Tu *et al.,* 2004; Lau *et al.*, 2007; 2009; Worren *et al.,* 2002):

- Use the same component in several products for the same functional purpose (commonality).
- Carry over components from previous product generations (carry-over).
- Minimize the complexity and enhance the speed of assembly (quick assembly).
- Make changes to key components without changing others (independence).
- Combine different sets of components to create multiple products (combinability).

Modularization is related to the use of product platforms, i.e. platform thinking, as both focus on creating a "*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. xii) based on a common product architecture. Similar to the use of product modularity, platform thinking promotes having a set of common modules from which a series of derivative products can be produced (commonality and carry-over), replacing subsystems while maintaining the overall structure (independence), and achieving simplicity in design through modular construction (quick assembly). Another concept focusing on simplicity in design is the design for manufacturing and assembly methodology (DFMA), which seeks to simplify the product structure by reducing the underlying part count and production steps and using standard common parts and modular designs (Boothroyd, 1994; Emmatty and Sarmah, 2012). As these concepts are closely interlinked, this paper focuses on modularization, including the use of product platforms and DFMA, and seeks to understand how these concepts affects operational performance.

2.2 Inter-Functional Integration

Integration can be defined as "*the process of achieving unity of effort among the various subsystems in the accomplishment of the organization's task*" (Lawrence and Lorsch, 1967, p. 4). The organization's task is to perform the input-transformation-output cycle, represented by the purchasing, manufacturing and sales functions and supported by the design function.

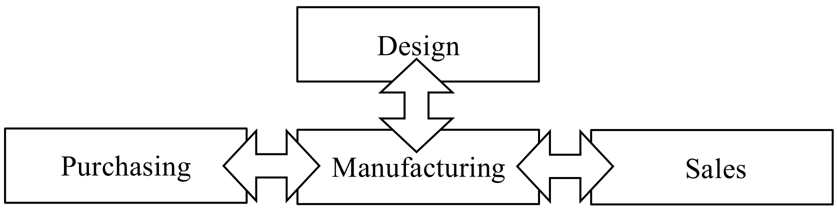

Figure 2. Inter-functional integration

Integration between these functions (Figure 2), needed to enhance the unity of effort referred to, can be achieved through various mechanisms that can be grouped into the following categories (Paashuis and Boer, 1997):

- *Organizational integration*: Structural arrangements to divide and coordinate labor. Examples are liaison roles, co-location and cross-functional teams.
- *Technological integration*: Use of standardized methods, techniques, tools, and equipment to coordinate work. Examples are CAD/CAM and House of Quality.
- *Strategic integration*: Standardized goals and strategies to achieve these goals through, for instance, policy deployment and performance management.

2.3 Modularization and Operational Performance

Modularization can help firms to overcome the product variety-operational performance trade-off (Salvador *et al.*, 2002) and creates the opportunity for firms to use combinatorial variety of assemblies in manufacturing (Starr, 1965), as it allows firms to produce finished products based on a smaller set of subassemblies (Arnheiter and Harren, 2004) and use "*one of several alternative component options to implement a functional element in design"* (Ulrich and Tung, 1991, p. 5). As modularization leads to a relatively smaller set of components, firms can achieve economies of scale, not on product level but on component level (Ulrich and Tung, 1991), increased manufacturing efficiency, lower overall inventory levels, and increased reliability. The use and, especially, re-use of a limited number of components, supports learning curve effects, as employees get more experienced with the relatively stable component base over time. Combined with postponed manufacturing (Van Hoek, 1997), modularization allows for delayed product differentiation to the final processing steps, when customer requirements are known.

Modularization may also improve purchasing performance. For instance, Ulrich and Tung (1991) posit that firms can achieve costs benefits due to the supply of standard components. For less standard components, the standardized interfaces of a modular product portfolio allow for "black-box sourcing" (Cabigiosu *et al.,* 2013), where suppliers not only manufacture, assemble and deliver but also develop and design modules according to the interface and functional specifications (Boutellier and Wagner, 2003).

In the design and product development processes, modularization may aid in increasing innovation rates by having teams work individually on module level (Baldwin and Clark, 1997), that is, product modularity supports modular innovation. However, "*modular systems are* [also] *more difficult to design than comparable interconnected systems"* (Baldwin and Clark, 1997, p. 86) as it requires extensive knowledge of the product, its components and interfaces, as well as the underlying processes to design a modular system. In addition, it may introduce system rigidity (Ernst, 2005) and reduce the opportunities for breakthrough innovation (Fleming and Sorensen, 2001), as the underlying modular product architecture may be difficult to change once implemented and instituted.

Standardized interfaces support the replacement or upgrade of modules after the end product has been sold, to accommodate for wear and consumption (Ulrich, 1995). When a failure occurs in the end product, it also is easier to diagnose and localize the failure and replace the failed module (Karmarkar and Kubat, 1987). However, modular upgradability may result in an increase in spare parts inventory (Huang and Kusiak, 1987). Compared to their integrated counterparts, which allow for function sharing and geometric nesting (Ulrich, 1995) and have components specifically designed for the individual products, modular products may exhibit lower product performance, as their components are not designed for one application but have been designed so that they meet the requirements of multiple products.

Area	Performance effects
Manufacturing	Component economies of scale Combinatorial variety of assemblies Learning curve effects Delayed product differentiation
Purchasing	Component economies of scale Black box sourcing
Design	Increased innovation rates through modular product development Resource intensive upfront development System rigidity and complexity
Sales	Upgradability and product retirement Lower product performance Enhanced product support

Table 1. Performance effects of modularization

2.4 Modularization and Inter-functional Integration

Modularization can provide a foundation for organizational, technological and/or strategic integration (Paashuis and Boer, 1997), since it is based on the *standardization* of components and their interfaces. Sanchez and Mahoney (1996, p. 66), for example, state that modular products, and in particular, the use of standardized interfaces "*permits effective coordination of development processes without the continual exercise of managerial authority*". If the interfaces, i.e. interactions between modules, are fully understood and standardized, different groups of designers can perform module-level improvements in parallel, as long as they adhere to these interface specifications (Baldwin and Clark, 1997; Ulrich and Tung, 1991).

For most firms, however, product modularity is a matter of degree, as the creation of fully decoupled modules is difficult (Persson and Åhlström, 2006). As a result, most products are located on a continuum between the extremes of pure modularity and pure technological interdependence (Ernst, 2005). Therefore, in most cases, it can be expected that there are unmatched design interfaces (Sosa *et al*., 2004), caused by undocumented product-related interdependencies that are discovered during the subsequent work with the product portfolio. Coordinating only across established interfaces and ignoring other underlying dependencies might result in inferior designs and increased time spent in the testing and integration phases of product development (Ethiraj and Levinthal, 2004). Therefore, modularized products with standardized interfaces still need organizational coordination (Persson and Åhlström, 2006). To coordinate the different development teams, Baldwin and Clark (1997) propose that, amongst others, the firm needs to articulate a strategy and plans for the product line's evolution (strategic integration), and specify what roles senior management, the core design team, and support groups should play in carrying out the project's work (organizational integration).

Modularization and platform thinking promotes the use of the underlying platform architecture to create and launch a stream of derivative products (Meyer and Lehnerd, 1997) and using economies of substitution where "*technological progress may be achieved by substituting certain components while reusing others"* (Garud and Kumaraswamy, 1995). This creates the need not only to develop and produce new modules, but also to develop interface specifications iteratively. Realizing economies of substitution requires the design of systems, incentives, and structures that promote knowledge sharing rather than knowledge hoarding (Garud and Kumaraswamy, 1995), as firms need to balance different organizational functions' requirements to the product modules (Persson and Åhlström 2006). Ahmad *et al.* (2010, p. 49) state that "*at least three functional units such as marketing, R&D, and manufacturing need to coordinate their activities so that the subsystems ultimately work together and meet customer requirements*", each of which have different objectives and challenges. This paper examines whether the effects of modularization are enhanced by inter-functional integration of four functional units, that is, integration between purchasing, design and sales, respectively, and manufacturing.

3. METHOD

3.1 SAMPLE AND DATA COLLECTION

This paper uses data from the third release of the 6th international manufacturing strategy survey (IMSS VI) data set. The IMMS aims at studying the development of manufacturing strategies on both a national and international scale. The questionnaire enquires about more than 250 items, of which 28 are used in this paper. Furthermore, the 599 participants were used who had responded to all these 28 items. Table 2 depicts differences between the total sample and chosen subsample (figures in **bold** refer to the subsample analyzed in this paper).

ISIC Code	N		%	
25 Metal Products	239	**185**	30	**31**
26 Electronics	116	**89**	15	**15**
27 Electrical	115	**88**	15	**15**
28 Machinery	202	**152**	26	**25**
29 Motor Vehicles	80	**58**	10	**10**
30 Other transport	34	**25**	4	**4**
Total	786	**597** (1)	100	**100**

Region	N		%	
Northern Europe	125	**94**	16	**16**
Western Europe	120	**85**	15	**14**
Southern Europe	111	**68**	14	**11**
Eastern Europe	113	**88**	14	**15**
Asia	296	**247**	37	**41**
America	25	**17**	3	**3**
Total	790	**599**	100	**100**

Number of employees	N		%	
50-99	159	**123**	20	**21**
100-249	186	**150**	24	**25**
250-499	150	**114**	19	**19**
500-999	99	**69**	13	**12**
≥1000	182	**134**	23	**23**
Total	776	**590** (2)	100	**100**

(1) Two respondents did not fill in the ISIC code
(2) Nine respondents did not fill in the number of employees

Table 2. Sample demographics

Independent country-based research teams performed the data collection. Each team was also responsible for testing for late- and non-response bias. The third release of data consisted mostly of European contributions, where a total of 14 countries participated, but it also had data from four Asian countries and Canada. The survey was oriented at single plants that have a minimum of 50 employees. The target respondent was the manufacturing manager (or similar) of the plant. The plants that participated in the questionnaire belong to the ISIC Rev. 4 codes 25-30, which manufacture:

- Fabricated metal products (ISIC 25)
- Computer, electronics, and optical products (ISIC 26)
- Electrical equipment (ISIC 27)
- Machinery and equipment (ISIC 28)
- Motor vehicles, trailers and semi-trailers (ISIC 29)
- Other transport equipment (ISIC 30)

So, the IMSS VI data includes industries that have been widely covered within the modularity literature, i.e. the automotive and electronics industries, as well as other, less researched industries.

3.2 Research Variables and Measures

For each of the constructs a five-point Likert-type measurement scale is used. To measure the modularization degree (MD) and the individual integration levels, the respondents were asked to evaluate their current implementation level from none (1) to high (5). To assess operational performance, firms were asked to rate their performance

to be much lower (1), equal to (3) or much higher (5) than their main competitors.
MD is measured using a single item (see Table 3). In the questionnaire, modularization and related practices are viewed as a way to achieve integration between design and manufacturing, which is consistent with our earlier presentation of product modularity as an integration mechanism. To check if the one-item construct actually is a measure of the modularization degree, the construct was validated using a subset of respondents who were asked to answer to a more elaborate scale. This subset validated that the construct used in the questionnaire is a good representation of:

- The degree to which the firm uses common or carry-over components in their products,
- The firm's ability to combine modules to create variants and to make changes to key components without changing others, and
- The deliberate use of standardized connections between components.

The integration between manufacturing and design (DI), manufacturing and sales (SI) and manufacturing and purchasing (PI) is measured using the items shown in Table 3. Both SI and PI measures focus on joint decision making and the sharing of information, whereas DI is measured along the lines of Paashuis and Boer's (1997) distinction between organizational, strategic and technological integration. The Cronbach Alphas for the three constructs were all above 0.7, which indicates high internal consistency.

Constructs	Items
Modularization Degree (MD)	Design integration between product development and manufacturing through e.g. platform design, standardization and modularization, design for manufacturing, design for assembly
Design integration (DI) ($\alpha = 0.860$)	Informal mechanisms, such as direct, face-to-face communication, informal discussions, ad-hoc -meetings Organizational integration between product development and manufacturing through e.g. cross-functional teams, job rotation, co-location, role combination, secondment and coordinating managers Technological integration between product development and manufacturing through e.g. CAD-CAM, CAPP, CAE, Product Lifecycle Management Integrating tools and techniques, such as Failure Mode and Effect Analysis, Quality Function Deployment, and Rapid Prototyping Communication technologies such as teleconferencing, web-meetings, intranet and social media Forms of process standardization, such as a stage-gate process, design reviews and performance management
Sales integration (SI) ($\alpha = 0.785$)	Sharing information with purchasing department (about sales forecast, production plans, production progress and stock level) Joint decision making with purchasing department (about sales forecast, production plans and stock level)
Purchasing integration (PI) ($\alpha = 0.872$)	Sharing information with sales department (about sales forecast, production plans, production progress and stock level) Joint decision making with sales department (about sales forecast, production plans and stock level)

Table 3. Constructs, items and Cronbach's Alphas

To identify different components of operational performance, a principal component analysis with direct oblimin rotation was used (Table 4). Direct oblimin was used as the components were correlated stronger than 0.3. The Kaiser-Meyer-Olkin measure of sampling adequacy was 0.839, above the commonly recommended value of 0.6 and Bartlett's test of sphericity was significant ($p < 0.05$). A three-factor solution was chosen, named quality/delivery (QD), cost/speed (CS) and flexibility (F). These three factors had eigenvalues over one and the scree plot also leveled off after three factors. Each of the three factors had Cronbach Alpha values well above 0.6, which indicates an acceptable to good level.

	Quality/Delivery (QD)	Cost/Speed (CS)	Flexibility (F)
Product assistance and support	**.776**	-.005	-.103
Product quality and reliability	**.741**	.002	.013
Conformance quality	**.697**	-.048	.107
Customer service quality	**.694**	.074	-.125
New product introduction ability	**.635**	-.041	.146
Delivery reliability	**.633**	.054	.140
Delivery speed	**.523**	.029	.298
Ordering cost	-.116	**.788**	.125
Unit manufacturing cost	-.168	**.775**	.112
Procurement lead time	.189	**.737**	-.131
Manufacturing lead time	.179	**.719**	-.088
Volume flexibility	.029	.037	**.834**
Mix flexibility	.065	.038	**.807**
Product customization ability	.368	.013	**.417**
Total variance explained	34 %	14%	8 %
Total number of items	7	4	3
Cronbach's α	0.834	0.756	0.677

Table 4. Factor analysis using principal component analysis with direct oblimin rotation

4. RESULTS

Three separate regression analyses were conducted to detect whether integration mediates the relationship between modularization and operational performance. The first regression analysis tested design integration as a potential mediator, the second tested sales integration as a potential mediator, and the third regression tested purchasing integration as a potential mediator (Figure 3).

For each regression, the standardized coefficients were calculated based on the method outlined by Baron and Kenny (1994), who propose that three regression equations should be tested:

1) Regression of the mediator on the independent variable (*a* in Figure 3 and Table 4).
2) Regression of the dependent variable on the independent variable (*b* in Figure 3 and Table 4)
3) Regression of the dependent variable on both the independent variable and the mediator (*c* and *d* in Figure 3 and Table 4)

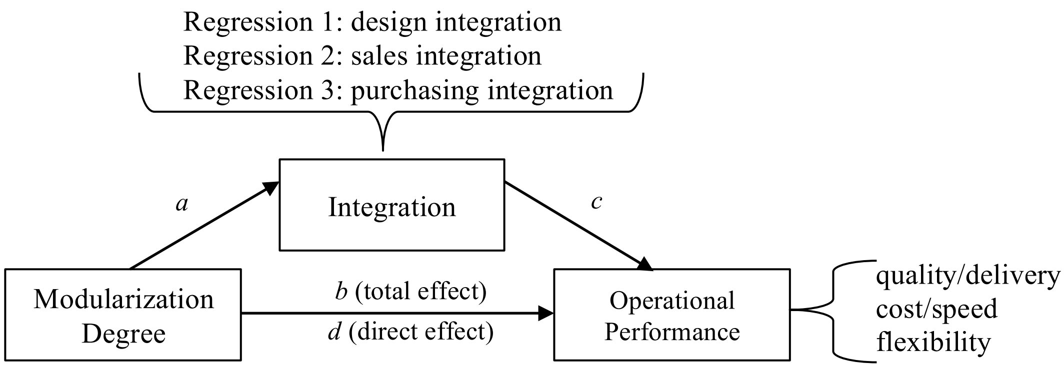

Figure 3. The regression model

For mediation to be present, a couple of conditions must be met. First, the independent variable must affect the mediator (*a*) and the dependent variable (*b)*. Second, the mediator must affect the independent variable (*c*). For partial mediation, the effects of the independent variable on the dependent variable must be smaller in the third equation (*d* must be smaller than *b*). For full mediation to occur, the independent variable should have no effect in the third equation (*d* = 0). In addition, the PROCESS software developed by Hayes (2013) was used to validate whether the indirect effect is actually present within a confidence interval of 95%. The Sobel test was conducted to check whether the indirect effect is significant. The results of the three regressions and the R^2 values are shown in Tables 5-8.

4.1 Results: The Effects of Modularization on Inter-Functional Integration and Operational performance

Column *a* in Tables 5-7 indicates that modularization has a positive effect on all three inter-functional integration types. The standardized coefficient for design integration is 0.616, for sales integration 0.321 and for purchasing integration 0.321. Column *b* in the tables shows that the total effect of modularization is positive for each performance dimension. The standardized coefficient for quality/delivery is 0.343, for cost/speed 0.212, and for flexibility 0.264. This column is identical in the three tables, as there is no integration involved in this regression.

a	The regression coefficient of integration on modularization
b	**Total effect:** The regression coefficient of the performance dimension on modularization
c	The regression coefficient of the performance dimension on the integration controlling for modularization
d	**Direct effect:** The regression coefficient of the performance dimension on modularization controlling for integration

Table 4. Coefficients calculated during the regression analyses

	a	*b*	*c*	*d*	Result	Hayes	Sobel
QD	0.616***	0.343***	0.338***	0.134***	Partial	[0.079,0.164]	0.000***
CS	0.616***	0.212***	0.124**	0.136***	Partial	[0.055,0.084]	0.015**
F	0.616***	0.264***	0.147***	0.174***	Partial	[0.017,0.107]	0.004***

Table 5. Regression 1: Mediation by design integration (DI)

	a	*b*	*c*	*d*	Result	Hayes	Sobel
QD	0.321***	0.343***	0.158***	0.292***	Partial	[0.015,0.082]	0.004***
CS	0.321***	0.212***	0.048	0.197***	None		
F	0.321***	0.264***	0.130***	0.222***	Partial	[0.010,0.077]	0.004***

Table 6. Regression 2: Mediation by sales integration (SI)

	a	*b*	*c*	*d*	Result	Hayes	Sobel
QD	0.321***	0.343***	0.202***	0.275***	Partial	[0.023,0.059]	0.000***
CS	0.321***	0.212***	0.106**	0.177***	Partial	[0.005,0.041]	0.016**
F	0.321***	0.264***	0.151***	0.213***	Partial	[0.016,0.056]	0.009***

Table 7. Regression 3: Mediation by purchasing integration (PI)

Significant at 0.1 *
Significant at 0.05 **
Significant at 0.01 ***

		PM	*PM and DI*	*PM and SI*	*PM and PI*
Quality/Delivery	R^2	0.118	0.189	0.140	0.154
	ΔR^2		0.071	0.022	0.036
Cost/Speed	R^2	0.045	0.055	0.047	0.055
	ΔR^2		0.010	0.002	0.010
Flexibility	R^2	0.070	0.083	0.085	0.090
	ΔR^2		0.013	0.015	0.020

		PM
DI	R^2	0.379
SI	R^2	0.103
PI	R^2	0.112

Tables 8. R^2 values

4.2 Results: The Indirect Effects of Modularization on Operational Performance

Columns *c* and *d* in the Tables 5-7 show the regression coefficient of the different performance dimensions on each integration type (*c*) and modularization (*d*). Note that the total effect (column *b)* is equal to the sum of the direct effect (column *d*) and the indirect effect (column *a* × column *c)*. For example, in Table 5, the row denoted CS, the total effect is *b* = 0.212, which is equal to the sum of direct effect *d* = 0.136 and the indirect effect 0.076 (calculated as 0.616 (*a*) × 0.124 (*c*)).
All the regression coefficients are positive and significant for all cases, except for the insignificant regression coefficient of cost/speed on sales integration controlling for the modularization degree (Table 6, column *c*). This indicates that there is no mediation in this particular case; all other relationships are mediated. In all these cases, the mediation is partial, as there are direct effects (*d)* as well as indirect effects (validated through the PROCESS method and the Sobel test). Table 8 presents the R^2 and ΔR^2 values, representing the explanatory power and its increase in the different regressions.

5. DISCUSSION

5.1 MODULARIZATION AND OPERATIONAL PERFORMANCE

Similar to Jacobs *et al.* (2007), we find that there is a positive total effect of modularization on the three performance dimensions – quality/delivery, cost/speed, and flexibility. This is an important contribution to a field that has been characterised by conceptual discussions and generalizations based on limited empirical backgrounds (Ernst, 2005). However, this finding should not be interpreted to suggest that it is beneficial for all firms to pursue a higher degree of modularization *per se*. It should be noted that some authors find that modularity is more a balancing act (Fleming and Sorensen, 2001; Ethiraj and Levinthal, 2004) than the Holy Grail. Other survey-based research has found that the relationship between modularization and performance is more nuanced. For instance Lau *et al*. (2007, 2009) and Worren *et al*. (2002) found that modularization is significantly correlated with some performance indicators, but not all. We did not check for the possible influence of any contextual variables, such as firm size, type of production process, and type of industry, on the modularization-performance relationship. Firm size, for instance, could affect the amount of resources a firm has to pursue modularization, whereas type of industry and production process could influence the appropriateness of modularization. The lack of control variables may also explain the relatively limited explanatory power of our findings (Table 8).

5.2 MODULARIZATION AND INTER-FUNCTIONAL INTEGRATION

Whereas Jacobs *et al*. (2007) found that modularization positively affects the implementation of functional integration (in manufacturing and design), we find that modularization positively influences *inter*-functional integration. We suggest that the underlying reason for this is twofold. First, modularization creates a *need* for coordination. It is not a one-off activity, but an iterative process, which needs constant sharing of knowledge to realize the economics of substitution (Garud and Kumaraswamy, 1995). Four important in-house sources of knowledge are purchasing (supplier knowledge), sales (market knowledge), design (product knowledge) and manufacturing (process knowledge) and their coordination is crucial in ensuring that the product portfolio can meet both operational requirements and customer needs. Second, modularization can also provide a *basis* for coordination. Through the standardization of components and interfaces, modularization not only simplifies the product portfolio by reducing the number of different components, but also creates standardized interface specifications, which can be used to achieve embedded coordination (Sanchez, 1995).

5.3 THE MEDIATING ROLE OF INTER-FUNCTIONAL INTEGRATION ON THE MODULARIZATION-PERFORMANCE RELATIONSHIP

This paper is based on the assumption that, in order to achieve the benefits of modularization, it should be embedded in a suitable infrastructure. We operationalize infrastructure as the integration between manufacturing and design, purchasing and sales, respectively. The results from the regression analyses largely corroborate our assumption. Although modularization in itself can provide a firm with positive performance effects, additional effects can be achieved if a suitable infrastructure is created. Modularization has a direct effect on both quality/delivery and flexibility, as well as indirect effects through design, sales and purchasing integration. This indicates that complementary integration mechanisms in the realms of design, sales and purchasing, can strengthen the performance effects in these areas. For cost/speed, additional performance effects can be expected through the simultaneous implementation of integration mechanisms between design and manufacturing and between purchasing and manufacturing. This relationship is, however, not mediated by integration between sales and manufacturing. This can be explained by the fact that cost/speed is measured in terms of manufacturing and procurement costs and lead-time, none of which are related to sales and sales performance.

6. CONCLUSIONS AND FURTHER RESEARCH

6.1 THEORETICAL AND PRACTICAL CONTRIBUTIONS

Prior to the turn of the century, research on product modularization was typically based on a limited empirical background, in the form of conceptual discussions or single success stories. This paper contributes to a recent stream of survey-based studies of the relationship between product modularization and firm performance. Results of the regression analyses based on IMSS VI data indicate that modularization does indeed have a significant effect on operational performance, and that inter-functional integration can provide additional performance effects. This is especially true for the integration of design and purchasing with manufacturing, which can provide supplementary performance effects in all the areas of operational performance examined, i.e. quality/delivery, cost/speed and flexibility. Manufacturing-sales integration can create additional performance effects in the areas of quality/delivery and flexibility.

For practitioners, this indicates that modularization may help a firm to overcome the operational performance-product variety trade-off, especially if modularization efforts are supported by the creation of a suitable infrastructure, in the form of integration between manufacturing and design, purchasing and sales, respectively.

6.2 LIMITATIONS AND FURTHER RESEARCH

One limitation to this study is that the results have not been controlled for variables such as firm size, type of industry and type of production process. Furthermore, the independent variable, product modularization, was operationalized using a one-item construct. Further statistical analyses should include appropriate control variables, and also use a more elaborate scale to measure the degree of modularization of a firm's product portfolio. In-depth case studies will be needed to further explore the nature of the relationship between product modularization and operational performance in more detail, as well as indicate not only *that* but also *how* particular inter-functional integration mechanisms complement modularization. Finally, the relatively limited, albeit not poor, explanatory power of the findings presented in this paper suggests that there may be more mechanisms and/or contingency factors in play. In-depth case will help identify such mechanisms and factors.

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