Bundling resources across supply chain dyads

The role of modularity and coordination capabilities

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Abstract

Purpose – The purpose of this paper is to analyze how firms are redesigning the organizational architecture of supply chains, bundling and unbundling resources, sharing information and coordinating flows in order to facilitate capability partitioning. It aims to analyze how process interdependencies are managed either through modularity or coordination mechanisms. The paper is anchored in the emergent theory of modularity, a transaction cost-based perspective of modular systems.

Design/methodology/approach – This paper adopts the case study methodology. It uses an in-depth case study of Logoplaste, a global supplier of plastic packaging, in particular investigating how the firm organizes supply chain activities around an integration mode designated as "hole-in-the-wall."

Findings – In a context of high process interdependence the firm has developed a coordination capability, an ability to manage the interfaces at minimum cost either by modularizing the process or defining appropriate coordination mechanisms. This capability becomes a core competence of the firm that enables it to further appropriate rents that lie at process interfaces.

Research limitations/implications – The case study method limits the generalization of the findings, but allows more depth in the analysis of the proposed framework.

Practical implications – As the complexity of sourced components increases firms will need to complement their modular approach to supply chain design with new organizational-coordination skills and an ability to externalize knowledge. The case study provides several examples of the type of coordination required.

Originality/value – This research adds to the literature on organizational modularity in two distinct ways. First, it focuses on the development of a coordination capability to manage process interdependences rather than the partitioning of technical capabilities across the supply chain. Second, it brings to the discussion of modularity recent developments in transaction cost economics that go beyond the engineering perspective. A coordination capability represents the organization's ability to organize transactions in order to appropriate rents, rather than merely minimize transaction costs.

Keywords Production processes, Supply chain management

Paper type Research paper

Introduction

The role of modularity in the design of organizations is a research topic that has raised interest among scholars from several disciplines, including operations management, strategic management, and industrial organization (Schilling and Steensma, 2001;

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Baldwin and Clark, 2002; Sanchez, 2002; Langlois, 2006). Modularity is a general set of principles for managing complex systems (Langlois, 2002) and is becoming more important as a strategy for organizing systems efficiently (Schilling and Steensma, 2001; Baldwin and Clark, 2002). The concept of modularity, initially applied to product design, has been extended to inform the design of processes, organizations and supply chains (Sanchez, 2002), in particular regarding the choice of sourcing and integration modes. An emergent theory of modularity explains module configuration based on the cost of transfers between system units (Baldwin and Clark, 2002; Langlois, 2006). A modular system is composed of units whose structural elements are powerfully connected among themselves and relatively weakly connected to elements in other units (Baldwin and Clark, 2000). According to these authors, modular product architectures provide a form of coordination that reduces the need for managerial coordination, hence reducing the costs of organizing. A significant body of literature has explored the proposition that modular products drive modular organizations (Sanchez and Mahoney, 1996, 2001; Schilling and Steensma, 2001; Sanchez, 2002). However, ensuring compatibility of technical specifications and standard interfaces between product modules is just the starting point for designing modular systems (Brusoni and Prencipe, 2001).

This study will focus on the management of interdependences among both operational and coordination processes within a production system, and the associated opportunity to generate and appropriate economic rents. Opportunities to generate and appropriate economic rents exist because of competitive imperfections in factor or product markets. Firms who know about these opportunities have the potential to generate economic rents if they bundle adequate resources at the right cost. Activity interdependences in supply chain networks have increasingly come to cross-organizational boundaries. The increasing complexity of organizational processes across the supply chain requires an organizational skill to coordinate the resulting interdependences. One source of complexity is the shift from the pursuit of efficiency (cost minimization in production and distribution) to responsiveness, the matching of the quantity and variety of product supplied through the chain to the level of demand (Kopczak and Johnson, 2003). In this context, firms who define collaborative arrangements, such as vendor managed inventory value coordination of order procedures, technical assistance and quick response when unforeseen events take place. Another source of complexity arises from outsourcing the design and production of complex systems rather than product components. For example, automakers tend to increase the purchases of complete subsystems for their vehicles, instead of isolated components. Outsourcing relations with higher value added (system sourcing) imposes a greater problem of pooling resources than relations that were limited to well-defined production activities (component sourcing), as complex components increase the requirements for integration (Novak and Eppinger, 2001). Collaboration has to persist given the recurrent need for knowledge, and presumably there are greater economic rents to be appropriated through integration when the interdependence occurs between subsystems rather than at the component level (Figure 1).

Forms of collaboration with partners to improve process efficiency include sharing information, eliminating task duplication, reducing overhead at the interface, and transferring responsibilities for task execution (Hammer, 2001). In these instances, it is not sufficient to ensure compatibility of product interfaces at the technical level.

The objective of this paper is twofold. First, it explores the role of modularity in organizing processes among supply chain partners, in particular the impact in terms of capability partitioning, i.e. the specialization of each partner on subsets of process activities and associated skills and knowledge. Second, the paper analyzes the requirements for integration that result from such partitioning. It argues that in order to appropriate rents that exist at the interdependency level, firms must weave relationships between firm capabilities and agree on how those rents are distributed among partners. Hence, the key research questions that we aim to address are: what is the role of modularity in the design of supply chain management processes and what are the coordination mechanisms that firms use to appropriate rents at the interface? The answer to these questions should lead to a better understanding of how to deal with process interdependencies between supply chain dyads.

The paper empirically investigates these issues in one firm, Logoplaste (LPT), a global player in the plastic packaging industry that gained competitive advantage by implementing lean management principles (Womack *et al.*, 1991). LPT redesigned their relationships with customers based on long-term partnerships, supplying a combination of product and service and integrating physically in the customer's premises, a practice they termed "hole-in-the-wall."

The paper proceeds as follows. The next section, presents a review of the relevant literature and the conceptual framework for this study. Then the paper describes the context of the study and the data collection process and methodology. Thereafter it presents the case analysis with detailed discussion of the practices surrounding the "hole-in-the-wall" practice. Finally, the paper discusses the managerial and theoretical relevance of the study findings and presents suggestions for future research.

Conceptual background

This section presents a brief review of some contributions that focus on the role of modularity in the organization of supply chains. This literature is mostly anchored in the transaction cost economics (TCE) and resource-based view (RBV) approaches. The purpose is not to conduct an extensive review of TCE and RBV, but to review the key explanations of the role of modularity in operations across supply chains.

Modularity

Modularity is an approach for organizing the design, production and distribution of complex products and processes (Baldwin and Clark, 2000). A modular system is composed of units (modules) that have minimal interactions between them. Modularity makes complexity manageable, modules can be designed independently but still function as an integrated whole.

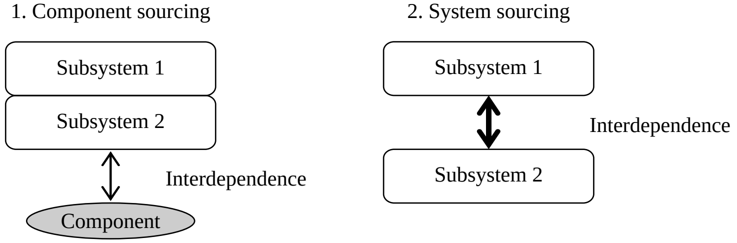

Figure 1. Sourcing complex modules

To achieve modularity, firms partition information into visible design rules and hidden design parameters. Visible design rules fall into three categories: rules that specify what modules will be part of the system and what their functions are; interfaces that describe in detail how the modules will interact, including how they will fit together; and standards for testing a module's conformity to the design rules. Hidden information encapsulated in each module does not need to be communicated beyond the module design effort. For example, a modular architecture for an electronic appliance necessitates management inputs for the specification of the product platform, interface standards, required upgrading measures during the product life cycle, etc.

The idea of modularity is crucial in understanding organizational design choices given its impact on the costs of organizing. Baldwin and Clark (2002) have put forward the argument that the location of transactions (and contracts) in a system of production will depend on engineering design. They view the process of production as a system of tasks assigned to different agents, who need to transfer material, energy and information between them. Firms in the supply chain incur costs to turn these transfers into transactions – "mundane" transaction costs, such as the cost of counting, measuring, transporting, or standardizing information. Baldwin and Clark (2002) argue that only transfers that are amenable to counting, valuing and collecting compensation become transactions. When it is costly to convert these transfers into transactions, transfers should occur within modules. When the transaction cost is low, module development can be contracted with third parties or outsourced. Partitions that are not well-defined give rise to incomplete contracts, bargaining processes and informational loops that increase transactions costs. This engineering perspective helps us understand the view of modularity as a form of embedded coordination that facilitates external sourcing of module development which prevails in the organizational literature (Sanchez and Mahoney, 1996).

This view is consistent with the TCE perspective that firms organize transactions in order to appropriate rents associated with interdependences (Williamson, 1975, 1985). These potential gains derive from allowing the partner to concentrate on what they can do most efficiently, their core competences, and pooling production to reach a scale of production that they cannot reach by themselves. The organization of transaction enables rent appropriation. This means that a way must be found to let parties know about the existence of potential gains and to avoid excessive costs to enforce the terms of the bargain.

Strategy scholars have looked at the extent to which modularity in design of products leads to modularity in the design of organizations that produce such products (Sanchez and Mahoney, 1996; Hoetker, 2006). The ability to design modular product architectures provides a form of embedded coordination that reduces the need for overt exercise of managerial authority to achieve process coordination, making possible the effective functioning of loosely coupled organization structures. The design of the organization has to support the autonomy between the component development groups instead of frequent communication and coordination (Sanchez and Collins, 2001). On the other hand, when production tasks are loosely coupled, their successful execution requires shared division of labor (Imai *et al.*, 1985).

Interdependencies

Interdependence refers to the existence of complementarities between tasks such as test data produced by a testing task that feeds into further development work.

Coordination of interdependent activities to maximize combined value involves information processing activities such as decision making and communication, and ongoing mutual adjustment. The costs of transmitting large volumes of structured information are unlikely to be the binding constraints in organization design. The nature of interdependence is more relevant than the thickness (volume) of coordination requirements (Puranam and Jacobides, 2005). If the pattern of interdependence is predictable, coordination becomes a routine affair (Gulati *et al.*, 2005); on the other hand, rich unstructured coordination requires complex information processing and decision-making capabilities. This type of coordination has been referred to as "unstructured technical dialog" (Monteverde, 1995) or "qualitative coordination" (Langlois, 2002). Empirical studies have shown the association between task interdependence and coordination and problem solving costs (Gomes and Joglekar, 2008).

The need for qualitative coordination and mutual adjustment impacts organizational design choices (Thompson, 1967). The cost of unstructured coordination between two parties is lower when both are part of the same firm (Kogut and Zander, 1996). Hence, firms seek to specialize in activities for which their knowledge, experience and skills are similar (Richardson, 1972) but also complementary activities that require qualitative coordination. Langlois (2002, p. 34) argues that the essence of the firm is non-modularity, "firms arise in order to generate externalities, that is, they facilitate the communication of rich information for purposes of qualitative coordination, innovation, and re-modularization." Hence, value creation at a firm level depends to a great extent on its capability to deal with unstructured coordination.

Modular designs must define interfaces for each subsystem with the objective to economize on the need for unstructured coordination between modules. These efforts equate to reducing mundane transaction costs, or, in the words of Baldwin and Clark (2002), devising transaction-free zones. Mundane transaction costs will be lower when the common information needed on both sides is minimized and the cognitive division of labor is maximized. Otherwise, collaborations have to persist given the recurrent need for knowledge. Gomes and Joglekar (2008) have shown that even modular structures give rise to some level of process interdependencies.

Though it is recognized that modularization requires reorganization of value creation activities and resources (Doran, 2003), the potential complications stemming from interdependencies between processes have not been sufficiently addressed. One issue is the impact on the overall performance of the product or production system. For instance, Arnheiter and Harren (2006) argue that modularity can have potentially negative effects on five dimensions of product quality, namely aesthetics, perceived quality, serviceability, technical performance, and conformance. Buenstorf (2005) highlights how the interdependence between operations negatively affects the ability to adapt a production process to changing factor prices, technological change, new product specifications, and process innovations. Another potential complication arises from interdependencies in performance (Hui *et al.*, 2008). For instance, well-defined software requirements or customer specifications facilitate subsequent development and testing tasks. Changes in one task may facilitate the execution of other tasks, either by directly increasing their productivity or by creating opportunities for future productivity increases. The realization of these opportunities may require further adaptations or innovations, which can only be undertaken if the interdependence is well understood. Other studies question the proposition that modular systems experience few interdependencies, or the direction of the relationship between modularity and organization of activities. Staudenmayer *et al.* (2005) found that firms involved with inter-firm modular systems, tend to experience more rather than fewer interdependences. The authors present two explanations for their finding: first, these interdependences were not identifiable in advance, they emerged unexpectedly over time – hence, the impact of changes in product design was not anticipated by the involved parties; second, managing interdependencies is difficult because changes often require the coordination of multiple parties. Upfront minimization of interdependences with the overall system, as initially suggested by some theorists, is in fact replaced with ongoing and systematic management of interdependencies. Fixson *et al.* (2005) find that the relation between product architecture and firm boundary decisions, namely which decision is made first (modularity or outsourcing), is influenced by characteristics of individual processes, such as the amount of technological change or the cost structure.

A core proposition of this study is that firms need to manage process interdependencies even in the presence of modular product architectures. But there is another fundamental perspective on the role of qualitative coordination, which has not been sufficiently debated in the literature. TCE views organizations as a forum to exchange and pool capabilities in order to extract rents from interdependencies. Potential rents may not be extracted from interdependencies across the supply chain because of the inability of the parties to organize transactions at a cost that is lower than the expected rents (Hennart, 1982). Hence, coordination entails *ex ante* joint maximization of rents and the modularity of the process will depend on the ability of the parties to organize transactions or their coordination capabilities. The paper will now develop the notion and relevance of a firm's coordination capability integrating concepts from distinct literature streams.

Coordination capability

Following the RBV of the firm (Wernerfelt, 1984; Barney, 1986; Peteraf, 1993), strategy scholars have argued that modular architectures offer the framework for a firm to decide which capabilities it should leverage, discover capabilities bottlenecks, and identify best targets for focusing its efforts for learning and capability development (Sanchez and Collins, 2001). Modular architectures have also been studied as a means to coordinate and accelerate distributed learning processes within supply networks, enabling focal firms to quickly link resources and capabilities of many organizations to respond to environmental changes (Sanchez and Mahoney, 2001). Scholars have focused on the separation of technical capabilities and how the development and distribution of such capabilities affects the evolution of firm boundaries (Mota and Castro, 2004). With few exceptions (Gulati *et al.*, 2005; Jacobides and Winter, 2005; Puranam and Jacobides, 2005), less attention has been given to a different type of capability, the ability to integrate processes and allied knowledge that has been partitioned.

In the process of creating and realizing products, organizations create three kinds of architectures: product, process and knowledge (Sanchez, 1999). The knowledge boundaries resulting from task decomposition may be different from production boundaries (Brusoni *et al.*, 2001). Lawrence and Lorsch (1967) have highlighted that task decomposition, i.e. the partitioning of a task into a subset of modules, goes hand in hand with mechanisms for coordination that penetrate the boundaries of the resulting modules. Integration refers to the achievement of collaboration; it encompasses cooperation (alignment of interests) and coordination (alignment of action). Langlois (2006) refers to modules with special a function: that of ensuring coordination among the otherwise decomposed modules. For example, the definition of standards for communication may be regarded as a process module that ensures the integration of activity in the development of hardware and software components of medical devices. Modularity requires an intense effort of knowledge and organizational coordination, interactive management of actors and activities involved. Cooperation yields gains but also entails information, bargaining, and enforcement costs.

Hence, the coordination capability arises due to a requirement for cognitive resources to handle unstructured coordination (Jacobides and Winter, 2005). One element of a coordination capability is the ability of firms to reduce the costs in organizing internal and external transactions (Hennart, 2008). Coordination capability may be amenable to the capability accumulation process, or learning process associated with managing unstructured coordination. Repeated interactions between coordinating individuals gives rise to trust, shared perceptions, routines, and common language offsetting of coordination costs (Noorderhaven, 1995; Mayer and Argyres, 2004). From a TCE perspective inter-firm transactions are contracts for outputs, while internalizing a transaction replaces contracts for outputs by contracts for inputs. Hence, coordination capability requires contracting for inputs. This paper argues for the relevance of a particular type of capability – coordination capability and does not explore interest alignment issues. The following sections explore the application of the modularity and coordination capability constructs to the case analysis.

Research methodology

The paper presents an in-depth case study of LPT, an international producer of plastic packaging with 50 factories spread across Europe and South America. The firm has become a benchmark for key competitors in the industry, given its explicit strategy of organizational integration with customers, customer loyalty (it has never lost the renewal of a contract) and outstanding financial and technical performance.

The study follows guidelines for case research in operations management drawn from the literature (Yin, 1984; Stuart *et al.*, 2002). The theoretical foundations were established early on and allow for alternative explanations of the events observed in the field. The research questions were defined in the initial stage of the research. The data gathering followed and relied on analysis of secondary-data (company records such as annual reports, press releases, performance scorecard data, and internal procedures) as well as interviews with key informants.

Informants were knowledgeable about the organization, product and the production process and were selected from a mix of functional areas and multiple levels of the hierarchy, namely: the chief executive officer, the chief operating officer, the quality director, the production planning director, responsible for production planning and procurement at the country level, and the engineering manager, responsible for setting up production processes for new products required by partners while assuring the technical interface with the partner and the R&D department. Each interview lasted between two and three hours. The two primary researchers were present and took extensive notes. An interview protocol was developed that defined a common introduction and description of the research and a set of specific questions pertaining to each activity that comprised the supply chain, as well as the interdependences between activities. The interviews had three parts. First, interviewees were asked to describe the processes they were associated with in an open-ended fashion. Second, detail was gathered on how each process fitted into an overall system. Third, the interviewees were probed for information about external relationships, namely the nature and strength of dependence between activities. Regarding dependence informants were asked to consider both physical and information dependence between activities. In most cases it was possible to corroborate information about specific processes with more than one individual.

To model the modularity in the supply chain architecture the study uses the design structure matrix (DSM), a tool for system modeling that enables system decomposition and analysis of need for system integration (Steward, 1981; McCord and Eppinger, 1993; Smith and Eppinger, 1998). The DSM displays system elements as rows and columns in a square matrix. Table I shows a DSM developed for the design and production of injection moulds (Ulrich and Eppinger, 1995). The diagonal cells represent the production activity, while the off-diagonal marks represent requirement for coordination between two tasks. A mark on cell (B and A) in the design matrix means that Task B depends on information released by Task A. If Task A precedes Task B the situation would represent a feed-forward dependency, otherwise it would represent a feedback dependency. In the example, Tasks G, H, and I are characterized by interdependence and need to be managed in a non-modular fashion. Otherwise, the structure is characterized by little feedback dependence.

Activities	A	B	C	D	E	F	G	H	I	J	K	L	M	N
A	·													
B	X	·												
C	X	X	·											
D			X	·										
E	X	X	X		·									
F			X	X	X	·								
G	X	X	X			X	·	*X*	*X*					
H	X	X				X	*X*	·	*X*					
I							*X*	*X*	·					
J					X		X		X	·				
K								X			·			
L							X	X			X	·		
M					X						X		·	
N										X		X	X	·

Notes: A, receive specification; B, generate/select concept; C, design beta cartridges; D, produce beta cartridges; E, develop testing program; F, test beta cadridges; G, design production cartridge; H, design mould; I, design assembly tooling; J, purchase manufacturing equipment; K, fabricate moulds; L, debug moulds; M, certify cartridge; N, initial production run
Source: Adapted from Ulrich and Eppinger (1995)

Table I.
Structure matrix for injection moulding

The DSM can represent the mapping of product or service architectures, as shown in Table I, the mapping of interactions between teams, a task-based system architecture (task-based DSM), or a parameter-based architecture, such as in systems engineering (for a review of DSM applications, see Browning, 2001). In the first two cases system decomposition into modules is usually done through clustering, i.e. integration of components or teams under same structure. The DSM mapping of task or parameter interdependences shows the information flows that result from sequencing choices, hence integration is achieved by sequencing.

We will illustrate the application of the DSM methodology to facilitate decomposition of supply chain management tasks across a dyad and analysis of integration requirements. The next section reports the case analysis and key findings.

Case analysis and key findings

In the past decade LPT grew to become the third largest supplier of plastic packaging in Europe. In 2007, it produced 6.4 billion packages, such as polyethylene terephthalate (PET) bottles for drink manufacturers, obtaining a turnover of €240 million. It continues its global expansion with a presence in South America and Eastern Europe and plans to expand to North America with the objective of maintaining growth rates around 15 percent per year (annual growth of 19 percent over the last five years). During this time, the company has maintained profitability levels around or above the industry average.

LPT redesigned their relationships with customers based on long-term partnerships, building their new factories next to, or even within, their customers' premises – these onsite factories are designated as integrated production units (IPUs) and customers are referred to as partners. The IPU capacity is defined in the contract for a minimum of five years based on the customer's production plans. Capacity is projected for maximum partner's needs with a maximum and minimum threshold. The actual capacity of the IPU is set above the maximum threshold to ensure flexibility. LPT overall service, includes R&D (2D/3D design, prototyping, proto-mould, and production moulds), quality assurance, and technical support and advice. They were pioneers in setting up this arrangement with customers in the plastic packaging industry. LPT technicians work on an ongoing basis with the customer's technicians, both through the dedicated local teams at the IPU and through central departments.

They designate their production process as "hole-in-the-wall" as packages are produced on site and delivered just in time to the customer's assembly line through the use of a conveyor belt that literally goes through the wall that separates the two production areas. In fact, the IPU has three alternative production layouts:

(1) *Independent warehouse*. In this layout the onsite factory has storage capacity and customers pick up material from the warehouse and assure the transport.

(2) *Warehouse direct supply*. Production feeds directly to the warehouse and the warehouse typically holds a day-shift capacity.

(3) *Hole-in-the-wall*. Production feeds the partner production line directly, allowing a buffer of about ten minutes.

As we move from independent warehouse to hole-in-the-wall supply, we notice greater levels of interfaces with the customer process, hence a greater need for flexibility (for example to adjust to real time changes in production schedules), less buffer inventories, which places more pressure on preventive maintenance but also on coordination mechanisms related to material and quality and control.

The case illustrates modularity and interdependencies in operational processes rather than product modularity. The package itself has an integral product architecture (Ulrich and Eppinger, 1995): there is usually a single physical component, but the overall product is modular. For example, bottle cap designers present alternative caps that fit the same bottle neck thread, labels can be made of plastic or paper and wrapped to the package using different technologies and within limits the package content can also vary independently of the package shape or material.

The two main production processes are based on injection moulding and blow-moulding. The latter is a two-stage process: the PET packages are produced from pre-forms manufactured by injection which converts PET resin into pre-forms; in the second stage, the pre-forms are blown on-site into PET packages. The two stages are modular elements of the system with visible design rules: work is done independently at each sub-process under a well-defined architecture that manages interdependencies. For instance, the neck thread of the package is already designed into the pre-form and the stretching ratio delimits the flexibility in producing packages with distinct forms out of the same pre-forms. The information provided on the production process activities and their interdependences by the informants enabled the researchers to create a matrix showing interdependences between activities. This matrix was further validated by the quality manager, given her detailed knowledge of processes and procedures. The DSM initially developed is shown in Figure 2. The sequence of activities follows the logic of the supply chain, starting with the activities of the IPU followed by the activities of the partner (PNT) even when they are clustered for methodological purposes. The numbers on each cell measure the strength of the dependence as indicated by key informants (1 = weak, 2 = medium, and 3 = strong). Note that the supply chain was given and determined by the sequence of decisions made by the firm according to its explicit strategy. The purpose of using the DSM is to highlight the different degrees of interdependence of the information flow.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1. IPU product specification		3	3	3						3			3		3			3
2. IPU mould concept	3		3	3						3			3		3			3
3. IPU test mould	3	3								3					3			3
4. IPU capacity planning	2	3			3									3				
5. IPU production planning	1			3					3					3				
6. IPU material req. planning	3	1			3													
7. IPU material quality control	3					2				3			3		3			3
8. IPU materials inventory mgt						3	3											
9. IPU production scheduling					3		3	3									3	
10. IPU product quality control	3			2		3	3						3		3			3
11. IPU product inventory mgt									3									
12. Material delivery									3		3							
13. PTN product specification	3	3	3															
14. PTN production planning				3													3	
15. PTN material quality control	1									3			3					
16. PTN material inventory mgt											3	3		3			3	
17. PTN production scheduling									3					3		3		
18. PTN product quality control										3			3		3			

Figure 2.
Dependency structure matrix for Logoplaste supply chain architecture

The analysis of the inter-organizational relationship established between LPT and their partners is centered on the DSM and its decomposability, i.e. task partitioning in such a way that the interactions of elements within a module are greater than the interactions between them (Simon, 1969). In a typical task-based DSM sequencing and partitioning is the appropriate integration technique given that activities are dynamic and not static as in product architectures (Browning, 2001). In Figure 3, the DSM has been rearranged to emphasize process flows and integration requirements between sub-systems of activities. The three sub-systems or blocks are:

(1) the development block;

(2) the production block; and

(3) the quality management block.

The resulting structure is not entirely modular, blocks group activities that have high interactions among them, yet interactions between modules still persist. The study does not attempt to redesign the supply chain, instead it analyzes each block of activities and its pattern of interdependences and explores the mechanisms used to reduce transaction costs and increase flexibility.

Development

Figure 3 shows that product specification, mould concept and capacity planning are tightly coupled activities. All the activities in this block are to a great extent internalized by LPT. However, evidence gathered from interviews reveals requirements to externalize knowledge associated with this set of activities. For example, in most cases product specification requires joint problem solving with the partner. LPT deploys a particular set of knowledge, skills and experience – in the choice of raw material and in industrial design to ensure mechanical resistance of the package across the supply chain (which is also an important source of material savings and design differentiation). There is a risk of knowledge leakage as the level of interdependence requires informational openness between partners. But there is also the requirement to develop qualitative coordination skills and externalize knowledge so that partners agree on suggested product specifications. In most cases, partners

	1	13	2	3	4	5	9	14	17	6	8	11	12	16	7	10	15	18
1. IPU product specification		3	3	3	3											3	3	3
13. PTN product specification	3		3	3														
2. IPU mould concept	3	3		3	3											3	3	3
3. IPU test mould	3		3													3	3	3
4. IPU capacity planning	2		3			3		3										
5. IPU production planning	1				3		3	3										
9. IPU production scheduling						3			3		3				3			
14. PTN production planning					3				3									
17. PTN production scheduling							3	3						3				
6. IPU material req. planning	3		1			3												
8. IPU materials inventory mgt										3					3			
11. IPU product inventory mgt							3											
12. Material delivery							3					3						
16. PTN material inventory mgt								3	3			3	3					
7. IPU material quality control	3	3								2						3	3	3
10. IPU product quality control	3	3		2						3					3		3	3
15. PTN material quality control	1	3														3		
18. PTN product qualitycontrol		3														3	3	

Development

Production planning module

Hole-in-the-wall production

Quality management

Figure 3. Partitioned DSM for Logoplaste supply chain

trust LPT expertise on this area and agree to recommended specifications. In a few cases) about 10 percent of the package designs) the specification is fully driven by the partner, in which case the information flow is unidirectional and activities are independent. There are regular product adaptations that require new product specifications and renewed investment in moulds, for example, LPT is continuously redesigning packages to use less material and obtain cost savings.

There is also a high interaction between product specification and mould concept. For instance, the optimization of mechanical performance and material savings is driven from competence in integrating knowledge in both areas. LPT developed a strong internal knowledge of the physical and chemical properties of the material. The design of injection moulds is contracted to Northern European manufacturers and obeys rules of modularity, i.e. exchanges between LPT and injection mould manufacturers are mostly market transactions based on submitted specifications and little unstructured technical dialogue. While LPT does not have the knowledge and skills to develop injection moulds, it nurtures a core competence in developing blow-moulds. This is essential to keep good product design and quality control. The design of the mould is hidden from the partner, the technical dialogue is based on package specifications. However, testing of the mould creates a team production situation: the partner is involved in initial production runs due to the interdependence between test mould and product specification (a co-design effort in most cases).

Product specification and mould concept decisions are also interdependent with capacity planning. The capacity planning activity is critical in the process of integration of both plants. Capacity planning is fixed in the contract between LPT and the partner taking into account production requirements. However, capacity building can be achieved in different forms depending on product and mould concept decisions. To manage the interdependence, LPT specifies, contractually, a maximum and a minimum level of production for each IPU, visible design rules (Baldwin and Clark, 2002) that contribute to the coordination of production activities with the partner.

Hole-in-the-wall production

The production-related activities include production planning, scheduling, material management and material delivery activities. The analysis of interdependences, as shown by the DSM, reveals the existence of a module related to production planning and scheduling (Figure 3). This sub-module is characterized by both the existence of intra and inter-organizational dependencies. For both the IPU and the partner, production planning, and production scheduling are interdependent activities. More interestingly, the DSM shows inter-organizational dependencies, which are unidirectional in terms of planning (the IPU production planning depends on the partner production planning but not vice versa), and bidirectional in terms of production scheduling. The decisions on the actual production schedule require more interaction since the IPU and the partner are physically interdependent. An interesting situation occurs at one factory, BLOPAK, where LPT hands control of the IPU production scheduling to the partner, allowing a non-modular organization of production to emerge to deal with the high level of interdependence. To remain flexible LPT has a capacity level much above the desired efficiency level at this plant, with capacity utilization levels around 30 percent, much lower than standard.

This high interdependence within the production-planning module is mediated by the capacity rules limiting space for conflict. As the Production Planning Director said "the integrated [production] units live in a world of infinite capacity." LPT defined a set of visible design rules to bring in modularity to a highly interdependent sub-module (modularity here refers to the decomposability of production and associated coordination processes). For example, they require weekly reports from the partners regarding their production plans – these plans that are not mandatory but enable some anticipation of change. The IPU production plan is defined monthly and revised weekly based on these reports.

LPT uses several mechanisms to coordinate production in order to ensure efficiency and quality. For example, the company created a scorecard system, which they use to manage internal efficiency and quality and also to report to the partner several factors along the entire supply chain, which affect efficiency and quality control. One of the metrics used by LPT to evaluate the performance of the relationship is the number of times the production line halts due to stock levels beyond buffer levels. Sharing of these reports enables LPT to continuously improve their processes and integration with partners. As LPT improves knowledge of their partners' production plans and schedules, they are able to do a better job with their own planning, which results in higher capacity utilization and continuous process improvement. In turn, as LPT becomes more knowledgeable about its production scheduling, it can also provide the partner with enhanced guidelines to rationalize their production.

The remaining activities within the hole-in-the-wall production module are characterized by feed forward dependence and reduced feedback loops. Consistent with the high modularity of these activities, LPT has specialized knowledge and skills that are hidden to the partner. Two core competences of LPT are its ability to maintain high process reliability and the procurement of materials. Associated activities such as preventive maintenance were omitted from the DSM since they had no dependencies. Preventive maintenance requires the best possible mould machinery and good personnel through training with a culture on quality – what they call the "Logoplastians" culture. Procurement of quality material at good trading conditions is critical, since up to 88 percent of the cost of a package is due to materials.

Quality management

Quality management is a major core competence at LPT. Even when production scheduling is handed over to the partner, as the case of BLOPAK, production efficiency becomes a responsibility of the partner but quality management still remains under LPT control. Quality assurance is a concern along the whole process: from product conception to production, to delivery. Material quality control drives detection of areas for improvements in product design, material savings, and capacity utilization, all sources of LPT competitive advantage. Preliminary test and pilot production is done in-house, but LPT contracts services to external laboratories, for example to analyze the chemical properties of a specific new material combination. LPT must dominate the process of material quality control despite the high level of reliability of their suppliers. It is a core competence of LPT to find the best combination of materials at the lower cost.

The analysis of the partitioned DSM (Figure 3) reveals organization choices related to the activities within the module, strong interdependence of this module with the development module, and loose dependence with the production module. In terms of organization choices, LPT has assured the partner about its incoming material quality control, merging activities ten and activities 15 in the DSM under their control. As the Quality Director said, "we tell our partners that quality assurance is not your job, it is part of what we sell."

There is a strong interdependence between quality management and the development module. The firm's intervention in package industrial design contributed to the development of a core competence in assuring product quality. The resulting knowledge about package mechanical resistance is protected as a trade secret. On the other hand, the interaction with their partner's product quality control provided opportunities for further improvements in product specification – a case of feedback dependence. For example, there is an electrical effect that draws particles of dust to some product packages before filling. Understanding the cause of this effect and determining a technical solution required skills beyond mechanical resistance and a greater interface between LPT quality management system and their partners.

Conclusions and future research

This paper seeks to extend the research agenda on supply chain modularity in two different ways. First, it introduces the DSM methodology as an important tool for analyzing dependences in production and coordination processes across supply chain dyads and networks. Our case research illustrated the application of this system-modeling tool to supply chain management, highlighting strategies for managing modularity, requirements for coordination skills and for knowledge externalization.

Second, the case analysis reveals that firms manage process level modularity by both reducing the need for exchanges and by developing coordination capabilities. These capabilities enable firms to create and capture rents at the interdependence level. LPT's concept of production integration is more demanding in terms of integration skills than the standard concept of modularity. In several instances, the firm made the relationship with their partners more complex, appropriating rents at the interface level through a shift in the logic of simple interfaces to the organization of more complex interdependencies.

The idea of modularity is an idea of exchange, unbundling knowledge in order to increase efficiency and decrease transaction costs (Baldwin and Clark, 2002). To a great extent, LPT aggressively pursues production efficiency through unbundling of resources. Its low cost depends on high production volumes, production planning emphasizes high utilization of capacity, development efforts focus on optimization of material use, and optimization of process efficiency. On the other hand, case evidence showed that to gain flexibility and agility in an environment of physical integration with the customer, the traditional module maker set its capacity much above efficiency levels trading off modularity for coordination ability, and efficiency for responsiveness.

Our findings have important implications for practitioners. While LPT is able to maintain hidden information in several areas, such as blow-mould development or material procurement, a traditional prescription from modularity, in other activities there is a need to externalize knowledge and coordinate tightly with the customer. One of the bundled process areas is quality management another is development. Specialized knowledge that becomes a core competence does not necessarily become hidden information when modularizing a system.

By understanding the interdependence patterns firms can focus on system efficiency, not the economic efficiency concept focused on production costs and transaction costs. The system efficiency concept encapsulates the requirement for bundling knowledge and obtaining agility. Core competences may need to be developed at the level of the interdependences or qualitative coordination (Langlois, 2002) rather than the level of specialized production. In sum, understanding which interdependencies hide potential rents and organizing transfer to appropriate such rents becomes a formidable weapon for firms competing in industries characterized by outsourcing and modularity.

Our findings also point to interesting avenues for further research. Module makers can capitalize on rents that exist at the task interdependency level in order to maximize *ex post* rent appropriation. One issue for further research is how these rents are distributed, and how the pattern of distribution affects the organization of transactions. The choice of the partner is the result of *ex ante* joint maximization of prospective rents by partners in the transaction (negotiation), although their *ex post* distribution from *ex ante* agreement distribution may diverge from *ex ante* agreement. In the empirical case under study long-term contracts incorporate the flexibility to adjust these two moments by *ex post* transferring rents to the party which distribution outcome is less favorable. Future research could explore the co-evolution of transaction costs and coordination capability. The study was conducted for one dyad of the supply chain, but the analysis should be extended to the network level of analysis. Zaheer and Bell (2005) have found that firm performance is enhanced by its position in the network structure and suggest that firms need to develop network enabled capabilities. Research should focus on firms' ability to manage interdependences systematically, as these become more dependent on the resources and activities of other parties in their value network.

There are important limitations to our study. Case research attempts to ground theoretical concepts with reality. Hence, cases are not aimed at being representative, but exemplary and generalization cannot be made from sample to population. In addition, the benefits and risks associated with strategic outsourcing may depend on the industry's characteristics. Celly *et al.* (1999) address this subject, stating that empirical evidence establishes a positive relationship between uncertainty and vertical integration, but in the cases where uncertainty is originated from competition and technological development, the effect could be the exact opposite.

We have only grasped some of the potential in using the DSM methodology to understand and track the supply chain architecture. Several techniques used beyond sequencing could be applied to re-define the architecture. One is the possibility of removing dependencies, a procedure designated as "tearing the DSM." Another is analyzing the reachability matrix, i.e. augmenting the dependence structure to second- and third-order interdependences.

Baldwin and Clark (2004), who studied modularity in the computer industry, have argued that modularity may be quickly diffused in others industries due to a number of factors: breakthroughs in material science; due to information technology diffusion which decreases the cost of capturing, processing and storing knowledge; reduction in the cost of designing and testing modules; innovative contractual arrangements; increasing technological complexity and uncertainty which favors more experiments and flexibility at the module level. We have shown modularity in the plastic packaging industry and applied a tool from the engineering design literature to make modularity and non-modularity visible. Studies across industries using the same methodology may help identify the conditions under which theories that explain strategic outsourcing are applicable.

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