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LAPPEENRANNAN TEKNILLINEN YLIOPISTO

Elina Karttunen

MANAGEMENT OF TECHNOLOGICAL RESOURCE DEPENDENCIES IN INTERORGANIZATIONAL NETWORKS

LUT
University

Elina Karttunen

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Abstract

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The superior performance of a firm is achieved neither through technology nor the surrounding organizational structure per se, but through the successful alignment of technological resource dependencies and interorganizational structures in interorganizational networks. This dissertation focuses on the dependencies that emerge from the product system level and from technological knowledge, and their impact on interorganizational relations and the boundaries between firms. This thesis adopts the viewpoint of a focal firm that is either a systems integrator or incumbent firm engaged in technology acquisition, and is trying to manage these technological resource dependencies.

Publication I concentrates on concerns of how direct and indirect dependencies in a network could be better understood. This approach was also applied in conceptual publications II and III, which investigate the characteristics of buyer-supplier relationships and the make or buy question faced by a focal firm due to technological resource dependencies, as well as the moderating role of the complexity of the product system. Publication IV provides the main empirical part of this dissertation by leveraging patent data with data on mergers and acquisitions. Statistical analyses of U.S. technology acquisitions in various high-technology industries confirm the expectation that the target firm prices increase, especially when many other firms directly or indirectly build on the target's knowledge, as measured through patent citations. Thus, this thesis develops and empirically tests the hypothesis that the position of a target in its interorganizational resource dependence network affects the value of their resources to the acquirer, as reflected in the acquisition price.

This thesis mainly contributes to the theory of systems of production by suggesting that technological resource dependencies at the technology and product system levels are the ones which influence where the boundaries of firms are, but there are technological knowledge level structures emerging from technological trajectories that set the directions of these dependencies. It is crucial to emphasize the sequence of tasks, such as design or production from the focal firm's perspective, and thus the direction of technological resource dependencies, both direct and indirect, between the focal firm and other firms.

Keywords: modularity, product architecture, product system, interorganizational network, outsourcing, make or buy, technology acquisition

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I warmly welcome Juliana Hsuan to act as my opponent when I defend my dissertation. I am sure that this event will be something I will look back on with joy and amusement. I also am very grateful to examiners Juliana Hsuan and Saku Mäkinen for their constructive feedback. I appreciate the time and effort they invested in reading this dissertation and guiding me toward improvements.

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I also want to thank my parents, who always read me bedtime stories when I was a child, usually something from their imagination. These and other great stories provided me with a huge reserve of strength, having helped me through difficult times. I also want to express my gratitude to my siblings and their families for spending their spare time with me during these years.

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Elina Karttunen
September 2018
Lappeenranta, Finland

Some dove in the river and tried to swim away
through tons of sewage, fate written on their foreheads

PJ Harvey –Written on the forehead

Contents

List of publications

This thesis is based on the following papers. The rights have been granted by publishers to include the papers in dissertation.

I. Karttunen, E., Immonen, M., Pynnönen, M., Koivuniemi, J. (2018). Hidden structure and value network: Shedding light on position assessment. Accepted for publication in *The International Journal of Services and Operations Management*. Article in press.

II. Karttunen, E., Nerg, J. (2017). Linking technological system architecture and purchasing categories. *In Proceedings of the 50th Hawaii International Conference on System Sciences*, pp. 5068-5077.

III. Karttunen, E., Immonen, M. (2017). Technological system complexity and system integration. *In proceedings of the 77th Academy of Management Annual meeting.*

IV. Karttunen, E., Huotari, P., and Immonen, M. (2018). Interorganizational resource dependence and the value of firm resources in technology acquisitions. *In proceedings of the 78th Academy of Management Annual meeting.*

Author's contribution

PUBLICATION I: The author wrote most of the paper, having collected and analysed the empirical data from secondary sources. The co-authors wrote some parts of theory section.

PUBLICATION II: The author wrote the paper. The second author provided help with the illustrative empirical example employed in this paper.

PUBLICATION III: The author wrote most of the paper. The second author wrote some parts of the theory section.

PUBLICATION IV: The author wrote most of the paper. The author collected the data together with the second author. The author analysed the data and wrote results and conclusions. The theory section was written by the author together with the co-authors.

1 Introduction

Technological change appears to be ceaseless, and firms must innovate continually to survive the pressures of competition. Some technologies are systemic in their nature, meaning that they consist of multicomponent products that connect to each other. The automotive industry or the building of a turbo generator or wind turbine are examples of industries, in which products are not just products but product systems. In this thesis I use the terms product system or complex product system when I refer these product systems. Complex product systems can be defined as sets of humans and technologies merged to perform a specific function beyond the capabilities of a single person, but which can be accomplished collectively (Johnson, 2003). The development and production of complex product systems require significant investments in valuable and complementary resources, such as expert scientists from various fields, engineers, manufacturing personnel, and operations management personnel. Complex product systems are engineering constructs that are highly costly and technology-intensive, covering multiple technological domains (Davies, Brady, and Hobday, 2007).

For a single firm, such an amount of diverse technological resources militates against the ability to concentrate on core competences (Teece, 1980). That is why firms in these industries do not produce entire products alone, but as part of interorganizational networks. System integrator firms ensure that the integrity of the system is maintained. The integrity of a technological system (or entire product) is defined as "the consistency between a product's function and structure: the parts fit smoothly, components match and work well together, the layout maximizes available space" (Clark and Fujimoto, 1990: 108). This thesis takes the viewpoint of incumbent firms that operate in product systems (or complex product systems) industries with large engineering-sensitive capital goods, and take the roles of buyers that outsource and acquire other firms. These firms are large industrial manufactures, coordinating their suppliers and trying to cope with interdependencies between components and other technological resources (Argyres and Bigelow, 2010; Brusoni, Prencipe, and Pavitt, 2001). These firms are called system integrators, defined as firms that manage the integration of larger systems or the end-product. The term often refers to car manufacturers (Jacobides, MacDuffie, and Tae, 2016) but this thesis is not limited to that sector. Rather, system integrator is seen as a role that a firm bears.

From the viewpoint of system integration, the overarching question concerns how interorganizational relations are arranged between buyers and suppliers, even though technological resource interdependencies are present, and when the overall product architecture must be coordinated (Johnson, 2003). Where are the boundaries of firms in this interorganizational network, and how do technological resource dependencies influence these boundaries? Which components should a firm design or produce in-house and which can be bought from suppliers? Or, if there is no internal option, what kind of resources are drivers for technology acquisition? What is the role of technological resource dependencies in determining the boundaries between firms? Previously, answers to these questions were sought not only from system integration literature but from modularity and technology acquisition research streams, with the support of grant theories of transaction cost economics (TCE) and a knowledge-based view (KBV) (Baldwin, 2008).

Figure 1 provides an overview of the technological resource flows from the firm's perspective. It indicates the interactions between different activities, as well as technical resource flows from the system integrator's perspective, within firm boundaries but also outside of these boundaries. There are business processes inside a firm, and project contexts related to these processes, but also firms external to a specific project's context, emphasizing the focal firm's coordinative role (Gann and Salter, 2000).

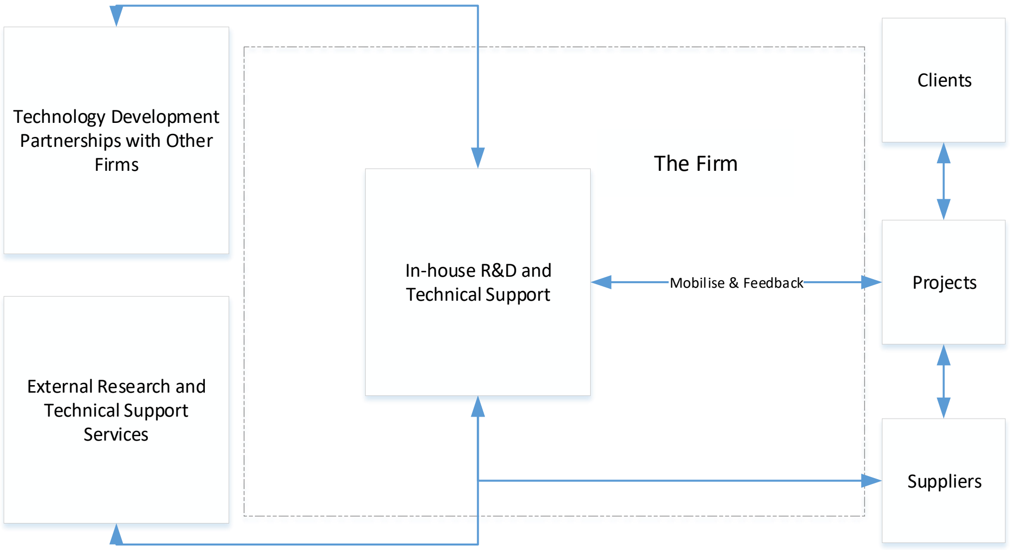


Figure 1. System integrator firm and technical resource flows (adapted from Gann and Salter (2000)).

In complex product system industries, firms must manage both projects that lead to product outcomes as well as business processes beyond the project-level (Gann and Salter, 2000). Projects demand capabilities such as the ability to complete projects within a schedule, within a budget and the ability to respond to unique customer specifications (Davies and Brady, 2000). To achieve this, internal functional departments and their business processes, such as R&D, design, production, marketing and top management capabilities must be in line with upcoming projects, and these capabilities must be replicable across projects (Davies and Brady, 2000). The projects which this thesis focuses on can be divided into roughly two distinct types: product development projects and implementation projects, such as the implementation of production (Winch, 1996). Regardless of the internal capabilities of these firms, they also leverage suppliers to design and produce product system entities. Projects related to product systems involve various tasks, involving the cooperation of many organisations such as clients, suppliers, and partnerships with other firms from a range of industrial sectors. Competitiveness and performance are not up to a single firm, but rely on the efficient functioning of the whole network (Gann and Salter, 2000).

Individual projects are often burdened with a heritage of constraints defined by existing systems and the legacy of the current technologies they apply (David, 1985). The strategic management of resources concerns issues such as how firms develop their core technical competences, solve issues of integration in planning, design, systems integration and assembly (Gann and Salter, 2000). System integrators have multiple competencies, first, of course, the core and fundamental technological knowledge for their activities, but they also possess more marginal competencies (Paoli and Prencipe, 1999). This more marginal knowledge can be fundamental for system integrator's suppliers, which manufacture components for system integrators, but the system integration of a focal firm also requires this kind of knowledge, especially with complex parts such as aircraft engines (Paoli and Prencipe, 1999; Prencipe, 1997).

1.1 **Research gaps**

This thesis focuses on the influence of technological resource dependencies on interfirm relations. Thus, it is linked with the strategic management literature that is interested in where to locate firm boundaries and transactions in the presence of technological resource dependencies. In the traditional view of previous studies, when technological resource dependencies between tasks are intense, they are better to be left within the firm's boundaries (Baldwin, 2008; Sanchez and Mahoney, 1996). Briefly, Gap 1 shows a defect in knowledge on how technological resource dependencies influence the characteristics of the buyer-supplier relationship. Gap 2 concentrate on mixed findings, how technological resource dependencies, in terms of the modularity of components, influence the make or buy question, and moderate the effects of complexity on that relation. Finally, Gap 3 lays the foundations for why technological resource dependencies could have an impact on the price of technology acquisition.

Gap 1. There has been interest in shedding light on the relationship between product modularity and buyer–supplier characteristics, including information and knowledge sharing, to describe the intensity of the relationship, and speculate on the performance implications of these settings (Cabigiosu and Camuffo, 2012). It is important to understand how modular architecture influences buyer-supplier relationships among other organizational choices and processes (Ethiraj, 2007; Hoetker, Swaminathan, and Mitchell, 2007). Modular components enable buyers to easily change suppliers if they want to respond to changing conditions (Garud and Kumaraswamy, 1995). From the supplier's view point, suppliers of highly modular components benefit more from autonomy, but suppliers of low-modularity components benefited more from strong ties to system integrator firms (Hoetker *et al.*, 2007). With modularity, suppliers can serve several buyers and reach economics of scale (Hoetker *et al.*, 2007). Thus, it is proposed that modularity enables more market-based, arms-length relations, whereas integral design is suitable for relations that are not easily switched. Empirical support for this proposition is ambiguous, and a more nuanced view is needed (Cabigiosu and Camuffo, 2012; Colfer and Baldwin, 2016). To respond to this, switching the costs of, and needs for, investments of buyers and suppliers, and the technological expertise employed in buyer-supplier relationships, are characteristics which are proposed to be influenced by technological resource dependencies that are seen and investigated in a more nuanced way than the previous division between the modular and the integral.

There is a need for interplay between technical resource dependencies and buyer-supplier characteristics in purchasing and supply management literature. Buyer-supplier relations have also inspired interest in the purchasing and supply management literature, in which supplier relations or items purchased have been categorized into a four-category framework called the Kraljic Portfolio Matrix (Caniëls and Gelderman, 2005; Kraljic, 1983). This matrix approach has been argued to represent the best available tool for diagnostic and prescriptive purposes with which purchasing organizations can differentiate between supplier relations (Wagner, Padhi, and Bode, 2013). Although these attempts to categorize buyer-supplier relationships have investigated industries that produce product systems, such as the automotive (Bensaou, 1999), they do not straightforwardly discuss component-level technological interdependencies, but, for example, use supply risk and profit impact as subjective measures with to which categorise products or components and direct the characteristics of the buyer-supplier relationship (Caniëls and Gelderman, 2007; Padhi, Wagner, and Aggarwal, 2012). The weakness of the matrix is that it cannot take into account interdependencies between products (Olsen and Ellram, 1997), and therefore further research should strive to incorporate new attributes that objectively contribute to the matrix's dimensions (Howard and Squire, 2007; Montgomery, Ogden, and Boehmke, 2018). By problematizing the simple modular-integral division with a more sophisticated concept of technological resource dependencies and applying that to the current knowledge on buyer-supplier relations regarding the purchasing matrix, a contribution about the influence of technological resource dependencies on buyer-supplier relationships is developed in this thesis.

Gap 2. One should examine the relationships between tasks (such as design and production) and technical knowledge, however the knowledge partitioning between buyer and supplier is not the same thing as the partition of design and production tasks (Takeishi, 2002). System integrator firms need careful management of technical knowledge while making make-or-buy decisions about components (Brusoni *et al.*, 2001; Takeishi, 2002). The direction of technological resource dependencies between components is connected to the knowledge structures of firms; which firm has knowledge that lets it set technological dependencies on others. In the context of the make or buy question, the direction of technological dependencies and hierarchical positions between components matter. This is the broader viewpoint when compared to the division between the modular and the integral.

It is informative to consider a firm’s decision to make or buy in the context of complex product systems, which have multiple interactions between design and production activities (Parmigiani and Mitchell, 2009). There is also a need to consider of the performance implications of these choices, by taking the system level into account (Parmigiani and Mitchell, 2009). Park and Ro (2013) suggest further theoretical and empirical research into the relationship between product architecture and the make and buy choice of a firm, and about the impact of sourcing decisions on performance, because their current empirical findings are mixed.

The conventional view proposes that the high degree of interdependence among components and subsystems demands a close configuration of their performances to successfully integrate these components into the product-system entity. It is suggested that the conventional view on the product modularity of interfirm relations is too simplistic to be applied generally, since it does not always hold (Colfer and Baldwin, 2016). There are empirical examples of when this conventional view has not held, for example, modular products do not let firms out of the hierarchy between them, or let them be more loosely coupled (Hoetker, 2006).

Rather, one should ask the question in a new way: *when* does it hold, *and when it does not* (Colfer and Baldwin, 2016; Ülkü and Schmidt, 2011). When product modularity and interfirm relations are investigated, the complexity of the product system has an influence on this relation (Sorkun and Furlan, 2017). Complexity hampers the correct identification of the dependencies between components, which may lead to an insufficient alignment of the interactions between developmental units (Sosa, Eppinger, and Rowles, 2004). In turn, Gokpinar et al. (2010) found that misalignments with interactions between development units occur when technological resource dependencies are at intermediate degrees in components, since firms have difficulties setting the right level of interaction for those, and complex systems usually feature this kind of components.

Gap 3. The dynamics of a new technology can intersect with existing organizational relations, and thus require adjustments to these relations (Brusoni and Prencipe, 2006), such as technology acquisitions. The existing technology acquisitions literature has largely focused on analysing dyadic resource relationships between the acquiring and the target firm (a firm that is bought), for example in terms of how their resource relatedness affects the benefits of the acquisition (Chondrakis, 2016; Grimpe and Hussinger, 2014a). However, a few studies have taken the more broader view of the interorganizational relationship: when acquiring a target, it results in a structural change in the whole interorganizational network of the acquirer and the target (Hernandez and Menon, 2017; Hernandez and Shaver, 2018). It has been shown that the network position of the target adds acquisition likelihood (Hernandez and Shaver, 2018). However, there is a lack of empirical evidence on how the network position of the target and technological resource dependencies influence the acquisition price. For example, if a target firm has technological resources that have a possibility to be foundational for the further technological trajectory of that industry, will this influence the acquisition price? Acquirers cannot obtain all strategically valuable resources from outside, but they must strategically choose which technological resource dependencies to absorb and which to control indirectly (Brusoni and Prencipe, 2011; Santos and Eisenhardt, 2005).

1.2 Objective

Ties between organizations can be categorized as ties caused by product architecture and technologies, organizational level ties, and ties caused by knowledge (Brusoni and Prencipe, 2011). This thesis focuses on the dependencies that emerge from product architecture and technological knowledge, and their impact on interorganizational relations. Figure 2 clarifies the positioning between publications and different analytical levels (organizational relations, knowledge, technology and the product system level). The different publications of this thesis are marked P1, P2, P3 and P4 with a summary of their main objectives. The overall main objective is to adopt the viewpoint of a focal firm and investigate how technology-level and knowledge-level dependencies influence its boundaries. Extant modularity literature mainly concentrates on technological-level dependencies that come into existence from networked technological knowledge. That knowledge is owned by several firms, and their patents are one visible source of this knowledge.

The argument that technological resource interdependencies have a one-way influence on interorganizational relations, and thus on industry architecture, is reductionistic (Zirpoli & Camuffo, 2009). Rather, the organizational level and product architecture level influence one another mutually; the relationship between organizational architecture and product architecture is bidirectional (Zirpoli and Camuffo, 2009), and a change in either of the architectures would influence the other (Brusoni and Prencipe, 2011). The overall objective of this thesis is to shed light on the relationship between technological resource dependencies and interorganizational relationships in terms of the buyer-supplier relationship, the make or buy question, and the price of the target of a technological acquisition. This thesis adopts the perspective of a focal firm that is a system integrator or incumbent firm that makes technology acquisitions.

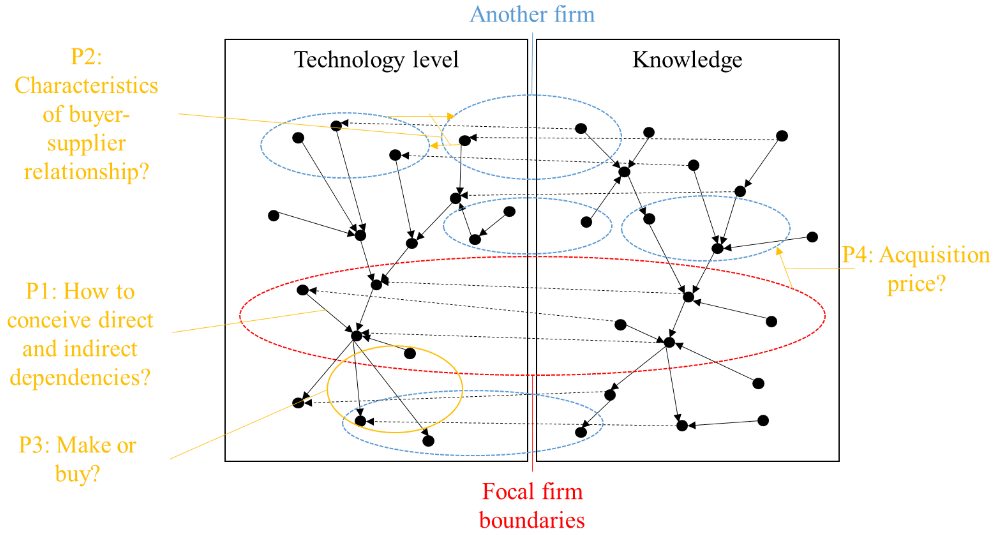


Figure 2. Publications and objectives.

Therefore, this thesis focuses on one main research question:

How do technological resource dependencies affect interorganizational relationships from a focal firm's perspective?

To answer this, theoretical development and empirical work in the form of four publications were established. Two publications (P1 and P2) develop a way to conceive indirect and direct dependencies in a network, a way of understanding technological dependencies, and how these affect buyer-supplier relationships. A buyer-supplier relationship is the consequence of a firm's decision to *buy*, whereas a *make* decision (understood here as, and used interchangeably with, internalisation) leads to a focal firm's internal tasks, or if not feasible, to technological acquisition. That is why P3 concentrates on the influence of technological-resource dependencies on a firm's internalisation/externalisation decisions. Finally, P4 assumes the perspective of technological-acquisition and technological-resource dependencies, using patent data together with mergers-and-acquisitions data. Table 1 shows the connections among the publications, the related sub-questions and the main research question of this thesis.

Together with main research question, this thesis has three sub-questions:

1) How do technological resource dependencies affect buyer-supplier relationships?

2) How do technological resource dependencies affect a firm's decision to internalize design or production?

3) How do technological resource dependencies affect a target firm’s price in technological acquisitions?

Table 1. The research questions and the related publications.

Dissertation	**Main RQ:** **How do technological resource dependencies affect interorganizational relationships from a focal firm’s perspective?**		
	Sub-RQ1: How do technological resource dependencies affect buyer-supplier relationships, and how to measure technological resource dependencies?	**Sub-RQ2**: How do technological resource dependencies affect a firm’s decision to internalize design or production?	**Sub-RQ3**: How do technological resource dependencies affect a target firm’s price in technological acquisitions?
Publications	**I**: Hidden structure and value network: Shedding light on position assessment		
	II: Linking technological system architecture and purchasing categories		
		III: Technological system complexity and system integration	
			IV: Interorganizational resource dependence and the value of firm resources in technology acquisitions

1.3 Definitions and research positioning

This thesis is positioned in the field of technology and innovation management, being in intersection of the management of product systems, modularity and technology acquisitions literatures. From the perspective of system integrator firm, technological resource dependencies at the component level are important questions in the management of product systems and their architectures, (Brusoni and Prencipe, 2011). The modularity research stream discusses the mirroring of the product architecture to organizational structures (Colfer and Baldwin, 2016; Sanchez and Mahoney, 1996). By conceiving technological acquisition as a transfer some knowledge resources inside a focal firm boundaries, I also view the technological acquisition literature as one of the research streams of this thesis (Chondrakis, 2016; Grimpe and Hussinger, 2014b).

The theoretical point of departure of this thesis stems from Baldwin’s theory of systems of production (Baldwin, 2008), which leverages theories such as knowledge base view (KBV), transactions cost economics (TCE) and modularity. Interorganizational relations are defined by the location of the transaction between firms, and these transaction locations are not only technologically determined, but are a consequence of the interplay of firms’ strategies and knowledge, and of the requirements of specific technologies. Tasks can be, for instance, design or production tasks. Transfers are movements of energy, material or information. Areas in the task network where transfers between tasks are dense and complex should be located in transaction-free zones, for example, inside one organizational unit that does not require work to define, count or compensate these transfers (Baldwin, 2008). Thus, interdependent tasks should be located inside a firm’s boundaries or in an environment of strong and close relations between firms, which is similar to the conclusion provided by KBV or TCE (Baldwin, 2008). Technological resource dependencies between components at the product system level or knowledge level suggest transfers of information between tasks. When dense, the transactions costs rise, whereas thin transfer (low amount of transfers) points to groups of tasks associated with low transactions costs. This theoretical viewpoint is fully explained at the beginning of Chapter 2. Next, the key concepts of this thesis and their definitions are listed below.

Technological resource dependence. This is defined as: a resource is dependent on another resource if the former builds on the knowledge required to develop the latter. In other words, resource A is dependent on resource B if A builds on knowledge that is intrinsic to resource B. Technological resource dependence is similar to the concept of technological knowledge dependence (Howard, Withers, and Tihanyi, 2017). Publications II and III discuss technological resource dependence from the viewpoint of the interdependencies between physical components of the product system, in which the unit of analysis is at the technological level rather than at the level of pure knowledge about a production system (Baldwin, 2008; Baldwin and Clark, 2000; Brusoni and Prencipe, 2011; Ulrich, 1995). There, the definition is, “if something in component 1 changes, then component 2 may change as well” (Baldwin and Clark, 2000; Colfer and Baldwin, 2016). Publication IV discusses technological resource dependencies in the context of patents, following a definition of dependence at the knowledge level.

Interorganizational relationships. Firms enter relationships with one another, and form linkages with each other. This thesis take the approach that the choice of firm boundary depends on economic incentives and on production and transaction costs (Riordan and Williamson, 1985). The place of business firms’ boundaries and the division of tasks between them is signalled by transactions between firms. Technology acquisition is a situation in which a transaction with a target is not a sufficient condition for the acquirer to get access to target’s resources.

Product architecture. Product architecture is a scheme in which the function of the product is allocated to components. It is defined through the following three aspects. First, the arrangement of functional elements defines what the product does (its functions from the global level to the subsystem and component levels). Second, the mapping from functional elements to physical components combines the function and components that implement that function. This mapping may be one-to-one, many-to-one, or one to many. Third, the specification of the interfaces between interacting components is also a part of product architecture (Fixson, 2005). An interface specification defines what kind of primary interactions between components or subsystems there may be. (Ulrich, 1995) Fixson and Park (2008) found that product architecture can be changed from modular to more integral, and that change can be made by a firm that possesses a broader component spectrum, or at least related knowledge of the components involved. Simultaneously, this product architecture change can negatively affect suppliers that provide components by destroying the compatibility of their components with the entire system (Fixson and Park, 2008). However, the evolution of product architecture usually develops from integral to modular, but can also be reversed for reasons such as the incorporation of a previously modular component into a new product system (Shibata, Yano, and Kodama, 2005).

1.4 Structure of the thesis

Following this introduction, this thesis begins by providing background knowledge on technological resource dependencies and what is known about the influence of these dependencies on the interorganizational relations between firms. At the beginning of the second chapter, I discuss the theoretical premises of this thesis. Then, in the third chapter, I discuss the methodology as well as ontological and epistemological foundations of this thesis. I provide an overview of the results of the four publications in the fourth chapter. Regarding the research questions, I discuss and conclude the contribution of this thesis in the fifth chapter. In the fifth chapter, the theoretical and practical implications and conclusions of this thesis are summarized.

2 Theoretical background

2.1 Theoretical lenses for systems of production

In this thesis I follow the theories of Baldwin, (2008) who draws her arguments on the synthesis of insights mainly from transaction cost economics (TCE), knowledge based view (KBV) and the theory of modularity to construct a theory of the locations of transactions and the boundaries of firms in a productive system with multiple tasks (Colfer and Baldwin, 2016; Langlois, 2006; Nickerson and Zenger, 2004; Williamson, 1973). Williamson’s theories concentrate on the risks that are related to opportunistic actions and provide only little theoretical backbone for questions that deal with both technological products and organizational boundary choices. For example, TCE is unable to discuss situations when technological change influences firms’ boundaries (Baldwin, 2008). Regardless of the tempting logic of KBV, it is insufficient in its current form to explain firm boundary choices in the context of product systems (Baldwin, 2008). This is because there is misalignment between knowledge levels and firm boundaries. For instance, system integrators have more knowledge than they actually employ in production activities (Brusoni *et al.*, 2001). Baldwin (2008) concludes that knowledge and firm boundaries are related, but not the same. That is why TCE or KBV alone are not sufficient to frame this thesis, but a synthesis of TCE, KBV and modularity theory within a theory for systems of production is (Baldwin, 2008). First, the background of TCE and KBV is provided in the following sections, then Baldwin’s theory that, based on grant theories of TCE, KBV and modularity. I then highlight the modularity theory at the end of this section in more detail because of its importance for this thesis.

Transaction cost economics. The literature on TCE originates from the work of Coase (1937), who noted that there is a cost for organizing production through price mechanisms between firms. The stages of a production process can be designed to take location within one firm or across several firms, depending on costs. A transfer of goods or service is the unit of analysis in TCE, and firms want to achieve effective outcomes in their actions (Williamson, 1985). Costs emerge from production costs but also from opportunistic actions that arise from misalignment of incentives between actors, known as transaction costs. Williamson notes that, ‘Kenneth Arrow has defined transaction costs as the “costs of running the economic system”’ (1969: 48). Such costs are to be distinguished from production costs, which is the cost category with which neoclassical analysis has been preoccupied. “Transaction costs are the economic equivalent of friction in physical systems.” (Williamson, 1985: 18–19). The central proposition of TCE is that transactions will be handled in such a way as to minimize these costs and the risks involved in the transaction. The fundamental question is, when will allocating resources beyond the boundaries of the firm provide higher gains than the risks involved with choosing market options.

Williamson (1973: 1–2) found the key insight of TCE to be that, “transactions and the costs that attend completing transactions by one institutional mode rather than another”, referring to the choice of governance mode and its influence on costs. These governance mode options include three generic forms of economic organization: market, hierarchy and hybrid (Williamson, 1991). These governance modes differ in terms of contract law, and each employs its own coordination and control systems (Williamson, 1991). Market refers to governance in which transactions are made purely through the market, in which price method is leveraged, and no dependency between the parties exist. In hybrid governance mode, the parties of a transaction maintain autonomy but are bilaterally dependent on each other's actions in a way that is not trivial (David and Han, 2004; Williamson, 1991). The identity of the parties matters, which is the difference between market and hybrid (Williamson, 1991). Hierarchy refers a governance mode in which the law of forbearance is present. Any issue rising between parties is resolved by parties themselves or by the hierarchy (Williamson, 1991), which is the case, for instance, within the boundaries of a firm. The governance mode is decided by reflecting on the attributes of transaction.

Transactions have different attributes, including asset specificity, which refers to assets that are directly bound to a specific transaction relationship and that have no alternative use (Peteraf, 1993). If two product designs are interdependent, each is specific to the other, meaning that change in the one may produce change in the other. That is why Baldwin (2008) reasons that design interdependency is a form of Williamson's asset specificity (Williamson, 1985). Thus, she further develops the TCE lenses for the question involving technological products and the organizational governance mode. TCE propose that when asset specificity increases, the optimal choice of governance mode moves towards hierarchy because of the increase in governance costs (David and Han, 2004; Williamson, 1991). Thus, an increase in design interdependency is a move towards hierarchy if a decrease in governance costs is desired. In general, asset specificity as a transaction characteristic has been regarded as quite a convincing variable in TCE theory, having empirical support, and thus explaining both the choice between make or buy (hierarchy vs. market) and integration between independent buyers and sellers (David and Han, 2004).

Knowledge based view. The creation of new design or production facilities for a product, for instance, is a problem-solving activity (Nickerson and Zenger, 2004). Firms have technological resources such as knowledge that is required conceive of technological products (Huenteler *et al.*, 2016). Knowledge is needed to transfer inputs into valuable outputs, and these valuable knowledge resources should be kept within the boundaries of firms so that they may remain competitive (Barney, 1991). A firm that has specialized and advanced knowledge of a technology can probably stay ahead of its competitors in technological development (Grant, 1996). The internal development of strategically valuable technological resources in not fast, and firms should concentrate on accumulating unique resources gradually if they are developed internally (Dierickx and Cool, 1989). Taking that into account, firms often engage in mergers and acquisitions to obtain technological resources from outside the firm (Barney, 1988; Holcomb and Hitt, 2007). Instead of only focusing on internal knowledge protection, the topical question is how to produce that knowledge, and how the boundaries of firms are related to this matter (Nickerson and Zenger, 2004).

Alternative organizational forms for generating knowledge or capabilities regarding to KBV theory are market-based, authority-based and consensus-based hierarchies (Nickerson and Zenger, 2004). Market-based forms of governance rely on decentralized decision making between parties, and are suitable for problem solving that has order and direction (decomposable problems and low knowledge-set interaction). For problems with moderate knowledge-set interdependence (nearly decomposable), there must be an authority to arbitrate the problem solving and order trials. When the type of problem and knowledge sets needed are non-decomposable, actors must first educate one another regarding in knowledge relevant to defining collective search heuristics (Nickerson and Zenger, 2004). This is a consensus-based hierarchy. Inside a firm's boundaries, there is infrastructure for more efficient coordination and communication when compared to market-based transactions (Kogut and Zander, 1996). In order to reach a viable solution, firms shift their boundaries in response to changes in the problems that they address to let search processes align with the problems (Nickerson and Zenger, 2004).

A theory of the location of transactions and the boundaries of firms in a productive system. Drawing on modularity theory, Baldwin (2008) define systems of production as networks in which tasks-cum-agents are nodes, and transfers (of materials, energy, information) between tasks (and agents) are edges between those nodes. In her theory, transactions are not the unit of analysis as they are for Williamson (1985), but defined as mutually agreed-upon transfers with compensation, that are located within the task network and serve to divide one set of tasks from another (Baldwin, 2008). Drawing from modularity theory, this network view uses units of analysis including decisions, components or tasks and their dependencies that are more concreate and directly observable than knowledge distribution (Baldwin, 2008).

In a reciprocal exchange between agents, a transfer must be (i) defined; (ii) counted (or measured); and (iii) compensated (Baldwin, 2008). Definition provides a description of the object being transferred. A quantity—a number, weight, volume, length of time, or flow of transfer is referred as counting. Compensation is moved from the recipient to the provider of the transacted object, which requires the system to valuate the object and for both seller and buyer to accept the valuation (Baldwin, 2008). These three conditions must be met to establish a mutually agreeable exchange. The creation of this common ground between agents requires work and thus adds new tasks to the task network. As a result, Baldwin (2008: 164) observes that, "a transaction is a transfer (or set of transfers) embellished with several added and costly features" and calls these costs the mundane transaction costs (Langlois, 2006). The location of transactions is based on the argument about the amount of mundane transaction costs in these locations in the task network (Baldwin, 2008).

KBV states that decomposable knowledge sets can be governed through markets, in which each agent can concentrate mainly on their own knowledge, and only limited amounts of transfers cross organizational boundaries (Baldwin, 2008; Nickerson and Zenger, 2004). In these thin crossing points, mundane transaction costs will be low.

Transactions are best located at these points at the boundaries of modules, not within task modules (Baldwin, 2008).

Whereas in thick crossing points (with plenty of complicate transfers of information, material and energy) between firm boundaries, the market-based governance mode is not optimal. Opportunistic actions are more likely, since agents want to reduce information transfers, and make defensive investments, because compensation is provided only for the product itself, not for tasks, per se. To reduce opportunistic actions, contracts are required, but the creation of a contract that can cover all these tasks increases mundane transaction costs (Baldwin, 2008). A thick crossing point between tasks is a location in which an attempt to fully compensate all transfers is impossible, since it will burden the productive system with extra overhead and create the wrong incentives for agents to initiate more transfers than necessary (Baldwin, 2008). Total transaction costs are the sum of mundane and opportunistic transaction costs, and relational contract forms with trust between parties reduces these costs when compared to formal contracts (Baldwin, 2008; Mayer and Argyres, 2004).

No transfers between tasks are optimal for contract-based governance, but transaction free locations are needed in the system of production. There are locations and time frames in which technology determines that transfers must be dense and complex (Baldwin, 2008). Mundane and opportunistic transaction costs will be high in such locations, and that is why transactions between sovereign agents could not be reasonable, because of the overload of mundane transaction costs (Baldwin, 2008). Modern corporations are transaction-free zones, encapsulated by transactions with others. This reasoning is in line with idea that if a contract between parties cannot be written because of output being idiosyncratic and uncertain, a firm should keep that activity inside its boundaries (Mowery, 1983).

Modularity and mirroring hypothesis. The mirroring hypothesis states that interorganizational structure leads to certain product architecture (Colfer and Baldwin, 2016). It implies a positive bi-directional relationship between product architecture and organizational architecture, whether analysed from intrafirm, interfirm, supply network or industry levels (Sorkun and Furlan, 2017). For instance, there are not many technological resource dependencies between firms that have an arms-length or adversarial relationship. However, high levels of organizational integration in terms of information sharing lead to integral product architecture instead of modular (MacCormack, Rusnak, and Baldwin, 2006). On the other hand, there is research that proposes the opposite direction of causality, suggesting that a given product architecture leads to a certain organizational structure, and if it does not, there is a misalignment (Gokpinar *et al.*, 2010; Sosa *et al.*, 2004).

In this thesis the interplay between product architecture and organizational structure is assumed to bidirectional, even though the actual research in this thesis focuses on the influence of product architecture (in terms of technological resource dependencies) on organizational structures. Mirroring hypotheses have received support in empirical studies, but also critique (Colfer and Baldwin, 2016; Sorkun and Furlan, 2017). Depending on the industry, and multiple contingency factors, the theory can be either more or less appropriate. For instance, it has been argued that the openness of designs between the actors in the industry reduces the appropriateness of the mirroring hypothesis, such as in software industries (Colfer and Baldwin, 2016). In the software industry, transfers of information can be visible to all participants simultaneously, diminishing the boundaries between firms that distract information transfers over boundaries. Sorkun and Furlan (2017) found six distinct contingency factors in their literature review: component technological change and diversity, innovativeness of product architecture, complexity of product architecture, capability dispersion along the network, rivalry among firms, and logistics costs. These factors challenged the expected pattern of the mirroring hypothesis in previous empirical work. To understand the mirroring, the principles of modularity in product architecture are described in the following sections.

Many kind of entities (e.g. technological, organizational and other social entities) can be regarded as hierarchically nested systems. In a system, varying unit of analysis levels can be found, suggesting that the entity is a system of components, and each of those components is, in turn, a collection of finer components, until the level of elementary particles is reached (Simon, 1962). Thus, technological entities can be viewed as hierarchical systems, meaning that regardless of the unit of analysis, the entity is a system of components and each of those components is, in turn, a system in itself (Simon, 1962). By extending the idea of hierarchy as an organizing principle of complex systems (Simon, 1962), Sanchez and Mahoney (1996) apply this idea to the analysis of product designs and new product development processes between organizations in order to define the concept of modularity.

When there is little or no managerial authority over hierarchy rules that refers to a decomposition of a complex product system into structured ordering of subsystems, both the organization structure and the product can be modular. For instance, at the firm level, it is suggested that when necessary tasks are more complex, there is a need to have more divisions to share managerial responsibilities, but also more hierarchy. On the other hand, when tasks are more interdependent, the number of work units involved decreases (Zhou, 2013). In line with that, Thompson (1967) argued that reciprocally interdependent tasks should be located within a common organizational boundary when complexity is present. Building on this, Puranam (2012: 421) states that “two tasks are interdependent if the value generated from performing each is different when the other task is performed versus when it is not”. Thus, independent tasks are those in which the combined value created is the same as the sum of the values created by performing each task alone, meaning they are discrete contributions to the whole (Puranam *et al.*, 2012). It is important to separate sequential from reciprocal (Thompson, 1967), one task can be asymmetrically interdependent with another task, but the converse need not be true (Puranam *et al.*, 2012). Organizations and tasks within organization differ in terms of their coupling to other tasks and the strength of these dependencies (Orton and Weick, 1990). Modularization of product architecture (product-level) might be insufficient to reduce dependencies at the actor or organizational level (Puranam *et al.*, 2012; Sorkun and Furlan, 2017).

Modular product architecture refers to de-coupled component interfaces (Sanchez and Mahoney, 1996). A de-coupled interface means that a change made to one component does not require a change to the other component to ensure the overall product works correctly. As opposed to modular, integral architecture requires changes to several components in order to ensure the overall product works when changes occur (Ulrich, 1995). An integral product architecture exists when functions of the product cannot be mapped onto a set of components on a one-to-one basis (Ulrich, 1995), and the interfaces are highly interdependent. Engineers look for modularity in product design to manage the complexity of technological systems, to allow working units to perform their tasks simultaneously (production and subsystems design), and to create innovation opportunities in the submodules of larger systems (Baldwin and Clark, 2000; Ulrich, 1995). Modularity can be seen both in product architectures and in organizational structures in the network, when product architecture enables this (Sanchez and Mahoney, 1996). Schilling (2000) defines modularity as a continuum describing the degree to which components can be separated and recombined. It also refers both to the tightness of coupling between components and to how well the system architecture within its design rules enable recombination. With modularity, there are greater opportunities to mix and match modules to the system and thus to respond to heterogeneous customer needs (Baldwin and Clark, 2000).

Standardized component interfaces let component design development processes happen in a more loosely coupled way, which decreases the requirements of effective coordination and managerial authority, since relational properties between components are defined (Schmidt and Werle, 1998). This is because the information structure embedded into interface specifications enables the modular form of units or organizations that develop the entire product. When product architecture is integral, organizations are more tightly coupled (Sanchez and Mahoney, 1996). A nearly independent system of loosely coupled components base on standardized interfaces, provides embedded coordination to firms involved in entire product design activities (Sanchez and Mahoney, 1996). Through connecting, transferring, transforming, and controlling, interfaces manage the interactive functions between components (Sanchez and Mahoney, 1996). This embedded coordination is enabled by an established information structure (standards) for functional, spatial, energy and other relationships between components that are not allowed to change during an intended period in a product development phase (Sanchez and Mahoney, 1996).

Some product systems reach their functionality only through sizing each of the components to work as entity. Each component is then specific to the system, and change to non-specific options could cause loss of performance (Schilling, 2000; Simon, 1962). Extensive interactions between components (caused by the design or nature of the component) may create a situation in which any change in a component requires extensive compensating changes elsewhere in the system, or desired functionality is lost (Sanchez and Mahoney, 1996). On the other hand, some systems have independent components, meaning that the degree of separation a system is able to retain lies on a continuum (Schilling, 2000).

Modularity of product architecture allows greater product variety since heterogeneous inputs to a system can respond to heterogeneous demands of customers (Sanchez and Mahoney, 1996; Schilling, 2000). Modularity can decrease or increase over time, depending on scientific advances and customer preferences (Schilling, 2000). Modular architecture adds flexibility to design processes, since parallel design is possible when design rules (specifications that ensure that components fit together) are obeyed by distinct design units (Baldwin and Clark, 1997; Sanchez and Mahoney, 1996). Thus, modular design can speed up incremental product performance improvement by decoupling the solution space from other constraining subsystems, maintaining stability of design rules, and the accumulation of experience of certain problems by certain development teams (Pil and Cohen, 2006). Modular architecture also provides strategic flexibility in terms of the number of different product models, having a positive impact on firm performance (Worren, Moore, and Cardona, 2002). A disadvantage of design modularity can be, especially when the product system is simple rather than complex, imitation by competitors, since the modular structure is easier to understand (Pil and Cohen, 2006).

2.2 Technological resource dependence

The evolutionary approach toward knowledge conceives of knowledge as a system of processes deeply rooted in their contexts of production (Paoli and Prencipe, 1999). These processes are never reducible to their outcomes nor have decomposability characteristics, since knowledge has a tacit dimension and an explicit dimension; individuals always know more than they can tell (Polanyi, 1962). Processes can also be described as interactions between agents and physical systems within teams of people (Greeno and Moore, 1993). In this thesis, I follow this evolutionary view on technological knowledge, leading to the following assumptions of its characteristics.

Technological knowledge has many characteristics that distinguish it from other types of knowledge: it is explicit but also heavily tacit in nature, sometimes hard to teach or even articulate, non-observable in use, complicated, involves elements of a system, is context-dependent and relies on the deeply multidisciplinary view of engineering sciences (Paoli and Prencipe, 1999; Winter, 1998). Similarly, Dosi (Dosi, 1982) defines technology not only as physical devices and equipment but as a set of pieces of knowledge. This knowledge refers both to theoretical and to technical knowledge (whether already applied or not), and to practical problem-solving skills, methods, and procedures and learning gleaned from previous failures and successes. This thesis uses the word technological a lot, which is defined by Oxford dictionary as an adjective that refers to using technology or relating to it directly.

The definition of technological resource dependence is the following: a resource is dependent on another resource if the former builds on the knowledge required to develop the latter resource. In other words, resource A is dependent on resource B if A builds on knowledge that is connected to resource B. Technological resource dependence is similar to the concept of technological knowledge dependence that exists between resources and across firms (Howard *et al.*, 2017). A system integrator firm deals with these resource dependencies that cross the organizational boundaries between firms. One trigger of product architecture change or a re-arrangement of relations in the network constitutes technological change (Fixson and Park, 2008).

Technological change in resources may emerge from market needs or from technological progress, being influenced by both (Dosi, 1982). The needs to upgrade parts of the product, add-ons, and different-use environments are motivations for product change during a product life span (Ramachandran and Krishnan, 2008; Ulrich, 1995). Technological change is easier to handle with modular architecture (Ramachandran and Krishnan, 2008; Ulrich, 1995), rather than when technological resource dependencies are present among components. But what forces cause dependencies between technological resources? One force is the cumulative nature of technological knowledge, caused by technological trajectories (Dosi, 1982; Murmann and Frenken, 2006). On the other hand, technological components sharing a common product architecture make these components depend on the entire product architecture in order to make the system function as a whole (Murmann and Frenken, 2006).

Communities of researchers hold incompatible meta-theoretical assumptions, which are consistent within a single scientific paradigm (Kuhn, 1962). By leveraging the analogy of the scientific paradigm, Dosi (1982: 152), defines the technological paradigm as a "model and a pattern of solution of selected technological problems, based on selected principles derived from natural sciences and on selected material technologies" that the community of engineers follows. Similarly, as the scientific paradigm determines the problems, the procedures, the tasks to solve and the field of enquiry in the natural sciences, so does the technological paradigm when selected constraints of its field of enquiry are met. The definition of technological trajectory is "the pattern of "normal" problem solving activity on the ground of a technological paradigm"(Dosi, 1982: 152). The technological paradigm retains strong prescriptions on the directions of technical change both to follow and to neglect. Technical progress is the actualization of former promises and expectations within the technological paradigm, building on an established foundation of knowledge. Technological progress (improvements in technology) solves the tasks the paradigm involves in respect of economic factors such as speed, noise-immunity or other factors.

There may be trade-offs between these economic and technological dimensions when technological development is established by engineers. That is why one can imagine the technological trajectory as a cylinder containing both economic and technological variables; the outer boundaries of which are limited by the paradigm itself (Dosi, 1982). That is why the state of technology forces trade-offs between economics and product features, in order to maintain the most preferred service characteristics (Casadesus-Masanell and Almirall, 2010). When new features are added, the product is likely to become less desirable in some dimensions in customers' judgement (Casadesus-Masanell and Almirall, 2010). Ethiraj (2007) found that in complex product systems, inventive efforts in terms of R&D are concentrated on components that constrain overall product performance. Even firms that do not producing constraining components participate in resolving constraints of the product system, since their investments into the R&D of their own components cannot fully be leveraged without reducing constraining issues (Ethiraj, 2007). This is one example of a situation in which the firm's own resources cannot be seen in isolation from the rest of the product system. Similarly, Ethiraj and Posen (2013) found that component-level interdependencies either expand or constrain the options for innovation activities available to a firm. Asymmetry of these dependencies can enable some firms to influence other firms by setting and dictating the trajectory of progress in their industry (Ethiraj and Posen, 2013). Empirical evidence from the PC industry suggests that constraint-enhancing design dependencies are negatively related to innovation productivity, whereas influence-extending dependencies positively affect innovation productivity (Ethiraj and Posen, 2013). The product development efforts of firms in PC and other systemic industries are governed by information received from others, and target a part of their R&D efforts depending on the stage of the technological trajectory (Mäkinen and Dedehayir, 2013).

Within technological product systems, components are organized in a hierarchical fashion (Clark, 1985; Murmann and Frenken, 2006). Component choices at any given level of the hierarchy place design constraints on the lower-order components. When the high-order components of hierarchy change, the compatibility between components is harder to maintain, because design constraints change simultaneously with many lower levels (Clark, 1985; Garud and Kumaraswamy, 1995). Core components are tightly coupled with other components, and these must be stabilized before design parameters are available for more peripheral components (Murmann and Frenken, 2006).

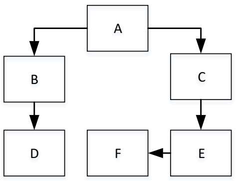
The amount of interdependencies between elements of the product system is not the only factor when interdependencies are considered, their pattern of distribution also matters (MacCormack *et al.*, 2006; Sosa, Eppinger, and Rowles, 2003). If the order is simple and hierarchically organized, it is much simpler than dependency patterns with non-hierarchical settings. Poorly placed dependencies, especially those that link otherwise independent entities, may cause a cascade of unwanted indirect dependency chains (Baldwin, MacCormack, and Rusnak, 2014; MacCormack *et al.*, 2006).

Simpler products do not have the same extent of innovation management problems as product systems with component interdependence (Nightingale, 2000). This is because these product systems have, to a larger extent, systemically related subcomponents and an increased possibility of widespread consequences when changing the design of one component (Sosa, Mihm, and Browning, 2013). Such a design change will produce design changes in sensitive subcomponents, also resulting in feedback loops to multiple components at many levels of the product system (Brusoni *et al.*, 2001; Sosa *et al.*, 2013).

These costly redesign loops are reduced by making sure that the design of a component matches its specifications and constraints, and making sure these specifications are correct (Nightingale, 2000). By managing these feedback loops of component dependencies, an organization has better control over the project schedule, costs and product system quality (Nightingale, 2000; Sosa *et al.*, 2013).

Component interdependencies and component types have been defined in many ways (Mikkola, 2006). One definition is provided by the modularity literature (modular vs. integral interfaces of components) (Cabigiosu, Zirpoli, and Camuffo, 2013; Hoetker *et al.*, 2007). Sosa, Eppinger and Rowles (2004) define interfaces between components *i* and *j* as component *i* depending on component *j* in terms of functionality. The functionalities that *j* imposes on *i* are geometric constraints or transfers of forces, material, energy, or signals. Component *i* functions properly when these constraints sent by *j* are considered when designing *i*. When applying this kind of logic, the extent to which a component depends on itself via other product components, and these components form cycles, is called cyclicality (Sosa *et al.*, 2013). This has been proposed to be an important product architecture feature, together with modularity (Sosa *et al.*, 2013). If the cyclical dependency chains between components also cross the module boundaries of the product, it increases proneness to defect (Sosa *et al.*, 2013). Ethiraj and Posen (2013) define technological design dependencies by leveraging both the nature of dependence (pooling, sequential, reciprocal) (Thompson, 1967) and the content of dependency (Sosa *et al.*, 2003). They concentrate on informational dependencies (Sosa *et al.*, 2003) between components in an R&D context, meaning the flow of design information or constraints between components.

To investigate technological resource dependencies at the component level, I have leveraged concepts called inbound and outbound dependence (Figure 3). Similar concepts have been applied as measurement tools in previous literature (Baldwin *et al.*, 2014). These are close to Ethiraj and Posen's (2013) concepts of below diagonal dependencies (the design influence of the focal component on the rest of the product ecosystem) which are closely related to outbound dependence, and above diagonal dependencies (the design influence of the product ecosystem on the focal component) which is closely related to inbound dependence.



	A	B	C	D	E	F
A	0	1	1	0	0	0
B	0	0	0	1	0	0
C	0	0	0	0	1	0
D	0	0	0	0	0	0
E	0	0	0	0	0	1
F	0	0	0	0	0	0

	A	B	C	D	E	F
A	1	1	1	1	1	1
B	0	1	0	1	0	0
C	0	0	1	0	1	1
D	0	0	0	1	0	0
E	0	0	0	0	1	1
F	0	0	0	0	0	1

Figure 3. Inbound and outbound dependency (modified from Baldwin et al. (2014)).

Integral versus modular concepts do not consider the technological constraints that components place on the components that are located at lower levels of the design hierarchy. The design hierarchy is an outcome of the demanded service characteristics that the product system must perform, and gives privileges to the core subsystems that are most important for those demanded service characteristics (Huenteler *et al.*, 2016). Innovative activity in technological knowledge base level is in line with design hierarchy of a given product system (Huenteler *et al.*, 2016). The knowledge structure between firms has been identified as an important factor when product architecture and firms' boundaries are investigated (Brusoni and Prencipe, 2001; Cabigiosu *et al.*, 2013).

The inbound and outbound concepts are based on the network view of a technological system (Ethiraj and Posen, 2013; Sosa, Eppinger, and Rowles, 2007), in which nodes are components and ties are dependencies. Dependency ties have directions, which form a design hierarchy between components (Ethiraj and Posen, 2013). The lengthier the dependency path a focal component can cause, the bigger the change in the system, if it is changing, the more outbound-dependent the component is. Inbound dependence reflects constraints in the design of focal components, because the component must adapt to the dependencies, not vice versa. It is important to consider both direct and indirect dependencies among the components in a system (Baldwin *et al.*, 2014; MacCormack, Baldwin, and Rusnak, 2012).

The outbound dependence of components indicates the degree to which components might be affected by a change in the focal component. The inbound dependence of a component indicates the degree to which components might affect the focal component if they change. The concepts of outbound dependence and inbound dependence are inspired by the measures of the hidden structure method (Baldwin *et al.*, 2014), although they are leveraged in that and previous research as measures instead of concepts, with only a few exceptions (Ethiraj and Posen, 2013). It should be noted that inbound and outbound dependency variables are independent of one another; thus, the same component can have high dependencies for both. In Figure 5, there is an example of the concepts describing them in a more understandable way. The graph is on left hand side, whereas the graph is matrix from in the middle. On the right-hand side, there is a matrix that has all direct and indirect dependencies in it, suggesting that component A is high in outbound dependence (row value) and component F in inbound dependence (column value).

2.3 Technological resource dependence and buyer-supplier relationships

The main assumption from the existing literature is that modular product architecture leads to more loosely coupled organizations, whereas integral product architecture leads to more tightly coupled organizations (Campagnolo and Camuffo, 2010; Sanchez and Mahoney, 1996). However, empirical evidence suggest that this assumption is oversimplified, since definitively supporting evidence has not been found (Cabigiosu and

Camuffo, 2012; Campagnolo and Camuffo, 2010; Furlan, Cabigiosu, and Camuffo, 2014). For instance, in some industries, coordination is not embedded into modular interfaces but rather into knowledgeable system integrators (Brusoni and Prencipe, 2001, 2006). In this section, modularity in the lenses of buyer-supplier relations is discussed, and after that the viewpoints from purchasing and supply-management literature are included to enrich the view on buyer-supplier relationships. This stream of research concentrates less on straightforwardly technological resource dependencies than the modularity literature does, but rather focuses on related issues such as the impact of technical specifications on buyer-supplier relationships (Bensaou, 1999).

Integral architecture entails intensive communication and knowledge sharing between buyers and suppliers when certain components are outsourced. Component and subsystem interdependencies create a need for the exchange of technical information across a range of engineering disciplines, which requires the teamwork of multiple experts (Gann and Salter, 2000; Sosa *et al.*, 2004). Product definition, development, testing and production are processes that necessitate knowledge transfer through complex networks of suppliers, including multiple rounds of interaction (Gann and Salter, 2000). Collaboration and information sharing with suppliers can reduce product interface constraints during the development phase of modular products (Mikkola, 2003). Asset specificity mediates the effect of supplier modularization on buyer-supplier collaboration (Howard and Squire, 2007). As explanation of this, a particular problem that can occur is opportunistic re-contracting, where either the buyer or supplier can act opportunistically when contracts are renewed, but relation-specific investments could hinder this (Howard and Squire, 2007).

The stronger the dependencies between physical components, the greater the likelihood that team interaction increases when designing those components (Sosa *et al.*, 2004). Customization is the extent to which a product is customized for a buyer, being one dimension which is related to the technological resource dependencies that influence the characteristics of buyer-supplier relations. A customized product is designed specifically to respond to the needs of a particular customer (Duray *et al.*, 2000). Suppliers can serve multiple buyers through customization, even if this may be challenging, since customization often requires non-transferable buyer-specific investments. A high degree of customization leads to buyer involvement in the design phase, whereas a low degree of customization leads to a situation in which the supplier provides standardized and repeatable components to many customers (Duray *et al.*, 2000).

By contrast to integral components, highly modular components can be incorporated into multiple product systems (Schilling, 2000). When the product architecture is modular, teams and developers can be more dispersed (MacCormack *et al.*, 2006). Highly modular products can be designed and produced by disaggregated networks of firms, and when there is no specialized interfaces between a particular buyer and supplier, the network is more flexible in terms of partner changes (Langlois and Robertson, 1992; Sanchez and Mahoney, 1996). Thus, component modularity enables buyers to change, add or drop suppliers easily (Garud and Kumaraswamy, 1995). From a buyer’s perspective, long-term and trust-based relations with suppliers are linked to integral design, whereas more arms-length and transaction based relations are linked with modular design (Ülkü and Schmidt, 2011).

When product architecture is stable (no technological change) at the component level, and the buyer designs more modular components (ex-ante), there is less information sharing between the buyer and component supplier (ex-post) (Cabigiosu and Camuffo, 2012). However, at the firm level, findings are more ambiguous; modular products can be associated with intense information sharing in the design phase, whereas product modularity and buyer–supplier information sharing go together because of the synergistic effects and benefits of adopting them simultaneously. Another choice for a firm is to make a trade-off between intense information sharing and modularity (Cabigiosu and Camuffo, 2012).

Technological change is positively related to buyer-supplier information sharing (Furlan *et al.*, 2014). Further, when a component is changing above the median over time when compared to other components, the effects of component modularity on buyer-supplier information sharing do not hold (Furlan *et al.*, 2014). However, a component characterized by high modularity and low technological change requires comparatively less buyer–supplier information sharing (Cabigiosu and Camuffo, 2012; Furlan *et al.*, 2014). Technological change goes beyond existing module boundaries, affecting interdependencies between the modules, and thus modular architecture does not decrease buyer-supplier information sharing, regardless of modular interfaces (Furlan *et al.*, 2014).

In their research on the interface definition process between buyer and supplier, Cabigiosu, Zirpoli and Camuffo (2013) found that the buyer's strategic orientation and choices in knowledge domain drive its choice on how new product development activities are managed, for instance by modular interfaces with clear specifications given by buyer, or by a process with changing and fluid interfaces managed together with the supplier. As a consequence, only system integrators, or firms with a knowledge domain that can span to coordinate multiple firms' design efforts, can take advantage of modularity (Cabigiosu *et al.*, 2013; Zirpoli and Becker, 2011).

The developmental paths of the knowledge bases of firms plays a fundamental role in mediating the relationship between product and organizational design (Brusoni *et al.*, 2001). Changes in organizational design can be driven by engineering know-how, which could be triggered by new core subsystems, including varying preference of what is important (Brusoni and Prencipe, 2006). This could be one explanation as to why component modularity is negatively related to buyer–supplier information sharing only when component technological change is low (Furlan *et al.*, 2014). These findings emphasize that the roles of engineering knowledge and technological interdependencies could together be more accurate tools for investigating the impact of product architecture on organizational relations than the traditional modular-integral divide.

The extent to which a supplier can act independently of its buyers is called autonomy, and is an important characteristic of the buyer-supplier relationship. A supplier's potential autonomy measures its opportunities to form relations with new buyers compared to the buyers' opportunities to develop ties with new suppliers. In terms of survival, highly modular component suppliers benefit more from potential autonomy than low modular component suppliers (Hoetker *et al.*, 2007). The reason for this is that low modularity component suppliers cannot increase their bargaining power over buyers with credible alternatives, since relation-specific coordination and routines bind it to its current set of buyers (Howard and Squire, 2007; Monteverde and Teece, 1982). Highly modular suppliers have low switching costs if they need to change their existing buyer relationships, whereas low modularity means high switching costs for the supplier. Whether the supplier is a low or highly modular component provider, it will survive better over time when its existing customer base provides it with autonomy and thus reduces its dependence on a single buyer (Hoetker *et al.*, 2007).

Buyer-supplier relationships and the characteristics of these relations, such as switching costs, relation-specific investments and the need for another party's technological expertise within these relations are widely discussed not only in modularity literature, but also in purchasing and supply management literature (Bensaou, 1999; Dabhilkar, Bengtsson, and Lakemond, 2016; Nellore and Söderquist, 2000). For instance, Bensaou found (1999) four types of buyer-supplier relationships in his survey of the context of car manufacturing. These were divided according to buyers' specific investments (low-high) and supplier's specific investments (low-high). Buyer-supplier relationship characteristics, or items purchased, have traditionally been approached with Kraljic's matrix (Kraljic, 1983) and its modifications (Caniëls and Gelderman, 2005, 2007; Dabhilkar *et al.*, 2016) to set how supply risk and profit impact the product's influence on the characteristics of the relationship and further strategy choices. Below, each purchasing category from Kraljic's matrix and its buyer-supplier relationship characteristics are discussed, as these are applied in theory developed in this thesis.

Non-critical components. Non-critical components have a low profit impact and low supply risk (Kraljic, 1983). Buyers have many alternative suppliers, and vice versa. Neither supplier nor buyer is tied to the other; thus, there is a balance of power and a low level of interdependence at the relationship level (Caniëls and Gelderman, 2007). Many different buyers can leverage the same component that the supplier provides. When the relationship specific-investments of both sides were low, an arms-length market-exchange type relationship with highly standardized and mature products was found (Bensaou, 1999; Nellore and Söderquist, 2000).

Strategic components. Strategic components have high profit impact and high supply risk (Kraljic, 1983). Strategic components are typically purchased from a single supplier and have high supply risk and profit impact. Single-source purchasing involves significant risks, which a buyer may attempt to reduce by building supplier partnerships. A situation in in which the investments of both supplier and buyer where high led to a strategic partnership with high customization (Bensaou, 1999). Both parties require the other party’s technical specifications (Bensaou, 1999). If a firm seeks to reduce its long-term supplier dependence risk, it may consider backward-integrating to achieve in-house production. With these components, firms seek to develop long-term, close, and collaborative relations with strategic component suppliers, which can be seen as extensions of the buying firm. Total mutual dependence is at its highest level in terms of essentiality and non-substitutability; in such a case there is high switching costs and no alternative partners are easily available (Caniëls and Gelderman, 2005).

Bottleneck components. Bottleneck components have low profit impact and high supply risk. Buyer’s specific investments are high and supplier’s low, the product is complex and the supplier has proprietary control over its technology (Bensaou, 1999). Thus, the system integrator is heavily depend on these suppliers, their technology and skills, and the suppliers of this type have strong bargaining power over the buyer (Bensaou, 1999; Caniëls and Gelderman, 2005). In this category, buyer switching costs are high but supplier’s switching costs are not that high (Caniëls and Gelderman, 2005). Buyers do not have alternative suppliers for these kind of components, and their supplier-specific investments are high (Bensaou, 1999).

Leverage components. Leverage components are associated with high profit impact but low supply risk (Kraljic, 1983). In this category, supplier’s specific investments are high but buyer’s low, products are, in many cases, technically complex. Even if the supplier has strong R&D skills in this relationship type, they have low bargaining power, and the supplier is heavily depended on the buyer (Bensaou, 1999). On the other hand, buyers can shift between suppliers; there are alternatives available (Bensaou, 1999; Caniëls and Gelderman, 2005). Because of heavy buyer-specific investments, switching costs are significant for the supplier. In addition, the specification of components comes mainly from the system integrator, even though co-development is possible, binding supplier to buyer (Nellore and Söderquist, 2000).

2.4 Technological resource dependence and the make or buy decision

The traditional make and buy decision has been expanded to cover both aspects: product design and production (Ulrich and Ellison, 2005). In this thesis, the terms internalization, externalization, make and buy are applied interchangeably respectively and understood the same way. The make-buy decision is also equivalent to the concept of the vertical integration decision, in the sense that a firm choses whether or not to integrate with a supplier (Ulrich and Ellison, 2005). Not all firms in product systems industries follow the view of component interdependencies when making make or buy decisions, since product design engineers and purchasing departments might be separated units, and units deciding strategic purchasing matters take care of make or buy decisions (Novak and Eppinger, 2001). Even if these departments certainly interact, in most cases, joint decision making is insufficient to incorporate the engineering perspective on make or buy decision making.

Design is a collection of instructions that specify how to produce a new product (Baldwin and Clark, 2000). With a particular design, one is trying to reach maximize functionality in the given dimensions that are considered important for that product system (Ulrich, 1995). To produce a component, design is needed, and it can be provided from the same firm that produces the component or from another firm. Park and Ro (2011) call the choice in which a firm only outsources production but keeps design in-house as the pseudo-make strategy. When the product architecture is integral, the pseudo-make strategy helps deal with this architecture (Park and Ro, 2011). In this strategy, the knowledge capability is kept in house (Brusoni *et al.*, 2001) while a firm is still learning from suppliers. Keeping this in mind, design and production choices are separated but interlinked choices, leading to four organizational arrangements from a theoretical perspective: 1) internal design, internal production 2) internal design, external production 3) external design, internal production and 4) external design, external production (Ulrich and Ellison, 2005).

Letting a supplier design or produce a component or subsystem of a product entity involves tempting but also forbidding characteristics. It is a trade-off between these characteristics when compared to keeping all design and production of system under a firm’s own authority. On the other hand, suppliers can stimulate innovation by providing multiple product features for the entire product that a focal firm could not imagine otherwise (Casadesus-Masanell and Almirall, 2010). As side effect, as new technology develops, design and production arrangements are mutually evolving and sensitive to interactions between firms and among their own interests (Garud and Munir, 2008).

Previously, the design choices of the firm and how the network of firms is organized were seen as outcomes of decisions taken to minimize transaction costs (Williamson, 2008), but this view does not take into account systemic interdependencies that arise between components that also influence costs (Garud and Munir, 2008). There are costs involved in informing other firms of product system changes but also in persuading them to cooperate accordingly (Baldwin, 2008; Langlois, 2006).

It is remarkable that a firm can end up with concurrent sourcing, meaning that the same component is both made internally and outsourced externally (Anderson and Parker, 2002; Parmigiani, 2007). Parmigiani (2007) found that concurrent sourcing may appear when there is greater combined firm and supplier expertise for a single component. Also, when a focal firm shares its technical expertise on multiple components (a family of components), it is more likely to end up concurrently sourcing this set of components than producing these components internally (Parmigiani and Mitchell, 2009). Thus, firms can outsource some parts of production and design effectively if they retain an understanding of the overall system (Brusoni and Prencipe, 2001; Parmigiani and Mitchell, 2009).

Design. When several firms are involved, these design preferences may be diverse over time (Garud and Munir, 2008). When a design change occurs, the relationship between design and production arrangements is not discrete or one-off, but can cause reactions in erstwhile partners that do not want to adapt to the change within their own business (Garud and Munir, 2008). That is why these design change costs are not fully calculable a priori (Garud and Munir, 2008). Thus, when multiple firms design product systems, decisions are not purely technical in nature, but also revolve around the self-interest of firms (Tuertscher, Garud, and Kumaraswamy, 2014; Tushman and Rosenkopf, 1992). Aligning interests among interdependent actors in a product systems context is a challenge for the firms involved (Tuertscher *et al.*, 2014).

When there is low complexity in terms of the mapping of product features to technologies involved, all industry participants agree on what the ‘right’ design should be (Casadesus-Masanell and Almirall, 2010). In this kind of situation, the cost of devolving control of product architecture is low since partnering firms will want to make similar choices as the original system integrator would have made (Casadesus-Masanell and Almirall, 2010). This kind of situation emerges when the product is not in its initial stages but mature, and thus allows a wide variety of product features to be available for the product (Casadesus-Masanell and Almirall, 2010).

Park and Ro (2011) found that when a firm in bicycle industry deals with integral product architecture, firms that choose a make strategy are more likely to have better product performance than those firms that choose a buy strategy. Further, when a firm is dealing with integral product architecture, firms that choose in-house design but outsourced production are more likely to exhibit better product performance than firms that choose to outsource both design and production strategy (Park and Ro, 2011). The reason for this is the effective knowledge integration and task coordination mechanisms that are in place when keeping design capability in-house. Keeping the design of components in-house can make a firm sensitive to the quality of its internal knowledge, and risks internal knowledge becoming obsolete when there is no new knowledge to obtain from suppliers (Henderson and Clark, 1990). On the other hand, Park and Ro (2011) found that the performance of integral products do not significantly differ between a pure make strategy and a strategy where design is done in-house and production is outsourced to a supplier.

Zirpoli and Becker (2017) found in their case study about car manufacturers that components of the car and the make or buy decisions of R&D can be set by matching the “level of interdependencies between component and the rest of the product” and a “component’s impact on overall product performance” (how much a component is responsible for the main service characteristics). When both interdependencies and impact on performance are high, the design competence should be keep in-house (Becker and Zirpoli, 2017). Similar to the bicycle industry, those firms that choose the make strategy with integral product architecture were likely to show superior technological and financial performance (Park and Ro, 2013). Since the study was about core parts of a bicycle (index shifting technology), with the buy strategy, the buying firm was sensitive to opportunistic actions of suppliers, and could not leverage the benefits of knowledge integration and sharing in the full range that would have been the case with an internal make decision (Park and Ro, 2013).

In contrast to assumptions of mirroring between product architecture and organizational structure, in bicycle markets, with integral product architecture, firms did not show a strong tendency to pursue a make strategy (neither for design nor production) (Park and Ro, 2013). However, this led to lower technological and financial performance when outsourcing integral components (Park and Ro, 2013). Zirpoli and Becker (2017) proposed that when the level of interdependencies is high, but a component's impact on performance low, the manufacturer should have collaboration with design activities, and the supplier could retain the component-specific knowledge (Becker and Zirpoli, 2017). With components with low interdependence and low impact on performance, the advice is to delegate the overall system development to suppliers and provide only a broad specification (Becker and Zirpoli, 2017). Similarly, with modular product architecture, the likelihood of firms to choose a buy strategy were not supported empirically (Park and Ro, 2013).

When interdependencies are low but impact on performance high, the advice is to provide detailed specifications but outsource subsystem development (Becker and Zirpoli, 2017). In sum, there are risks of gradually losing component-specific knowledge, creating difficulties in providing specifications to suppliers if too many tasks are outsourced (Becker and Zirpoli, 2017). Nevertheless, with modular product architecture, firms that chose the buy strategy for sourcing are more likely to exhibit greater financial performance than firms that chose a make strategy for sourcing, without losing technological performance (Park and Ro, 2013).

Besides dealing with a network of many firms, the division of design tasks inside *one* globally dispersed firm can be challenging because of the difficulty of harmonized coordination. If the design tasks of a subsystem are more globally dispersed within a firm, the higher the rate of design errors that lead to quality problems or delays requiring additional engineering work will be (Gokpinar, Hopp, and Iravani, 2013). These design errors emerge from difficulties in transferring technological knowledge, conflicts between dispersed teams, and a lack of communication quality and frequency between teams (Gokpinar *et al.*, 2013). In the context of dispersed design teams, when a subsystem has a lot of interfaces to other subsystems, and thus a central position in the product architecture, it is prone to a higher design-error rate (Gokpinar *et al.*, 2013). The reason for this is the increased need for coordination when interdependencies increase (Sosa *et al.*, 2004, 2013). This would suggest keeping the design of highly interdependent subsystems in one location (Gokpinar *et al.*, 2013). While coordination is a burden for subsystems with a central position in product architecture, this not the case with subsystems that have a limited number of interfaces with other subsystems. Sufficiently low error rates are present with these modular subsystems, when design tasks are globally dispersed among highly specialized and capable design teams (Gokpinar *et al.*, 2013). Similarly, Monteverde (1995) found that the efficiency of unstructured, interpersonal technical dialog in the design and production stages is positively related to an arrangement wherein a single hierarchy organizes both tasks with an integrated structure.

When there are organizational boundaries between design teams, the interaction between the teams was not sufficiently addressed because technological dependencies were seen as weaker than these dependencies actually were (Sosa *et al.*, 2004). Further, misalignment between interaction patterns and product architecture was also found be present because of indirect dependencies, in which the technical change came through other components to the focal component, and it seemed that these misalignments occur across organizational boundaries rather that within them (Sosa *et al.*, 2004). Gokpinar, Hopp and Iravani (2010) found that mismatches between product architecture and organizational structure (in terms of sufficient communication between engineers) cause product warranty claims, suggesting quality problems in the product. More specifically, subsystems with an intermediate level of dependencies on other subsystems had abnormally high levels of quality problems because of unnoticed communication needs (Gokpinar *et al.*, 2010). Even though there are computerized systems designed to facilitate communication and collaboration, it has not been sufficient to ameliorate every case, even within a single firm (Gokpinar *et al.*, 2013).

However, there are numerous technological trajectories involved that impact continuous innovation in product-systems (Prencipe, 1997). The joint interaction of a variety of technological paths is present, so that the most important strategic problem facing system integrators developing such products is located in the need to control these developments through dominance over those technologies regarded as being the most crucial (Paoli and Prencipe, 1999). Prencipe (1997) found through patent data and qualitative interviews that system integrators should keep the design of core technologies (in terms of product performance) inside the firm’s boundaries, both because of mastering technological change but also mastering and improving efficiency of highly interdependent design and production. However, with more peripheral technologies, some design can be outsourced as long as a firm can maintain full design capability over the entire system (Brusoni *et al.*, 2001; Prencipe, 1997).

As a consequence, system integrator research emphasizes a proposition that if a firm proceeds to reduce its investments in in-house R&D beyond a critical (sector-specific) level, the firm loses the ability to develop and model alternative development paths for the entire product system, because of the complex nature of technological knowledge inherent to the evolutionary approach (Paoli and Prencipe, 1999). Takeishi (2002) found that even though the actual tasks of design and manufacturing were outsourced, automakers retain relevant knowledge in order to obtain better design quality. The cumulative, context-specific nature of technological knowledge, and its need to integrate diverse knowledge domains are the reasons why system integrators ability to outsource R&D are limited (Paoli and Prencipe, 1999). If technological knowledge or components can be presented in simple format, it is more explicit than tacit, and if a firm possesses one discipline rather than multiple knowledge disciplines, tasks can be outsourced more easily (Paoli and Prencipe, 1999).

By outsourcing the design of some subsystems, a firm can leverage the design competencies of suppliers, and change between suppliers when conditions change

(Takeishi and Fujimoto, 2001). Outsourcing non-core subsystems can also help firms to concentrate on subsystems that are prominent in firm’s initial competitive advantage, as well as manage costs (Venkatesan, 1992). On the other hand, recent studies suggest that a buying firm can apply modular interfaces when it has enough knowledge about supplier’s components and technologies, and only then use modularity as a coordination and control mechanism (Cabigiosu *et al.*, 2013). Second, there is evidence that modularity alone is not a sufficient condition to ease interfirm coordination in new product development, at least not in the automotive industry (Cabigiosu *et al.*, 2013). Similarly, Park and Ro (2013) suggest that heterogeneous make or buy decisions within same architecture can be contingent on buyer’s degree of knowledge on a given component.

With their analytic model, Ülkü and Schmidt (2011) show that, in certain cases, external sourcing of product development leads to a more integral product design, whether the relationship with the supplier is adversarial (opportunistic) or collaborative (long-term). When the supplier is more technologically capable in design than the buyer, and the coordination penalty is not too high, integral design can be an option, otherwise modular design is suitable for outsourcing when the supplier has a low skill level. This is the reason for the high coordination costs of integral design between product development teams. Similarly, a higher volume of products can let integral design outperform the modular one when it provides a higher quality end product. Thus, outsourcing does not automatically imply modularity (Ülkü and Schmidt, 2011). Even though suppliers could be more involved in the design of product, digitalization may hinder this. Digital control systems inside the product system that are separate from the traditional product structure and integrate, monitor, and control the components that form that structure, are located over the traditional module boundaries of product (Lee and Berente, 2012). This integral structure of digital control systems underlines the role of the system integrator firm in the design activities, when these digital control systems are present (Lee and Berente, 2012).

Production. Production and manufacturing tasks can be allocated to many firms when modular design enables assembly afterwards, meaning independently produced subassemblies, in respect to technical constraints (Novak and Eppinger, 2001). Prencipe (1997) found that system integrators can outsource the production of peripheral components but still maintain the related R&D knowledge of these subsystems. Specialized suppliers can have, and aim for, economics of scale (Smith, 1776), especially with standard components (Arora, Gambardella, and Rullani, 1997). Three reasons to keep production in-house are that coordination benefits, the risk of information leakage and the large relationship-specific investments related to that exchange made by buyers (Besanko *et al.*, 2009). In this thesis, the information leakage risk is not discussed.

Product complexity in terms of number of parts, their newness and component interactions is one reason to keep production in-house, since efficiency and the goal of maximizing profits suffer if a firm acts in any other way (Novak and Eppinger, 2001). This is mainly because firms seek to capture the benefits of their investments in the skills needed to coordinate further development of complex designs (Novak and Eppinger, 2001). Monteverde and Teece (1982) found in their study of automakers that keeping components in-house is a more preferable choice when these components are firm specific and those designs must be highly coordinated with other parts of the automobile system. They also found that if the production of this kind of component is moved to a supplier, there are high switching costs to change to a new supplier, and the supplier has the possibility of opportunistic re-contracting thanks to the know-how received from the existing buyer. Thus, the most important components are best kept in house, when buyer-specific investments are present in that possible exchange (Grahovac, Parker, and Shittu, 2015; Williamson, 1973).

Firms that assemble product entities and source components to fulfil the rest of the stable body of product (so called swapping of components), reached product variety without losing operational performance (Salvador, Forza, and Rungtusanatham, 2002). In this case, suppliers were small, and located nearby these firms, and buying companies exerted more pressure and stronger direct influence on suppliers' actions (Salvador *et al.*, 2002). If a supplier is in a position in which components can be reused across product families or multiple product generations, scale effects can reduce the cost per unit by distributing the fixed cost portions across larger volumes (Salvador *et al.*, 2002). The negative consequences of design changes implemented by the buyer (e.g. a component and its production facilities become obsolete) can be moved to suppliers and thus reduce buyer's costs (Fixson and Park, 2008; Salvador *et al.*, 2002).

Contracts between members in network that produce a product together, enable the functioning of production in real time, but can constrain a member or members over time (Garud and Munir, 2008). A firm that produces a component may want to overcome constraining effects of design, which may trigger a profound impact on the emergence of new product architectures (Garud and Munir, 2008). The relationship between increasingly modular product architectures and the outsourcing of production was positive and significant in the early U.S. auto industry, because of the increased standardization of interfaces (Argyres and Bigelow, 2010). Firms that wanted to differentiate themselves with better quality or outstanding product features did not outsource production to same extent as firms that were concentrating on lower quality segments (Argyres and Bigelow, 2010). Thus, the outsourcing of production may have an influence on the quality levels of product systems, since it is reasonable for suppliers to aim for components that fit all customers directly or with only minor changes.

2.5 Technological resource dependence and technology acquisitions

Mergers and acquisitions refer to situations where two once separate companies are combined into one company. Mergers refer to the merging of two or more equal companies, whereas an acquisition is understood as a situation where one company obtains majority ownership over another (Hagedoorn and Duysters, 2002). Technology acquisitions are defined as acquisitions that provide technological resources to the acquiring firm (Ahuja and Katila, 2001). Non-technological acquisitions are made for other reasons, such as financial synergies between acquirer and target (Chatterjee, 1986;

Rabier, 2017). Here I view a technology acquisition as a form of keeping technological resources inside a firm boundaries, a form of a make decision (Steensma and Corley, 2000).

Acquisitions of small technology-based firms are an important source of technological resources for established firms, especially in rapidly developing high-technology industries (McEvily, Eisenhardt, and Prescott, 2004). Technological acquisition plays a vital role in the product development process, and acquirers benefit more in acquisition activities if they have prior detailed access to the target's research and development activities (Higgins and Rodriguez, 2006). In general, older target firms provide more immediate revenues, whilst new product introductions are connected to currently established young targets (Puranam, Singh, and Zollo, 2006; Ransbotham and Mitra, 2010).

A target in technology acquisitions can be seen as a combination of mature operations and unexplored growth options (Ransbotham and Mitra, 2010). Mature operations have tangible products and services which have their own business models as well as existing customers and established revenue streams (Ransbotham and Mitra, 2010). Unexplored growth options include technologies of the target that have potential to generate revenue streams, and can lead to breakthrough innovations (Fleming, 2001; Rabier, 2017). These unexplored growth options have not yet taken the form of products or services, and it might be that the target firm cannot fully exploit these opportunities with its existing capabilities or technologies without the complementary products of the acquirer (Ransbotham and Mitra, 2010). Thus, unexplored growth options can form private value for the buyer, since synergistic effects between technologies may emerge (Ransbotham and Mitra, 2010).

Acquisitions that are motivated by innovation opportunities and economies of scale, have more extreme positive but also negative performance outcomes, since accurate valuation of the novel and unfamiliar products and processes of a target firm is difficult for managers (Martin and Shalev, 2016; Rabier, 2017). The expected positive outcome from the innovations of the target firm are not necessarily to be realized and can lead to significant losses for the acquirer when compared to other types of acquisitions, because of the uncertain nature of technology development (Fleming, 2001; Rabier, 2017). The unexplored growth options offered by new resources and capabilities provide acquirers with flexibility and greater opportunities for private synergistic value (Rabier, 2017), and increase the valuation of young targets above what their age would otherwise indicate (Ransbotham and Mitra, 2010).

There are research streams that concentrate on post-acquisition performance, for example, managerial roles and actions (Graebner, 2004) and barriers to integration with target (Ranft and Lord, 2002). There is evidence that the transfer of technologies and capabilities from target to acquirer faces several barriers, including difficulties of distinct strategy, organizational structure, history and the culture of combined parties (Ranft and Lord, 2002). The process of integration of target into acquirer, as acquirers in many cases desire, is complicated by the dangers of badly affecting or losing the target's socially complex (in terms of teams and their affiliations or tacit knowledge) knowledge-based resources (Ranft and Lord, 2002).

Integration allows acquirers to use the target's existing knowledge as an initial input into their own innovation processes, but integration hinders the acquirer's reliance on the target as an independent source of ongoing innovation (what the target does with its capabilities) (Puranam and Srikanth, 2007). Target firms typically have high R&D expenses (Bena and Li, 2014), and specialized knowledge (Andersson and Xiao, 2016) that acquirers can apply in technology development (Puranam and Srikanth, 2007). Steensma and Corley (2000) found that if a desired technology is difficult to imitate, technology sourcing is more effective in more tightly coupled partnerships, such as technology acquisition. The likelihood of structural integration between acquirer's and target's units is stronger when the acquiring firm is buying a component technology rather than a standalone product (Puranam, Singh, and Chaudhuri, 2009). Thus, the attractiveness of the target is not only about combination with the acquirer's own resources but also about the existing interdependence between the parties (Puranam *et al.*, 2009). For instance, a prior alliance between target and acquirer generally does not have a positive impact on financial performance after acquisition, but when an alliance has been required in the context of intense partner-specific learning, there is an positive impact on post-acquisition financial performance (Zaheer, Hernandez, and Banerjee, 2010).

Multiple studies have investigated knowledge-relatedness between an acquirer and target, and its impact on performance after acquisition (Ahuja and Katila, 2001; Makri, Hitt, and Lane, 2010; Sears and Hoetker, 2014). Knowledge relatedness refers to both similarity of, and complementarity between, resources. Similarity is the extent to which an acquirer's and a target's knowledge resources reside within same narrowly defined areas of knowledge, while complementarity refers to the value of combining different types of knowledge resources (Makri et al., 2010). Knowledge relatedness between an acquirer's and a target's knowledge resources have been measured in terms how many of their patents belong to the same technology classes (Grimpe and Hussinger, 2014a; Jaffe, 1986). While knowledge base similarity contributes positively to the success of resource combination, complementarity in particular positively affects the benefits of acquisitions, especially in complex technology industries (Chondrakis, 2016). The acquirer is better off having those of the target's resources that create complementary benefits when successfully combined with existing internal resources, and this is reflected in the acquisition price of the target firm (Makri *et al.*, 2010; Sears and Hoetker, 2014; Yu, Umashankar, and Rao, 2016).

Network synergy is the extent to which combining an acquirer's and a target's networks through node merger results in a better structural position for the combined firm, as the acquirer receives control of the target's existing ties to other firms (Hernandez and Shaver, 2018). An acquirer can exert an influence on other firms through their technological dependence on the target's resources once acquired (Hernandez and Menon, 2017). Acquiring technologies on which competing firms depend gives the acquirer freedom to operate in R&D matters (Reitzig, 2004). Acquiring resources may enable the acquirer to offensively block patents and disrupting competitors' technological development (Blind *et al.*, 2006). It has been found that the likelihood of selecting a target increases when the expected network synergy is greater in technology acquisitions in an organizational level network (Hernandez and Shaver, 2018). It is more than likely that the interorganizational resource dependence network of a target affects the value of its resources to the acquirer (Ozmel, Reuer, and Wu, 2017). This is relevant since acquirers cannot obtain all strategically valuable resources from outside, but they must then strategically choose which dependencies to absorb and which to control indirectly (Brusoni and Prencipe, 2011; Santos and Eisenhardt, 2005).

3 Research design

3.1 Research approach

An epistemological approach to research asks the question of what is or should be regarded as acceptable knowledge in a research area (Godfrey-Smith, 2009). The epistemology of this thesis is grounded in (post-)positivism, and thus it intends to apply the methods of natural sciences to the study of reality. This leads to the following principles. First, phenomena and thus knowledge must be confirmed by the senses of the researcher in order for her or him to be able to talk and think about them (Godfrey-Smith, 2009). Regardless of this, the researcher's conceptualizations of the structures of the world are provisional categorizations employed to understand reality, and are accepted to be created by researchers, not being directly representative of reality (Bhaskar, 1975). The role of research is to test theories but also provide material for the creation of theoretical propositions (Pugh, 1983), having both a deductive and an inductive approach. A successful testing of hypotheses with empirical observations will thereby allow explanations of theoretical laws and knowledge to be made. These propositions of laws are approached by gathering of previously tested facts that provide bases for them (Bryman and Bell, 2011).

An ontological approach to research asks whether reality is regarded as something external to researchers or as something that people are fashioning continuously (Godfrey-Smith, 2009). The ontological foundation of this thesis is objectivism. It asserts that social phenomena and their meanings exist independently of the researcher (Bryman and Bell, 2011). Thus, the practical and theoretical work of science is a systematic attempt to express the structures of things that exist in a precise manner (Bryman and Bell, 2011). This thesis assumes that there is an external viewpoint from which it is possible to view the firm and its surrounding network of other firms as comprised of real processes and structures (Burrell and Morgan, 1979; Gioia and Pitre, 1990).

The synthesis of the epistemological and ontological foundations of this thesis embodies critical realism. Figure 4 shows its placement when compared to other approaches. There is a distinction between the objects of enquiries and terms and the language which describes them (Godfrey-Smith, 2009). The researcher's conceptualizations are simply a instruments for understanding that external reality (Bhaskar, 1975; Bryman and Bell, 2011). The critical realism approach also accepts that there are structures and theoretical concepts that are not easily observable, or directly amenable to observation (Bryman and Bell, 2011). In the research design of this thesis, the theoretical development and testing are intended to be conducted in a way that is as free as possible from the researcher's own values concerning the research topics. This thesis adopts the assumption that the purpose of business research is to describe what is happening in organizations but not to make any judgments about it (Burrell and Morgan, 1979). Instead, the practical suggestions are part of the outcomes of universal principles of research.

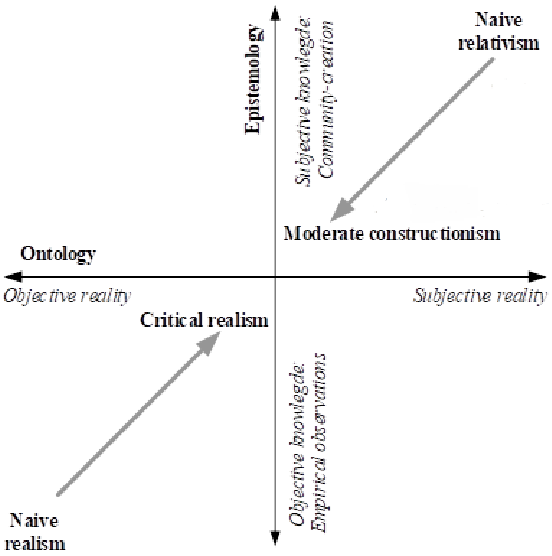


Figure 4. Epistemological and ontological positions (Adapted from Järvensivu and Törnroos (2010)).

Reasoning. One cannot have an argument about anything without proceeding from premises to conclusions in a credible manner (Toulmin, 2003). To present my process from premises to arguments, the logical reasoning, methods and analysis as well as data sources are listed in Table 2. As stated by Mantere and Ketokivi (2013: 72), “we predict, confirm, and disconfirm through deduction, generalize through induction, and theorize through abduction”. Here, I discuss the reasoning logic of this thesis. The deeper insights on methodology and data collection are located in section 3.3.

The main empirical results of this thesis and the reasoning of publication IV are based on deductive logic. Deductive reasoning takes existing theories as premises (Godfrey-Smith, 2009). After hypotheses are formulated from existing knowledge, data collection gathers observations for analysis (Bryman and Bell, 2011). Hypotheses are confirmed (or rejected) and these findings are applied when making a revision of theory (Bryman and Bell, 2011). This stage of theory revision is followed by inductive logic, when implications are interfered for the theory (Godfrey-Smith, 2009). In publication IV, the premise is that a target firm has a higher acquisition price when it has more technological resource dependencies on other firms in a technology network. The observation focus on the price of the target as well as to the technological resource dependencies of the target firm. Thus, the theory building approach is a refinement of existing theories through causal analysis between its variables, and follows deductive logic.

Publication I is based on inductive logical reasoning. It makes inferences about HSM and SNA methods and their differences when these methods are applied to interorganizational networks. Inductive reasoning takes together the observation and the possible explanation in order to infer the theoretical rule (Mantere and Ketokivi, 2013). Inductive reasoning starts with secondary data from two interorganizational networks. Observations are comprised of two networks and illustrated methods, whereas the varying results that depend on the applied method is the explanation for the proposed rule. The argument to favour HSM when one is interested in the direct or indirect relations of organizations (or technological level components), instead of using SNA methods alone, is the end outcome of this inductive reasoning.

The reasoning of publications II and III is based on abductive logic. While “deduction is interference to a particular observation, and induction is interference to a generalization, abduction is interference to an explanation” (Mantere and Ketokivi, 2013: 72). Abduction begins with a rule such as “all highly technologically-dependent components are made by system integrators and complexity increases this phenomenon”. Secondly, there are observations from previous research work, that are also used as inputs for abduction. In publications II and III, the observations come from previous literature (e.g. research that contributes to firms’ make or buy decisions). The goal of this reasoning is not generalization but a hypothesis about the structure that would explain the previous observations (Godfrey-Smith, 2009). That is why the explanation of publication III (e.g. system integrator’s need to maintain control over product architecture and technological dependencies interferes with the maintenance of that control) explains why a particular component with its dependencies on other components is designed or produced in-house rather than outsourced to a supplier. Theoretically, there are potentially multiple other explanations, but in abduction the search is for the best explanation that matches the observations and the rule. That is why the explanation is inferred in a way that it can explain the observation in the light of the theoretical rule (Mantere and Ketokivi, 2013). As an outcome of abductive reasoning one has a rule with an explanation, in other words, a theoretical argument.

Table 2. Research design of the publications

Publication	Reasoning logic	Method and analysis	Data
I	Inductive	Illustration and comparison of two methods: HSM and SNA	Two interorganizational networks, derived from secondary sources
II	Abductive	Conceptual theory development with illustrative example	Existing theoretical and empirical research, illustrative example
III	Abductive	Conceptual theory development	Existing theoretical and empirical research
IV	Deductive	Quantitative, ordinary least square (OLS) regression	Patent data and M&A data from databases

3.2 Selection of relevant literature

I selected relevant original research to be discussed in the theoretical background section of this thesis in a systematic manner. To create insights into what is already known about technological resource dependencies and interorganizational relationships, I followed the following procedure. The literature review is limited to the journal ranking of Financial Times 2016, including 50 top journals in business and management (Ft 50, 2016). The coverage of technology and innovation management topics in these journals are sufficient for this literature review, even if some journals in this list do not straightforwardly contribute on the topic of this doctoral thesis. To confirm the simplicity of journal selection, the Ft 50 ranking is applicable and sufficient in its coverage of my topic, including journals such as Strategic Management Journal, Management Science and Research Policy. In Table 3, the literature selection criteria are shown.

Table 3. Literature selection criteria and number of articles in each phase

Criteria	Number of articles
Title, abstract or keywords including one or more of these words: system integration, complex product systems, product architecture, mirroring hypothesis, technology acquisition, component interdependence, technological trajectory, modularity	
Published in FT50 journals	198
Title and abstract discuss about both interorganizational relationships and technological resources	71

The first initial sample from the Scopus database contained 198 articles. The Scopus database is the largest available peer-reviewed literature database, is provided by Elsevier and covers more journals than the second largest, ISI Web of Science (Mongeon and Paul-Hus, 2016). The selected keywords illustrate technological resources and dependency related concepts such as modularity, product architecture and system integration. From the initial set, articles that did not have any interorganizational relationship aspect in their abstracts were excluded from the sample.

3.3 Methodology and data collection

Publication I. The research process of Publication I included two main phases. In the first phase, the research team focused on identifying the actors and their interactions in the business networks of interest. For empirical context, the research team selected two pharmacy service value networks (pharmacy store and pharmacy online service networks). The research team evaluated connections between actors to conceive a pharmacy store network and online pharmacy service network from public reports and documents. The second phase of the study assessed the network positions of each actor using the HSM and SNA metrics. The modelling of networks was carried out using MS Visio and MS Excel-based tools to generate the network data regarding both networks. The research team constructed binary asymmetry adjacency matrices for both networks. These two matrices are the initial data for both HSM and SNA. Finally, the researchers calculated the n-order visibility matrix and used it to detect the longest cohesive path in the network. HSM partitioned all actors into groups, depending on each actor’s column and row values of visibility matrices. Both these HSM steps were conducted on both networks by programming. The initial matrices were loaded on UCINET 6 (Borgatti, Everett, and Freeman, 2002), which produced centrality measures as well as network visualisations.

Publication II. Publication II provided an illustrative example, which contained data from a product system and its technological resource dependencies. This data was gathered by asking an engineer with wide knowledge of turbo generators to fulfil component dependencies in a matrix form. This data was analysed with the help of HSM, which could arrange components depending their technological resource dependencies. This content helped to illustrate the concept of technological resource dependencies in this conceptual publication.

Publication III. Publication III is conceptual publication. There were neither data collection nor some special method to be applied for this publication.

Publication IV: Data collection. The research team leveraged Thomson One Banker, maintained by Thomson Reuters, to obtain U.S. mergers and acquisitions data. Both the acquirer's and target's nation was the U.S.A., which could reduce the amount of cross-border acquisitions. The research team excluded cross-industry acquisitions by choosing acquisitions in which the first two digits of both the acquirer's and target's primary standard industrial classification (SIC) code were the same. Acquisitions were included from multiple high-technology industries, named as follows in the Thomson Reuters database: 1) aerospace and aircraft, 2) measuring, medical and photo equipment and clocks, 3) communications equipment, 4) computer and office equipment, 5) electronic and electrical equipment, 6) machinery, and 7) transportation equipment. These industries are more involved in complex than discrete technologies, meaning that their commercializable products are sums of numerous separately patentable technologies (Chondrakis, 2016; Cohen, Nelson, and Walsh, 2000). That is why discrete technology industries such as pharmaceuticals are excluded from the sample (Chondrakis, 2016; Grimpe and Hussinger, 2014b). The mergers and acquisitions data contains the date of financials for both acquirers and targets, as well as deal-related information. The research team excluded acquisitions announced in 2015 or later from statistical analysis, hence available patent data do not cover those years.

The primary source of patent information and technological resource dependencies for the empirical part of this thesis has been PASTAT database. PATSTAT is a worldwide patent database, constructed and maintained by the European Patent Office (EPO). There is a practical reason, availability, to use PATSTAT instead of United States Patent and Trademark Office (USPTO) data, although there is not much difference in their coverage, since most PATSTAT patents are granted in the U.S. The available PATSTAT edition was Autumn 2015.The acquirer and target names from mergers and acquisitions data were matched to PATSTAT (harmonized) applicant names.

The research team obtained acquirer and target patent applications based on the person and application identifiers associated to the firm names. This enabled the research team to associate the patent applications with their cooperative patent classification (CPC) symbols. The research team used only the first four letters or digits of a CPC class symbol, to avoid excluding highly related patents that do not belong to the exact CPC classes of the acquirers' and targets' patents, but that share the same essential subject matter. Then the research team constructed a list of unique SIC codes and CPC class symbol pairs, based on the acquirers' and targets' patent applications. This list represents industry and patent subject matter linkages. Patents that had the CPC of a particular industry were included for further analysis.

As a consequence of the process described above, the research team gathered the relevant sample of PATSTAT patents, and categorized them based on acquirer and target industries. Then the research team obtained all backward and forward citations for the respective patent publications, and associated these with industry information, and with harmonized applicant names. From this information, the research team constructed interorganizational networks based on the citations.

Because an applicant (a firm, individual) represents the owner of a patent, it is relatively straightforward to aggregate patent publication-level citations at the applicant level, and then construct an interorganizational technology network. Specifically, if a patent publication A cites another publication B, the research team derived a directed knowledge dependence relationship from the respective applicant B to applicant A, as the citation indicates that applicant A's technology builds on that of applicant B (Huenteler *et al.*, 2016). In other words, the citations are reversed in the network. A target firm was included in the further analysis if 1) the interorganizational citations occurred in the target's industry (i.e., based on SIC codes associated with patent publication citations); 2) the citations occurred within X years before the acquisition date; and 3) there is a citation path from the target to another organization, or from the latter to the target. The research team applied three time windows: three, four, and five years, in network construction to assess the robustness of the results despite the influence of the chosen time frame. The final sample consists of 260 acquisitions, which had no missing values and were regarded as technology acquisitions in a way that their presence in interorganizational networks connected with cross-firm patent citations.

Publication IV: Data analysis. An ordinary least squares (OLS) regression model for the acquisition price was established by the research team. Independent variables were derived from directed eigenvector centrality that accounts for the influence of *indirect* linkages on the focal node, or the latter's indirect influence on others, which is important in understanding how firms interact in technology networks. Several control variables were included, such as the acquirer's characteristics, the target's characteristics and their mutual technological proximity. All three time windows (3, 4, 5 years) for patent data and network variables were included in each of the 12 different models.

4 Overview of the results of the publications

This section summarises the main objectives and contributions of the four publications of this thesis. Table 4 shows the research questions, related gaps, objectives and publications. The results start with publication I and its objectives and contribution. The results section begins from a way to determine the network position of a node that is directly transferred to a way to conceive of the network of components. This conceptualisation of technological resource dependencies is the starting point for the two subsequent conceptual publications. Publication II shows how technological resource dependencies and four different, already established purchasing categories from previous literature are connected. Purchasing categories keep inside the characteristics of the buyer-supplier relationship. Publication III connects technological resource dependencies to firms' internalization and externalization decisions in design or production. Finally, Publication IV presents research on how technological resource dependencies influence a target firm's acquisition price in the context of technological acquisition.

Table 4. Positioning of research questions to publications

Research question	**Explored gap**	**Objectives**	**Publication**
How do technological resource dependencies affect buyer-supplier relationships?	Gap 1	Conceive direct and indirect technological resource dependencies in network environment. Establish a theoretical framework that shows the linkage between technological resource dependencies and characteristics of buyer-supplier relationships from a system integrator's perspective.	Publications I & II
How do technological resource dependencies affect a firm's decision to internalize design or production?	Gap 2	Create a conceptual model with six propositions about the relation between technological resource dependencies and firms' decisions to internalize design or production, and show how complexity moderates these relations.	Publication III
How do technological resource dependencies affect a target firm's price in technological acquisitions?	Gap 3	Provide empirical evidence with M&A and patent data on how target's technological resource dependencies affect acquisition price.	Publication IV

4.1 Publication I

4.1.1 Main objective of the publication

Publication I, titled, “Hidden structure and value network: Shedding light on position assessment”, examines how one can find central and influential network positions in interorganizational networks. The hidden structure method (HSM) and social network analysis (SNA) based measures are applied to two distinct networks, a pharmacy store network and an online pharmacy service network. SNA-based measures in this study were indegree, outdegree, betweenness and closeness centralities (Wasserman and Faust, 1994). The question of network position assessment is important since each actor in the network has a role derived from its position (Borgatti and Li, 2009). Thus, the main objective of Publication I is to broaden existing SNA based measures with HSM and show what kind of benefits this methodological extension would give to researchers and practitioners.

4.1.2 Main findings and contribution

The main findings of Publication I show how HSM can complement the widely used SNA-based centrality metrics in the context of an interorganizational network. In directed networks, hierarchy between nodes and direct and indirect connections matter. That is why in any network, four different kinds of network positions can be found, core and periphery but also two other distinct positions depending on how the node is receiving or sending direct and indirect flows. HSM can find hierarchy between nodes and the location of the main operational paths of the network. The main paths are among the longest continuous chain of nodes in that network.

Together with Publication II, the findings of Publication I provide a contribution to the methodological question of how to measure and more importantly, conceive technological resource dependencies. The context of Publication I is different than actual technological resource dependencies, but the logic that the hierarchy of the nodes matters in a given network, and the regulative influence of actors is analogous to the hierarchical patterns between technological components. This logic is used in Publication II and in Publication III.

4.2 Publication II

4.2.1 Main objective of the publication

Publication II, titled, “Linking technological system architecture and purchasing categories”, presents a theoretical framework of how technological resource dependencies (publication II refers these dependencies with the term, system dependencies) influence buyer-supplier relationships, and is a conceptual publication.

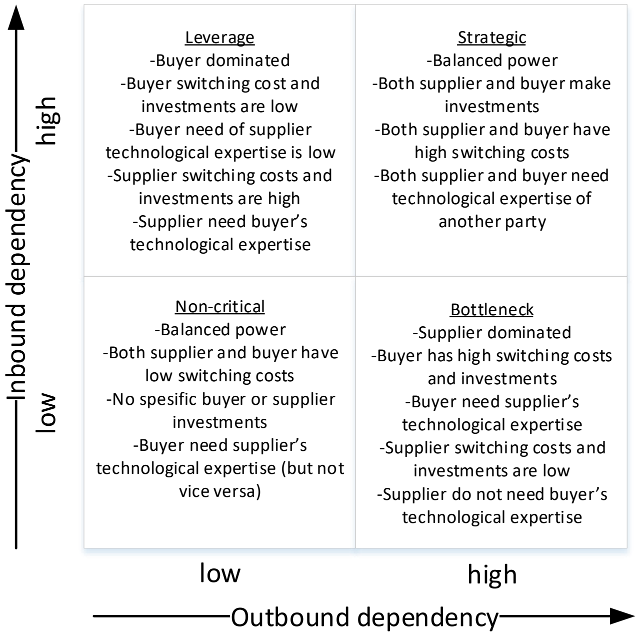
The characteristics of the buyer-supplier relationship which are included in the framework are buyer's or supplier's switching costs, need for investments, and technological expertise. Publication II aims to understand the link between technological resource dependencies and purchasing categories that previous literature has already set. Publication II adopts a buyer's perspective in the context where a buyer has a role as system integrator and assembler, and suppliers providing components or subsystems to a system entity. Traditionally, supply risk and profit impact of an item purchased have been indicators of which category the item and its supplier belong to. However, these indicators are imprecise and based on buyer's subjective decision making rather than on operationalized measures (Olsen and Ellram, 1997; Ramsay, 1996).

4.2.2 Main findings and contribution

The first contribution of Publication II is to introduce two concepts, inbound and outbound dependencies. The inbound and outbound values of a component are compared to the values of other components in that system entity, which reveals their positions in purchasing categories. The inbound and outbound values are based on the assumption that if one changes one component in a system, its change causes changes to other components too. This phenomenon forms potential change paths throughout the system, and components are not equal in their direct and indirect influences on others, and nor are the influences that these components receive. Outbound dependence indicates the extent of components that might be affected by a change to the focal component. Inbound dependence indicates the components that might affect the focal component if they change. Inbound and outbound can be measured, for instance, with HSM metrics (see Publication I for further descriptions and Publication II for an illustrative example that applies HSM).

The connection of inbound and outbound dependencies with purchasing categories is shown in Figure 5. This framework is the answer to the subquestion 1, and the main contribution of Publication II. Components can be divided into purchasing categories depending on inbound and outbound dependencies: leverage, strategic, non-critical and bottleneck. This divisions of categories set the buyer-supplier relationship characteristics, and the content of these categories have already been discussed in the literature.

Leverage category. When a component's inbound is high and outbound is low, it may have to adapt to several changes that emerge from other parts of the system. This means that its design is dependent on the design choices for other components, but its influence on others is low. If this kind of component is outsourced, the buyer must provide a detailed description of the kind of component needed in order to ensure system compatibility (Nellore and Söderquist, 2000). Thus, the supplier requires the buyer's technological expertise. A supplier adapts its production system to a component that is in line with the buyer's technological expertise, leading to the supplier making buyer-specific investments. This leads to dependence on the buyer over time if these investments are not transferable to other buyers. The buyer's supplier-related investments remain low due to low outbound, since changes in a focal component do not affect other components significantly. In the case of switching the supplier, the buyer must educate the new supplier to follow its design specification, which causes costs that are higher than non-critical component's switching costs, but definitely lower than switching costs related to strategic components.



	low	high
high	Leverage -Buyer dominated -Buyer switching cost and investments are low -Buyer need of supplier technological expertise is low -Supplier switching costs and investments are high -Supplier need buyer's technological expertise	Strategic -Balanced power -Both supplier and buyer make investments -Both supplier and buyer have high switching costs -Both supplier and buyer need technological expertise of another party
low	Non-critical -Balanced power -Both supplier and buyer have low switching costs -No spesific buyer or supplier investments -Buyer need supplier's technological expertise (but not vice versa)	Bottleneck -Supplier dominated -Buyer has high switching costs and investments -Buyer need supplier's technological expertise -Supplier switching costs and investments are low -Supplier do not need buyer's technological expertise

Figure 5. Theoretical framework for connecting technological dependencies of a component and a purchasing category.

Strategic category. If a component has high outbound and inbound dependencies, it has a high position in the design hierarchy of the system. Still, there are groups of other components that influence and require these components in to some extent adapt to their changes. Suppliers of this category cannot easily switch to other buyers due to the specific investments required by high inbound dependency. Hence, suppliers must do engineering work to adapt their components to buyers' systems, thus raising switching costs. On the other hand, buyers also face high investments, switching costs caused by high outbound dependence. In this category, both supplier and buyer need the other's technological expertise due to reasons of compatibility and design and manufacturing expertise. Components that belong to the strategic category are specific to certain system configurations because of high inbound and outbound values. The supplier and buyer are likely to mutually agree on design choices dedicated to the buyer's system. Power relations between the parties are in a balanced state, since high interdependency limits the chance to alternate suppliers or buyers.

Non-critical category. When a component has low outbound and inbound values, the technological dependency between the component and rest of the system is low. The supplier has more freedom to design components suitable for multiple buyers. A buyer can be more or less dependent on the supplier’s technological expertise and provide more or less their own specifications. Nonetheless, the supplier does not need the buyer’s technical specification for compatibility issues because of the low inbound value. Relation-specific investments caused by technological needs are not necessary, which leads to low switching costs. In this category, power relations between buyer and supplier are in balance.

Bottleneck components. If a component has low inbound and high outbound value, it has a high position in the design hierarchy. Other components adapt to its features, and it does not heavily adapt to changes made elsewhere in the system. If this kind of component is outsourced, the supplier has the technological expertise to design the component’s specifications (Nellore and Söderquist, 2000). Since the component has high inbound dependence, the buyer must adapt its entire system to the component. On the other hand, since inbound dependence is low, the supplier has no need to significantly to adapt the component to the buyer’s system. From a technological perspective, the supplier is unlikely to make buyer-specific investments because of the direction of dependencies. Similarly, as non-critical components, these components can be included in more than one supply chain and supplied to more than one buyer. This creates a situation in which multiple buyers may try to influence the supplier to secure component compatibility with their own systems. From the buyer’s perspective, switching suppliers may be challenging, since these components have long dependency paths throughout the system. Because of the low inbound value, suppliers of this kind of component face no technological constraints in switching buyers.

4.3 **Publication III**

4.3.1 **Main objective of the publication**

Publication III, titled, “Technological system complexity and system integration”, is a conceptual study. The main objective of this publication is to determine how the technological dependencies of the components of the system entity influence the internalization or externalization decisions of system integrator firms, and how system complexity influences this relationship. The mirroring hypothesis proposes that organizational structures reflect the interdependencies of components in product architecture (Colfer and Baldwin, 2016). On the other hand, there is empirical evidence that with integral product architecture, firms did not show a strong tendency to employ an internalization strategy (Park and Ro, 2013). Similarly, with modular product architecture, firms did not arrive at the decision to externalise (Park and Ro, 2013). To shed light on this contradiction with previous research, Publication III does not apply the traditional distinction between the modular and the integral since it does not consider the direction of technological dependencies. Thus, the main objective of publication III is to develop a conceptual model to determine how the technological dependencies of components of a system influence the internalization and externalization decisions of system integrators. The objective is to discuss the likelihood of internalization or externalization of design or production, and the influence of system complexity is included in the conceptual model.

4.3.2 Main findings and contribution

The main contribution of this paper is the detailed discussion regarding the ways the complexity of a technological system architecture differentially affects the design and production of components of the system based on their inbound and outbound component dependencies. The outbound dependence of components indicates the degree to which components might be affected by a change in the focal component. The inbound dependence of a component indicates the degree to which components might affect the focal component if they change. These same concepts are also essential for Publication II. As result of detailed discussion, six propositions form the main building blocks of the model. In Figure 6, the model is illustrated and relations between the concepts are proposed.

Propositions 1a and 2a. Proposition 1a suggests that all else being equal, an increase in system complexity has a positive effect on the internalization of design. Proposition 2a suggests that all else being equal, an increase in system complexity has a positive effect on the internalization of production. These propositions are based on the argument that when complexity at the system level increases, uncertainty about technological system control increases. The system integrator must make more relation-specific investments overall to control distinct relations with suppliers, because of increased uncertainty. In general, this leads to a restricted amount of externalization opportunities, and increases the likelihood of design and production internalization.

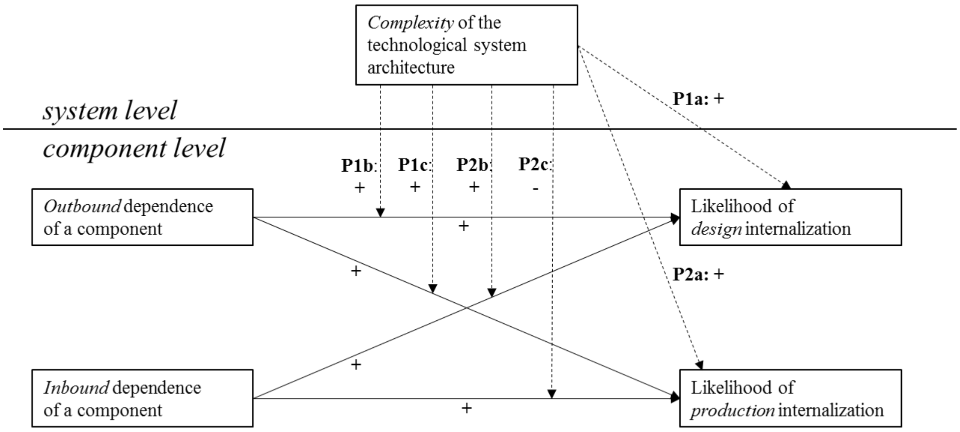


Figure 6. Conceptual model: Technological dependencies of component and decision of internalization

Propositions 1b and 1c. Proposition 1b suggests that all else being equal, an increase in system complexity positively moderates the positive relationship between the outbound dependence of a component and the internalization of the design. The externalization of highly outbound dependent component design is unlikely due to product architecture related reasons, since any small change in this kind of component can cause massive re-engineering cycles that jeopardize control over the product architecture. The increased complexity increases the probability of these re-engineering cycles in the system. If a supplier of outbound-dependent components is motivated to make changes to the design in which the system integrator has no control over to influence, the re-engineering cycles may have impulse outside the boundaries of the system integrator's firm. Proposition 1c suggests that all else being equal, an increase in system complexity positively moderates the positive relationship between the outbound dependence of a component and the internalization of production. This proposition is based on the argument that these outbound-dependent components are not the source of product variety, rather, product variety is reached by changing more peripheral components (Jiao, Simpson, and Siddique, 2007). For supply chain control related reasons, internalization of the production of highly outbound-dependent components is more likely, since any interplay between changes to design to ease production activities forces the system integrator to carry out many inter-organizational coordination activities. If a system integrator is not the only customer of a supplier, the supplier may have an incentive to reduce buyer-specific investments by changing a design so that it can serve many customers with same production facilities. When complexity increases, it makes a system integrator more vulnerable to any changes in design which also increases the likelihood of production internalization.

Propositions 2b and 2c. Proposition 2b suggests that all else being equal, an increase in system complexity strengthens the positive relationship between the inbound dependence of a component and the internalization of design. When inbound dependence increases, the design activities are more related to a specific system which requirements are adopted by this kind of components. If applying the constraints of inbound dependence of the supplier's component are not monitored by system integrators, the control of the entire product architecture will be lost. Since overall complexity makes it more difficult to control the entire product architecture, it strengthens the effect of inbound dependence on the design internalization decision. Proposition 2c suggests that all else being equal, an increase in system complexity weakens the positive relationship between the inbound dependence of a component and the internalization of production. The positive relationship between inbound-dependent components and their internalized production is based on the premise that integral design positively affects the internalization of production (Park and Ro, 2013; Ulrich and Ellison, 2005). The more complex the system, the more inevitably and frequently design changes will occur that are directed towards inbound-dependent components. System integrators can have a supplier that adapts to these changes and maintains the costs of the components' changes while providing possibilities for product variety. Thus, the increase in complexity weakens the positive relation between inbound dependence of a component and the internalization of production. The likelihood of production internalization decreases regardless of inbound dependencies when complexity of overall system is higher.

4.4 Publication IV

4.4.1 Main objective of the publication

Publication IV, titled, “Interorganizational resource dependence and the value of firm resources in technology acquisitions”, is an empirical study. Acquisition, one option for resource internalization, enables a focal firm to obtain strategically valuable technological resources. While the existing literature on technology acquisitions mainly discusses the combination of acquirer’s and target’s resources (Ahuja and Katila, 2001; Makri *et al.*, 2010; Sears and Hoetker, 2014), there is a burgeoning stream of research that notices the interorganizational network aspect of technology acquisitions (Chondrakis, 2016; Grimpe and Hussinger, 2014a; Hernandez and Menon, 2017). The acquisition of a target, results in structural change in the whole interorganizational network (Hernandez and Menon, 2017). Concentration solely on the resources of the acquirer and target neglects the broader resource dependence relationships of the target. The main objective of this publication is to develop and empirically test the suggestion that the position of a target in their interorganizational resource dependence network affects the value of their resources to the acquirer, as reflected in the acquisition price. Hence, hypothesis 1 suggests that the higher the extent to which the target firm’s technological resources depend on the technological resources of other firms in their technology network, the higher the price paid for the target by the acquiring firm will be. Hypothesis 2 suggests that the higher the extent to which other firms’ technological resources depend on the target firm’s technological resources in their technology network, the higher the price paid for the target by the acquiring firm.

4.4.2 Main findings and contribution

Publication IV provides extensive and supportive empirical evidence for both hypothesis on the effect of the target’s network position, as measured through patent citations aggregated at the applicant-level, on its acquisition price. These hypotheses are based on the ideas that significant incremental contributions to an existing or developing technological trajectory, or successful development of foundational technologies for new trajectories, respectively, make resources more valuable to the network and thus, for the acquirer too.

The hypotheses were tested with an ordinary least squares (OLS) regression. The results of the regression supported both hypothesis. The hypotheses were tested with three different time windows; 3, 4 and 5 years. All time windows had similarly significant results, even though the included patent citations occurred 3–5 years before merger or acquisition. To highlight the findings, I first discuss the models in the three-year time frame.

Model 2 for hypothesis 1 includes the variable: the extent to which target’s technological resources depend on other firms’ technological resources in their network (operationalized as *target eigenvector centrality, in-edges*). It has a positive and significant coefficient (β = 49.57, p < 0.01), supporting hypothesis 1. When dividing the β by 100, and thus expecting a 0.01 unit increase in *target eigenvector centrality, in-edges*, it results in an $\exp(0.4957) - 1 \approx 64\%$ increase in its acquisition price, all other things being equal.

Model 3 for hypothesis 2 includes the variable: the extent to which other firms' technological resources depend on the target firm's technological resources in their network (*target eigenvector centrality, out-edges*). It has a positive and significant coefficient (β = 47.98, p < 0.01), supporting hypothesis 2. The effect is not small, a 0.01 unit increase in out-edge eigenvector centrality value for the target would result in an $\exp(0.4798)) - 1 \approx 62\%$ increase in its acquisition price, all other things equal.

This study contributes to the technology acquisitions literature (Chondrakis, 2016; Grimpe and Hussinger, 2008, 2014a) by explaining how interorganizational resource dependencies beyond the acquirer-target dyad affect the value of the target firm's resources from the acquirer's perspective. Publication IV provides empirical evidence that if the technological resources of the target have multiple direct and indirect technological knowledge dependence relations to other firms' resources, this increases the acquisition price (Hernandez and Menon, 2017). The acquirer inherits the target's network position, including the possibility of an ability of control (Hernandez and Menon, 2017). Firms cannot acquire all valuable resources in complex technology networks, thus they must selectively choose targets for resource and technological dependency absorption (Santos and Eisenhardt, 2005).

In Publication IV, the explanation of why the dependencies of these targets are increasing the acquisition price is twofold. First, there are valuable target firms that contribute to the incremental development of core technological trajectories by having multiple in-edge dependencies to other firms, and thus still succeed in innovating incrementally regardless of existing knowledge dependencies. Second, there are valuable target firms that have out-edge dependencies to other firms, and thus have developed technologies on which other firms build on, possessing initial positions in some potential technological trajectory.

5 Discussion and conclusions

This thesis examined technological resource dependencies between firms from the theoretical perspective of the location of transactions and the boundaries of firms in a productive system (Baldwin, 2008). The main objective was to find out what the relationship between technological resource dependencies and interorganizational relationships is. Interorganizational relationships are discussed here in terms of the buyer-supplier relationship, the make-or-buy question, and technological acquisitions. Publication I focuses on the importance of indirect paths in networks and the assessment of four distinct network positions, instead of relying on the oversimplified core-periphery division of network positions. Publications II and III are conceptual papers that fully apply the logic of four distinct network positions of components, and their impact on either the characteristics of the buyer-supplier relationship or the make-or-buy decision. Publication IV is an empirical study that investigates the relationship between technological resource dependencies and the acquisition price of the target firm.

5.1 Answering the research questions

The main research question of the thesis was: “How do technological resource dependencies affect interorganizational relationships from the perspective of a focal firm?” It was addressed with four publications. The first and second publications shared the same sub-question, and third and fourth had their own sub-questions.

The first sub-question, “how do technological resource dependencies affect buyer-supplier relationships”, was answered by two publications. Publication I highlighted the difference between oversimplified core-periphery divisions between network positions, proposing a wider use of four distinct positions that let one also take into account indirect dependencies of the entire network (Baldwin *et al.*, 2014). This established the foundation for concepts of outbound and inbound dependencies that allow dividing technological components to four categories depending on their technological resource dependencies. The outbound dependence of components indicate the degree to which components might be affected by a change in the focal component. The inbound dependence of a component indicates the degree to which components might affect the focal component if they change.

The inbound and outbound dependencies can vary from high to low, and are mutually independent. Thus, the technological resource dependencies of a component formulate four categories or ends of the continuums, which can be applied in the context of complex product systems. The theoretical framework of Publication II proposes the relation between technological resource dependencies of a component (four distinct categories) and levels of switching costs, needs for relation-specific investments and technological expertise in buyer-supplier relationships. To conclude, when both inbound and outbound are low, both buyer and supplier have low switching costs, there are no relation-specific investments, and the buyer needs the supplier’s technological expertise, but not vice versa. When outbound is low but inbound is high, the buyer's switching costs and relation-specific investments are low and the buyer's need for the supplier's technological expertise is low, but the supplier's switching costs and investments are high, and the supplier needs the buyer's technological expertise. When both inbound and outbound are high, both supplier and buyer have relation-specific investments, both have high switching costs, and both need the technological expertise of the other. When outbound is high but inbound is low, the buyer has high relation-specific investments and switching costs, and the buyer needs the supplier's technological expertise, whereas the supplier's switching costs and investments are low, and the supplier do not need buyer's technological expertise. These insights address the need to categorize supplier relationships according to the level of technological resource dependencies (Howard and Squire, 2007; Montgomery *et al.*, 2018).

The second sub-question, "how do technological resource dependencies affect a firm decision to internalize design or production", was answered by Publication III. Technological resource dependencies, in terms of outbound and inbound of a component in a complex product system, increase the likelihood of design and production internalization if the premises of the conventional view on technological resource dependencies and organizational structure are adopted (Sorkun and Furlan, 2017). The relation between technological resource dependencies on interfirm relations has been seen as contingent on the complexity of the system (Sorkun and Furlan, 2017). Taking this into account, six propositions were developed by the authors. These imply the following conclusions, all else being equal: 1) outbound dependence of a component increases the likelihood of both design and production internalization of that component and complexity strengthen these relations 2) inbound dependence increases the likelihood of design internalization and complexity strengthens this relation 3) inbound dependence increases the likelihood of production internalization and complexity *weakens* this relation. To highlight this conclusion, which contradicts the conventional view of relations between technological resource dependencies and interfirm relations, an explanation of the third conclusion is as follows. Since a focal buying firm can and (must) maintain specifications for highly inbound components, the product architecture remains under its control. There are not many feedback loops feeding back into the system if these components change (when outbound is low). Complexity weakens the likelihood of the internalization of highly inbound components since suppliers maintain the costs of the components' changes and adaptations, which are more likely when the entire system is more complex. The focal buying firm does not have to determine which design would be the more durable choice for the system (Ulrich and Ellison, 2005).

The third sub-question, "how do technological resource dependencies affect target firm's price in technological acquisitions", was answered by Publication IV. It develops and empirically tests the argument that the position of a target in their interorganizational resource dependence network affects the acquisition price. Statistical analysis was based on patent citation data, and data on mergers and acquisitions including the acquisition prices of the targets. There are two main arguments in this publication, explained below.

The findings supported the hypothesis that the higher the extent to which the target firm's technological resources depend on other firms' technological resources in their technology network, the higher the price paid for the target by the acquiring firm. The explanation of this finding is that there are valuable target firms that contribute to the incremental development of *core* technological trajectories by having multiple received dependencies from other firms, but still succeed in innovating incrementally regardless of existing knowledge dependencies, which increase the acquisition price.

The findings also supported the hypothesis that the higher the extent to which other firms' technological resources depend on the target firm's technological resources in their technology network, the higher the price paid for the target by the acquiring firm. The explanation of this finding is that there are valuable target firms that are sources of dependencies on other firms, and thus have developed technologies on which other firms build, possessing initial positions in some potential technological trajectory. This increases the acquisition price.

The combined contribution of the four publications answers the main research question: "how do technological resource dependencies affect interorganizational relationships from a perspective of a focal firm?" A focal firm that operates in the product systems industry must consider technological resource dependencies when setting its boundaries in relation to other firms. Technological resource dependencies have a direction (of the inbound and outbound dependencies of a component), and are directed from core subsystems serving the main service characteristics to the more peripheral ones. Components differ in their inbound and outbound dependence levels. A high inbound level of a component binds it to a specific system entity, making a supplier conduct buyer-specific investments. When the complexity of a system increases, it also increases the buyer's likelihood to buy outside production of a highly inbound component. A highly outbound and inbound dependent component can, from the focal firm's perspective, be bought from a supplier, that has made buyer-specific investments to the same extent as the focal firm has made supplier-specific investments.

When a supplier has a component that is assessing design constraints to hierarchically lower, subsequent subsystems of a buyer, the buyer is dependent on the supplier but not vice versa. A buyer-supplier relationship in which components that have high outbound dependence with low inbound are exchanged leaves the buyer in a situation in which it has supplier-specific investments. A component that is high in outbound dependence has indirect influences on many other parts of the system, directly and indirectly. Indirectly, a change in the core can necessitate changes in many other components, and these could also precipitate changes forward along the product system. Especially when a buyer has the role of system integrator, re-engineering the system because of a supplier's decision to change a design may lead to difficulties for the focal firm. With these components, a supplier is not bound to a buyer with buyer-specific investments (low inbound). That is why the likelihood of a decision to make and produce these components inside of a focal firm is more likely than the decision to buy these components. However, if a focal firm has no capability or intellectual property rights to design and produce these components, technology acquisition is an option.

Technological resources in the form of knowledge, positioned at the beginning of the technological trajectory, must first be developed towards saturation before subsequent (sub)technologies follow (Clark, 1985; Dosi, 1982; Huenteler *et al.*, 2016; Murmann and Frenken, 2006). Technological knowledge generation will concentrate first on the (core) sub-systems that are most important for the required service characteristics, with given technological constraints (Clark, 1985; Huenteler *et al.*, 2016). After a new trajectory has emerged together with its initial knowledge base, its evolution proceeds by following the principles of design hierarchy (that is, set in component or product level) (Huenteler *et al.*, 2016). The knowledge base develops toward more peripheral sub-systems and components, as the evolution of the industry advances (Clark, 1985; Huenteler *et al.*, 2016). Second, changes in a subsystem that is responsible for the main service characteristics tends to precede changes in other parts of the system, even when the system is fully developed (Murmann and Frenken, 2006). This means that the hierarchy that is present when the system evolves and is applied into product systems does not change as long as the desired service characteristics for the entire system remain the same.

Knowledge that is applied to the design and production of highly outdependent components, that are at the top of design hierarchy and thus at the beginning of the technological trajectory, is knowledge that a focal firm must have in order keep outbound-dependent components inside the firm boundaries. That is why this study the found empirical results of higher prices for a target firm that possesses technological resources (knowledge as well as IPR) that are initial to a given technological trajectory.

To the best of my knowledge, while the extant literature has considered the effects of direct technological dependencies on firm boundaries, this study is among the few to have taken an in-depth look at *indirect* technological resource dependencies and their effects on interorganizational relationships. As such, this study takes a more comprehensive look at technological dependencies and interorganizational relationships by considering all types of dependencies (i.e., not just the direct ones) and a continuum of interorganizational relations from arms-length buyer-supplier relationships to technological acquisitions.

5.2 Contributions and implications to systems of production

Technical resource dependencies influence organizational relations between groups of firms that together produce a product system (Baldwin and Clark, 2000; Colfer and Baldwin, 2016). The conventional view of this phenomenon states that organizational relations are dense within tasks that are highly interdependent, and loosely coupled when tasks are independent (Baldwin, 2008; Baldwin and Clark, 2000; Sanchez and Mahoney, 1996). When looking at product systems as divided into modules in a technological sense, it means that the transaction costs are high in module interiors (tasks are interdependent) and low at module boundaries (tasks are independent) (Baldwin, 2008; Williamson, 1985). This thesis contributes to the theory of systems of production by suggesting that technological resource dependencies at the product and technology level are the ones which influence where the boundaries of firms are, but there are structures at the technological knowledge level emerging from a technological trajectory that sets the directions of these technology-level dependencies. It is crucial to emphasize the sequence of tasks from the focal firms perspective (Puranam *et al.*, 2012), and the direction of the technological resource dependencies, both direct and indirect (MacCormack *et al.*, 2012) between a focal firm and other firms. A focal firm has a tendency to make, design and produce components that are connected to the initial knowledge of the technological trajectory, and that *make* decision can lead to technological acquisition with an increased price when some target has this kind of knowledge.

The main contribution of this thesis to the theory of systems of production is described in more detail below. Firms and tasks that are truly reciprocally interdependent are more likely kept inside the firm's boundaries or within a strong buyer-supplier that can bear the burden of interdependencies (Colfer and Baldwin, 2016). My conceptual framework suggests that this is the case when the technological resource dependencies of a focal component determines supplier's buyer-specific investments. My conceptual propositions propose that from a focal firm's perspective, tasks that are interdependent are likely to be outside the firm's boundaries, especially production tasks, when complexity is high and the actions of buyers (e.g. design specification) is based on knowledge that has a higher position in technological trajectory. When the supplier holds this kind of knowledge, which has a high position in the technological trajectory and is applied to technologies that may accommodate changes in the others and their knowledge bases, it triggers a cascading effect on other firms' technologies. The focal firm is more likely to keep this kind of component in house, both for design and production (Becker and Zirpoli, 2017; Brusoni *et al.*, 2001). With these components and the related knowledge, complexity strengthens the likelihood of keeping these in-house. The design hierarchy between components emerges from the structure of the knowledge in the technological trajectory, from higher positions to lower ones (Huenteler *et al.*, 2016). Seeing technological acquisition as a form of make decision for some technology resources, and assuming these arguments above hold, we can expect that the target's resource dependencies to other firms at the knowledge level (foundational knowledge position in the technological trajectory) increase the likelihood of acquisition because of the better position in an overall technology network (Hernandez and Shaver, 2018), and the price paid for maintaining control over both direct and indirect technological resource dependencies.

Contribution to the literature on modularity and buyer-supplier relationships. In this thesis I refine the understanding of technological resource dependencies' impact on interfirm relationships. To do so, I leverage the existing frameworks that divide the relationship characteristics into categories (Bensaou, 1999; Caniëls and Gelderman, 2005, 2007; Nellore and Söderquist, 2000). My thesis provides an objective measure in terms of technological resource dependencies which help assess the relationship's characteristics before the relationship exists, since it based on technological resource dependencies. This answers the need of having objective measures of buyer-supplier relationship characteristics in the purchasing research field (Montgomery *et al.*, 2018).

I apply system level technological dependencies to assess the technological resource dependencies of a single component. It is to some extent a different approach when compared to the traditional modular-integral division, although not a totally new approach to the problem (Baldwin *et al.*, 2014). The view that the direct and indirect technological resource dependencies of a focal component and other components influence that component if they change, is leveraged in this thesis (Colfer and Baldwin, 2016). The direction of technological resource dependencies the (design hierarchy of elements of the system) originally emerged from the knowledge structure of technological trajectories that are subject to the desired service characteristics and to the technological constraints of that industry. I emphasize the role of the direction of technological resource dependencies on buyer-supplier relationship characteristics, which makes the findings more nuanced when compared to existing theoretical insights.

A low inbound and outbound of a component is indicative of a purely modular, independent component. Market-based transactions between buyer and supplier take place, since tasks related to a component and the rest of the product system are independent (Baldwin, 2008). This is in line with the traditional view of mirroring between technological resource dependencies and buyer-supplier relationship characteristics. This also in line with the KBV view that decomposable problems with low interaction between knowledge sets can be organized by markets (Nickerson and Zenger, 2004). In line with the view of TCE, when there is low asset specificity in terms of design interdependence, the governance mode can be *market* when the transaction costs are considered (Baldwin, 2008; Williamson, 1985).

At the other end of the continuum, when there are high numbers of design interdependencies, the governance mode is more likely to be *hierarchy* in order to reduce related transaction costs (Baldwin, 2008). Problem solving that leverages knowledge sets that are highly interdependent suggests a search for a consensus-based hierarchy that can remain within a firm’s boundaries (Nickerson and Zenger, 2004). However, when these highly interdependent tasks are brought into the context of a buyer-supplier relationship, we can expect high mutual dependence to exist. My findings indicate that this is the case when both the inbound and outbound component of a component is high. It is a situation in which both supplier and buyer have made relation-specific investments, and both are providing their technological expertise equally to the tasks performed. This goes against the mirroring hypothesis, but the strong relation between buyer and supplier in terms of credibility and a shared understanding of what is expected will allow them have high interdependencies across firm boundaries (Colfer and Baldwin, 2016).

The findings of previous studies propose that the low modularity of a component that a supplier provides decreases the supplier’s autonomy, and adds to the supplier’s switching costs as well as to the buyer-specific investments that the supplier has to make (Hoetker *et al.*, 2007; Monteverde and Teece, 1982). I argue that these influences are consequences of the high inbound dependence of a component. From a buyer's perspective, it must provide specifications to suppliers in order to maintain compatibility with rest of the system. Thus, when a buyer can provide specifications for a supplier and maintain enough technical communication, even if there are a lot of technological resource dependencies, the exchange can take a place (Mikkola, 2003). With highly inbound dependent components, a supplier is subject to the buyer's specifications and the design constraints provided. In this thesis, when other relational factors such as credibility and shared meaning between buyer and supplier are not discussed, from the buyer's perspective the inbound dependence makes the supplier more dedicated to that buyer, reducing the supplier's autonomy.

Empirical evidence has found that relation-specific investments were present when there were plenty of technological resource dependencies, but a successful buyer-supplier relationship was maintained(Colfer and Baldwin, 2016). My contribution highlights that the supplier's buyer-specific investments are a consequence of the technological resource dependencies of a focal component. I argue that when this technological resource dependence is not present in terms of high inbound dependence, the relationship characteristics between buyer and supplier are different in that supplier has low switching costs and no similar need for the buyer's expertise. This can be combined with the presence of a high outbound dependence of a component, and the supplier having a component, the related knowledge of which is in a more foundational position in the technological trajectory, creating a situation in which the supplier's design actions constrain the buyer's set of choices with design.

Contribution to technological resource dependencies and make or buy decision literature. This thesis continues in the stream of studies that distinguish the decision of design or production externalization (Brusoni *et al.*, 2001; Park, Ro, and Kim, 2018; Ulrich and Ellison, 2005), and view technological resource dependencies as something that add to the likelihood of one decision over others. It also discusses how this decision is contingent on the complexity of the system, which is proposed to be influential on the existence of mirroring patterns between technological resource dependencies and interorganizational relations (Sorkun and Furlan, 2017).

This make or buy choice is also contingent on knowledge structures between a focal firm and those it consider as its suppliers (Brusoni *et al.*, 2001). Firms can buy some components' of production and design effectively if they retain an understanding of the overall system (Brusoni and Prencipe, 2001; Parmigiani and Mitchell, 2009). This means that the knowledge boundaries of a firm are wider than their task boundaries (Colfer and Baldwin, 2016). My thesis contributes to this discussion by showing how components with a high number of technological resource dependencies are more likely to be produced externally by suppliers to a focal firm when complexity is increasing. This shows that complexity at the system level may actually weaken the conventional mirroring pattern of these specific components. When a buyer holds a specification because of its knowledge (located higher in the hierarchy of the technological trajectory), and supplier is dependent on these actions, it creates the need for information processing that is under buyer's control (Puranam *et al.*, 2012).

From a buyer's perspective, any component that can cause cascading changes to other components should be kept in-house (Brusoni *et al.*, 2001). The argument to keep-in-house core components and buy "the simpler ones" is in line with the contribution of this thesis (Novak and Eppinger, 2001), but it could highlight what these simpler components are in terms of technological resource dependencies, add to the moderating influence of complexity, and take a more nuanced view of the make-or-buy question by separating design and production (Brusoni *et al.*, 2001; Ulrich and Ellison, 2005).

Contribution to technological resource dependencies and technological acquisition literature. There are multiple studies that concentrate on the dyadic relationship between acquirer and target (Makri *et al.*, 2010; Sears and Hoetker, 2014). There are not many studies that have had taken a broader view of interorganizational relationships. Acquiring a target results in a structural change in the whole interorganizational network of the acquirer and the target (Hernandez and Menon, 2017; Hernandez and Shaver, 2018). In this thesis I, together with my co-authors, investigate this phenomenon at knowledge-level, with patent citations that cross the boundaries of individual firms. Firms cannot realistically acquire all valuable resources in complex technology networks. They must rationally select the targets whose resources and technological dependencies to bring under their firm boundaries, and which dependencies to leave out (Hernandez and Menon, 2017; Santos and Eisenhardt, 2005).

The extent to which combining an acquirer's and a target's networks through node merger results in a better structural position for the combined firm as the acquirer receives control of the target's existing ties to others, adds to the likelihood of acquisition (Hernandez and Shaver, 2018). In line with this, with my co-authors I found that the price of a target firm's resources is significantly affected by their dependence linkages to other firms' knowledge resources. In this thesis I have hypothesized and empirically established that the advantageous interorganizational network position of a target is not the only reason for acquiring it (Hernandez and Shaver, 2018), but, in addition to that, its position in its technological resource network positively influences the acquisition price of the target firm. Thus, the main empirical contribution of this thesis to the technology acquisition literature is that target firms' technological resource dependencies increase its acquisition price.

I argue in this thesis that the acquirer selectively targets firms that contribute to the incremental development of core technological trajectories or to development of new technologies and related knowledge on which other firms build, enabling the acquirer to retain indirect influence on the development of the whole trajectory or technology network in that industry (Brusoni and Prencipe, 2011; Huenteler *et al.*, 2016). Therefore, the ownership of interdependent resources is not a necessary condition for an acquirer to remain competitive, when strong technological dependencies can be managed indirectly through absorbing a target with a preferable position in a technological trajectory. This conclusion contradicts the view that all valuable resources should be controlled within a firm (Barney, 1988, 1991), which has also recently been contradicted by other researchers (Alexy *et al.*, 2018).

5.3 Managerial implications

The first and most important practical implication of this thesis is its implications for predicting acquisition price. There is a practical need to approximate the target firm's acquisition price, and create regression models of it before the acquisition takes place. As a practical contribution, the value of a firm resources can actually be predicted based on network measures provided in Publication IV, as indicated in the regressions included in that publication. To emphasize, Publication IV used patent citations generated prior to acquisition as input data, so these models realistically predict acquisition price. Related to this, firms can increase their likelihood of being acquired and demand a higher price from potential acquirers by concentrating their development on emerging and foundational technologies that other organizations would want to build on when their technological trajectory develops further. Coming up with an influential emerging technology is of course easier said than done; perhaps a more easily implemented strategy is to focus on making incremental contributions to existing technologies that are part of the core technological trajectory of a technology network. Nevertheless, there are two conditions that can be connected to the higher acquisition price: technological knowledge of patents that are influential on the knowledge of others, and knowledge that is necessary for the main service characteristics of the end product system.

Second, the superior performance of firms is achieved neither by the technology nor the organizational structure per se, but by the successful alignment between technological resource dependencies and the interorganizational structure, especially when there is no contingency factors such as strong technological change (Cabigiosu and Camuffo, 2012; Macher, 2006; Park and Ro, 2013). As Colfer and Baldwin (2016: 714) stated, "A competitive market economy will reward those combinations of technical architecture and organizational structure that deliver the greatest value at the least costs". A challenge is that technical resource dependencies may be hard for business managers understand since the knowledge domain of engineering differs from their own.

The theoretical framework described in Publication II can bridge engineers and business managers, since engineering decisions regarding system structure interact with the characteristics of the buyer-supplier relationship. Though the theoretical approach of this thesis takes the system's technological structure as a given, design choices should be made with input from the purchasing perspective, and vice versa. This conceptual development of the influences of technological resource dependencies on buyer-supplier relationship characteristics, has straightforwardly practical implications when managers are considering a make-or-buy decision and, if the result is buy, what the characteristics of that relation would look like from the perspective of technological resource dependencies. It also challenges the view that relationship characteristics could easily be changed without changing the underlying product architecture.

Related to this, the conceptual propositions provided in Publication III provide the implication that managers need to view the product architecture of a product system as a critical factor when considering a make-or-buy decision. Even though the benefits of buying a component can be attractive, consideration of technological resource dependencies cannot be neglected. A more fine-grained view of these dependencies at the system level is needed, since the direction of dependencies and their indirect influences on other components also matters (Brusoni *et al.*, 2001; Sosa *et al.*, 2004, 2013). Production tasks can be bought even if there are high numbers of technological resource dependencies, and this is more rational when a system is more complex, as long as a focal firm holds knowledge that determine the actions of suppliers, and not vice versa (Brusoni *et al.*, 2001; Puranam *et al.*, 2012).

5.4 Limitations and future research

Regardless of the soundness of the propositions provided in this thesis on the likelihood of make or buy decisions and the relationship between technological resource dependencies and the characteristics of the buyer-supplier relationship, these arguments are based on a developing conceptual theory. Supportive empirical evidence could strengthen the contribution provided by this thesis. However, the logic behind our empirical findings related to technological acquisitions supports the reasoning of other conceptual publications.

This thesis does not consider temporal dimensions, for instance, technological resource dependency structures are assumed to be static once they are developed. That is not the case in reality, since when the desired service characteristics of the product system change, technological resource dependency structures can also change (Fixson and Park, 2008). Future research should concentrate more on the temporal dimension of the design and production choices of a focal firm (Becker and Zirpoli, 2017). For instance, short-term buying would have different influences on the knowledge structure of the buying firm than long-term commitment to divide tasks with a supplier (Becker and Zirpoli, 2017). Together with the temporal dimension, concurrent sourcing choice should attain more attention (Parmigiani, 2007). Time in terms of the emergence of dominant design in an industry influences innovation performance when make or buy decision are investigated (Park *et al.*, 2018), but this thesis do not discuss this viewpoint in detail.

This thesis does not actively focus on the standard interfaces of components or the mass-customization capabilities of suppliers, which have an impact on the technological trajectories and choices of the firms (Kim, Lee, and Kwak, 2017; Park *et al.*, 2018). The role of standards can be understand as specifying an optimized version of technological variants and thus to some extent stabilizing technological resource dependency structures at the system level, concentrating mainly on most valuable elements (Kim *et al.*, 2017). From the standpoint of this thesis, I interpret that standards do not actually remove the technological resource dependencies that exist, but stabilize and share knowledge of these dependencies so that compatibility between components is increased.

In this thesis, many other factors that influence technological resource dependencies and firm relations are not discussed, such as logistic costs, capability dispersion along the network of firms or rivalry between suppliers (Sorkun and Furlan, 2017). Future research should highlight these factors. In addition, this thesis concentrates on technological resource dependencies and their influences on relations between firms. One interesting question is whether the relational factors between buyer and supplier diminish the influences of dependence on another's actions when, for instance, there is no buyer-specific investments on the supplier's side (Colfer and Baldwin, 2016; Puranam *et al.*, 2012) and whether this is a durable choice over time.

New forms of organization could also benefit from ideas of technological resource dependencies. Many firms are turning their products into platforms that attract external firms to provide complementary products, and technical resource dependencies in platform-based markets have been found to be a promising future research area (Colfer and Baldwin, 2016).

5.5 **Conclusions**

This thesis demonstrates the influence of technological resource dependencies on interorganizational relationships from the perspective of a focal firm that operates as a system integrator or as an acquirer. This thesis includes one publication that concentrates on methodological concerns of how direct and indirect dependencies could be understood better. Taking the viewpoint of the importance of direct and indirect technological dependencies, we have included two conceptual publications that investigate both the characteristics of the buyer-supplier relationship and the make-or-buy question faced by a focal firm in light of technological resource dependencies as well as the complexity of the product system.

The main empirical part of this thesis focuses on mergers and acquisitions and how technological resource dependencies influence the acquisition price of a target firm, reflecting the value of the target firm's resources. The empirical findings highlighted that technological resource dependencies increase the acquisition price. Since technological resource dependencies have a direction that emerges from a technological trajectory and its inner hierarchy at the knowledge level, the control over the initial knowledge resources of that trajectory is beneficial from a focal firm's perspective to control the technological resource dependencies at both the knowledge and technology levels. A focal firm should keep the knowledge related to these technologies, which are influential on other firm's knowledge and technological products, inside its boundaries. This thesis is a step forward toward various future research directions, since the optimal alignment of the boundaries of firms in the light of technological resource dependencies have gained plenty of attention in recent studies and will continue to do so in the future.

References

Ahuja G, Katila R. 2001. Technological acquisitions and the innovation performance of acquiring firms : A longitudinal study. *Strategic Management Journal* **22**(3): 197–220.

Alexy O, West J, Klapper H, Reitzig M. 2018. Surrendering control to gain advantage: Reconciling openness and the resource-based view of the firm. *Strategic Management Journal* **39**(6): 1704–1727.

Anderson EG, Parker GG. 2002. The Effect of Learning on the Make/Buy Decision. *Production & Operations Management* **11**(3): 313–339.

Andersson M, Xiao J. 2016. Acquisitions of start-ups by incumbent businesses: A market selection process of 'high-quality' entrants? *Research Policy* **45**(1): 272–290.

Argyres N, Bigelow L. 2010. Innovation, Modularity, and Vertical Deintegration: Evidence from the Early U.S. Auto Industry. *Organization Science* **21**(4): 842–853.

Arora A, Gambardella A, Rullani E. 1997. Division of labour and the locus of inventive activity. *Journal of Management and Governance* **1**(1): 123–140.

Baldwin C, MacCormack A, Rusnak J. 2014. Hidden structure: Using network methods to map system architecture. *Research Policy* **43**(8): 1381–1397.

Baldwin CY. 2008. Where do transactions come from? Modularity, transactions, and the boundaries of firms. *Industrial and Corporate Change* **17**(1): 155–195.

Baldwin CY, Clark KB. 1997. Managing in an age of modularity. *Harvard business review* (September-October): 84–93.

Baldwin CY, Clark KB. 2000. *Design rules: The power of modularity*. The MIT press: Cambridge.

Barney JB. 1988. Returns to bidding firms in mergers and acquisitions: Reconsidering the relatedness hypothesis. *Strategic Management Journal* **9**(1 S): 71–78.

Barney JB. 1991. Firm resources and sustained competitive advantage. *Journal of Management* **17**(1): 99–120.

Becker MC, Zirpoli F. 2017. How to Avoid Innovation Competence Loss in R&D Outsourcing. *California Management Review* **59**(2): 24–44.

Bena J, Li K. 2014. Corporate Innovations and Mergers and Acquisitions. *Journal of Finance* **69**(5): 1923–1960.

Bensaou M. 1999. Portfolios of buyer-supplier relationships. *Sloan Management Review* **40**(4): 35–44.

Besanko D, Dranove D, Shanley M, Schaefer S. 2009. *Economics of strategy*. John Wiley & Sons: US.

Bhaskar R. 1975. *A realist theory of science.* Harvester: Brighton.

Blind K, Edler J, Frietsch R, Schmoch U. 2006. Motives to patent: Empirical evidence from Germany. *Research Policy* **35**(5): 655–672.

Borgatti SP, Everett MG, Freeman LC. 2002. *Ucinet for Windows: Software for Social Network Analysis*. *Analytic Technologies*. Harvard, MA.

Borgatti SP, Li X. 2009. On social network analysis in a supply chain context. *Journal of Supply Chain Management* **45**(2): 5–22.

Brusoni S, Prencipe A. 2001. Unpacking the black box of modularity: technologies, products and organization. *Industrial and Corporate Change* **10**(1): 179–205.

Brusoni S, Prencipe A. 2006. Making Design Rules: A Multidomain Perspective. *Organization Science* **17**(2): 179–189.

Brusoni S, Prencipe A. 2011. Patterns of modularization: The dynamics of product architecture in complex systems. *European Management Review* **8**(2): 67–80.

Brusoni S, Prencipe A, Pavitt K. 2001. Knowledge Specialization, Organizational Coupling, and the Boundaries of the Firm: Why Do Firms Know More Than They Make? *Administrative Science Quarterly* **46**(4): 597–621.

Bryman A, Bell E. 2011. *Business research methods*, Third edit. Oxford University Press, USA.

Burrell G, Morgan G. 1979. *Sociological Paradigms and organisational Analysis - Elements of the Sociology of Corporate Life*. *Sociological Paradigms and organisational analysis*. Heinemann: London.

Cabigiosu A, Camuffo A. 2012. Beyond the “Mirroring” Hypothesis: Product Modularity and Interorganizational Relations in the Air Conditioning Industry. *Organization Science* **23**(3): 686–703.

Cabigiosu A, Zirpoli F, Camuffo A. 2013. Modularity, interfaces definition and the integration of external sources of innovation in the automotive industry. *Research Policy* **42**(3): 662–675.

Campagnolo D, Camuffo A. 2010. The concept of modularity in management studies: A literature review. *International Journal of Management Reviews* **12**(3): 259–283.

Caniëls MCJ, Gelderman CJ. 2005. Purchasing strategies in the Kraljic matrix - A power and dependence perspective. *Journal of Purchasing and Supply Management* **11**(2–3): 141–155.

Caniëls MCJ, Gelderman CJ. 2007. Power and interdependence in buyer supplier relationships: A purchasing portfolio approach. *Industrial Marketing Management* **36**(2): 219–229.

Casadesus-Masanell R, Almirall E. 2010. Open Versus Closed Innovation. *Academy of Management Review* **35**(1): 27–47.

Chatterjee S. 1986. Types of synergy and economic value: The impact of acquisitions on merging and rival firms. *Strategic management journal* **7**(2): 119–139.

Chondrakis G. 2016. Unique synergies in technology acquisitions. *Research Policy* **45**(9): 1873–1889.

Clark KB. 1985. The interaction of design hierarchies and market concepts in technological evolution. *Research Policy* **14**(5): 235–251.

Clark KB, Fujimoto T. 1990. The power of product integrity. *Harvard business review* **68**(6): 107–118.

Coase RH. 1937. The Nature of the Firm. *Economica* **4**(16): 386–405.

Cohen WM, Nelson RR, Walsh JP. 2000. *Protecting Their Intellectual Assets: Appropriability Conditions and Why U.S. Manufacturing Firms Patent (or Not).* NBER Working paper series. Cambridge.

Colfer LJ, Baldwin CY. 2016. The mirroring hypothesis: Theory, evidence, and exceptions. *Industrial and Corporate Change* **25**(5): 709–738.

Dabhilkar M, Bengtsson L, Lakemond N. 2016. Sustainable supply management as a purchasing capability: A power and dependence perspective. *International Journal of Operations & Production Management* **36**(1): 2–22.

David PA. 1985. Clio and the Economics of QWERTY. *The American economic review* **75**(2): 332–337.

David R, Han S. 2004. A systematic assessment of the empirical support for transaction cost economics. *Strategic Management Journal* **25**(1): 39–58.

Davies A, Brady T, Hobday M. 2007. Organizing for solutions: Systems seller vs. systems integrator. *Industrial Marketing Management* **36**(2): 183–193.

Dierickx I, Cool K. 1989. Asset stock accumulation and sustainability of competitive advantage. *Management Science* **35**(12): 1504–1511.

Dosi G. 1982. Technological paradigms and technological trajectories. A suggested interpretation of the determinants and directions of technical change. *Research Policy* **11**(3): 147–162.

Duray R, Ward PT, Milligan GW, Berry WL. 2000. Approaches to mass customization: Configurations and empirical validation. *Journal of Operations Management* **18**(6): 605–625.

Ethiraj SK. 2007. Allocation of inventive effort in complex product systems. *Strategic Management Journal* **28**(6): 563–584.

Ethiraj SK, Posen HE. 2013. Do Product Architectures Affect Innovation Productivity in Complex Product Ecosystems? In *Collaboration and Competition in Business Ecosystems (Advances in Strategic Management)*, Ron Adner , Joanne E. Oxley BSS (ed). Emerald Group Publishing Limited, 30: 127–166.

Fixson SK. 2005. Product architecture assessment: A tool to link product, process, and supply chain design decisions. *Journal of Operations Management* **23**(3–4): 345–369.

Fixson SK, Park JK. 2008. The power of integrality: Linkages between product architecture, innovation, and industry structure. *Research Policy* **37**(8): 1296–1316.

Fleming L. 2001. Recombinant Uncertainty in Technological Search. *Management Science* **47**(1): 117–132.

Ft 50. 2016. *The Financial Times*. Available at: https://www.ft.com/content/3405a512-5cbb-11e1-8f1f-00144feabdc0 [15 March 2018].

Furlan A, Cabigiosu A, Camuffo A. 2014. When mirror gets misted up: Modularity and technological change. *Strategic Management Journal* **35**: 789–807.

Gann DM, Salter AJ. 2000. Innovation in project-based, service-enhanced firms: the construction of complex products and systems. *Research Policy* **29**(7–8): 955–972.

Garud R, Kumaraswamy A. 1995. Technological and Organizational Designs of Substitution for Realizing Economies of substitution. *Strategic Management Journal* **16**(SI): 93–109.

Garud R, Munir K. 2008. From transaction to transformation costs: The case of Polaroid’s SX-70 camera. *Research Policy* **37**(4): 690–705.

Gioia DA, Pitre E. 1990. Multiparadigm Perspectives on Theory Building. *Academy of*

Management Review **15**(4): 584–602.

Godfrey-Smith P. 2009. *Theory and reality: An introduction to the philosophy of science*. University of Chicago Press.

Gokpinar B, Hopp WJ, Iravani SMR. 2010. The Impact of Misalignment of Organizational Structure and Product Architecture on Quality in Complex Product Development. *Management Science* **56**(3): 468–484.

Gokpinar B, Hopp WJ, Iravani SMR. 2013. In-House Globalization: The Role of Globally Distributed Design and Product Architecture on Product Development Performance. *Production and Operations Management* **22**(6): 1509–1523.

Graebner ME. 2004. Momentum and serendipity: how acquired leaders create value in the integration of technology firms. *Strategic Management Journal* **25**(89): 751–777.

Grahovac J, Parker G, Shittu E. 2015. The impact of costliness, competitive importance, and modularity of investments on outsourcing. *Production and Operations Management* **24**(3): 421–437.

Grant RM. 1996. Toward a Knowledge-Based Theory of the Firm. *Strategic Management Journal* **17**: 109–122.

Greeno JG, Moore JL. 1993. Situativity and symbols: Response to Vera and Simon. *Cognitive science* **17**(1): 49–59.

Grimpe C, Hussinger K. 2008. Pre-empting technology competition through firm acquisitions. *Economics Letters* **100**(2): 189–191.

Grimpe C, Hussinger K. 2014a. Resource complementarity and value capture in firm acquisitions: The role of intellectual property rights. *Strategic Management Journal* **35**(12): 1762–1780.

Grimpe C, Hussinger K. 2014b. Pre-empted patents, infringed patents and firms' participation in markets for technology. *Research Policy* **43**(3): 543–554.

Hagedoorn J, Duysters G. 2002. External Sources of Innovative Capabilities: The Preferences for Strategic Alliances or Mergers and Acquisitions. *Journal of Management Studies* **39**(2): 167–188.

Henderson RM, Clark KB. 1990. Architectural innovation: The reconfiguration of existing product technologies and the failure of established firms. *Administrative science quarterly* **35**(1): 9–30.

Hernandez E, Menon A. 2017. Acquisitions, Node Collapse, and Network Revolution.

Management Science **64**(4): 1652–1671.

Hernandez E, Shaver JM. 2018. Network Synergy. *Administrative Science Quarterly* **in press**.

Higgins MJ, Rodriguez D. 2006. The outsourcing of R&D through acquisitions in the pharmaceutical industry. *Journal of Financial Economics* **80**(2): 351–383.

Hoetker G. 2006. Do modular products lead to modular organizations? *Strategic Management Journal* **27**(6): 501–518.

Hoetker G, Swaminathan A, Mitchell W. 2007. Modularity and the Impact of Buyer–Supplier Relationships on the Survival of Suppliers. *Management Science* **53**(2): 178–191.

Holcomb TR, Hitt MA. 2007. Toward a model of strategic outsourcing. *Journal of Operations Management* **25**(2): 464–481.

Howard M, Squire B. 2007. Modularization and the impact on supply relationships. *International Journal of Operations & Production Management* **27**(11): 1192–1212.

Howard MD, Withers MC, Tihanyi L. 2017. Knowledge Dependence and the Formation of Director Interlocks. *Academy of Management Journal* **60**(5): 1986–2013.

Huenteler J, Ossenbrink J, Schmidt TS, Hoffmann VH. 2016. How a product’s design hierarchy shapes the evolution of technological knowledge - Evidence from patent-citation networks in wind power. *Research Policy* **45**(6): 1195–1217.

Jacobides MG, MacDuffie JP, Tae CJ. 2016. Acency, structure, and the dominance of OEMs: Change and stability in the automotive sector. *Strategic Management Journal* **37**(9): 1942–1967.

Jaffe A. 1986. Technological opportunity and spillovers of R & D : Evidence from firms’ patents, profits, and market value. *The American Economic Review* **76**(5): 984–1001.

Järvensivu T, Törnroos JÅ. 2010. Case study research with moderate constructionism: Conceptualization and practical illustration. *Industrial Marketing Management* **39**(1): 100–108.

Jiao JR, Simpson TW, Siddique Z. 2007. Product family design and platform-based product development: a state-of-the-art review. *Journal of intelligent Manufacturing* **18**(1): 5–29.

Johnson SB. 2003. Systems integration and the social solution of technical problems in complex systems. In *The business of systems integration*. Oxford: Oxford University Press: 35–55.

Kim D, Lee H, Kwak J. 2017. Standards as a driving force that influences emerging technological trajectories in the converging world of the Internet and things : An investigation of the M2M / IoT patent network. *Research Policy* **46**(7): 1234–1254.

Kogut B, Zander U. 1996. What firms do? Coordination, identity, and learning. *Organization science* **7**(5): 502–518.

Kraljic P. 1983. Purchasing must become supply management. *Harvard Business Review* **61**(5): 109–117.

Kuhn TS. 1962. *The structure of scientific revolutions*, Fourth edi. University of Chicago press.

Langlois RN. 2006. The secret life of mundane transaction costs. *Organization Studies* **27**(9): 1389–1410.

Langlois RN, Robertson PL. 1992. Networks and innovation in a modular system: Lessons from the microcomputer and stereo component industries. *Research policy* **21**(4): 297–313.

Lee J, Berente N. 2012. Digital Innovation and the Division of Innovative Labor : Digital Controls in the Automotive Industry. *Organization Science* **23**(5): 1428–1447.

MacCormack A, Baldwin C, Rusnak J. 2012. Exploring the duality between product and organizational architectures: A test of the ‘mirroring’ hypothesis. *Research Policy* **41**(8): 1309–1324.

MacCormack A, Rusnak J, Baldwin CY. 2006. Exploring the Structure of Complex Software Designs: An Empirical Study of Open Source and Proprietary Code. *Management Science* **52**(7): 1015–1030.

Macher JT. 2006. Technological Development and the Boundaries of the Firm: A Knowledge-Based Examination in Semiconductor Manufacturing. *Management Science* **52**(6): 826–843.

Mäkinen SJ, Dedehayir O. 2013. Business Ecosystems’ Evolution — An Ecosystem Clockspeed Perspective. In *Advances in Strategic Management*, Adner, Ron; Oxley, Joanne; Silverman B (ed): 99–125.

Makri M, Hitt MA, Lane PJ. 2010. Complementary technologies, knowledge relatedness, and invention outcomes in high technology mergers and acquisitions. *Strategic Management Journal* **31**(6): 602–628.

Mantere S, Ketokivi MA. 2013. Reasoning in organization science. *Academy of Management Review* **38**(1): 70–89.

Martin X, Shalev R. 2016. Target firm-specific information and acquisition efficiency. *Management Science* **63**(3): 672–690.

Mayer KJ, Argyres NS. 2004. Learning to contract: Evidence from the personal computer industry. *Organization Science* **15**(4): 394–410.

McEvily SK, Eisenhardt KM, Prescott JE. 2004. The global acquisition, leverage, and protection of technological competencies. *Strategic Management Journal* **25**(8–9): 713–722.

Mikkola JH. 2003. Modularity, component outsourcing, and inter-firm learning. *R and D Management* **33**(4): 439–454.

Mikkola JH. 2006. Capturing the degree of modularity embedded in product architectures. *Journal of Product Innovation Management* **23**(2): 128–146.

Mongeon P, Paul-Hus A. 2016. The journal coverage of Web of Science and Scopus: a comparative analysis. *Scientometrics* **106**(1): 213–228.

Monteverde K. 1995. Technical Dialog as an Incentive for Vertical Integration in the Semiconductor Industry. *Management Science* **41**(10): 1624–1639.

Monteverde K, Teece DJ. 1982. Supplier Switching Costs and Vertical Integration in the Automobile Industry. *The Bell Journal of Economics* **13**(1): 206–213.

Montgomery RT, Ogden JA, Boehmke BC. 2018. A quantified Kraljic Portfolio Matrix: Using decision analysis for strategic purchasing. *Journal of Purchasing and Supply Management* **24**(3): 192–203.

Mowery DC. 1983. The relationship between intrafirm and contractual forms of industrial research in American manufacturing, 1900--1940. *Explorations in Economic History* **20**(4): 351–374.

Murmann JP, Frenken K. 2006. Toward a systematic framework for research on dominant designs, technological innovations, and industrial change. *Research Policy* **35**(7): 925–952.

Nellore R, Söderquist K. 2000. Portfolio approaches to procurement. *Long Range Planning* **33**(2): 245–267.

Nickerson JA, Zenger TR. 2004. A Knowledge-Based Theory of the Firm—The Problem-Solving Perspective. *Organization Science* **15**(6): 617–632.

Nightingale P. 2000. The product–process–organisation relationship in complex development projects. *Research Policy* **29**(7–8): 913–930.

Novak S, Eppinger SD. 2001. Sourcing By Design: Product Complexity and the Supply Chain. *Management Science* **47**(1): 189–204.

Olsen RF, Ellram LM. 1997. A portfolio approach to supplier relationships. *Industrial Marketing Management* **26**(2): 101–113.

Orton J, Weick KE. 1990. Loosely coupled systems: A reconceptualization. *Academy of Management Review* **15**(2): 203–223.

Ozmel U, Reuer JJ, Wu C-W. 2017. Interorganizational Imitation and Acquisitions of High-tech Ventures. *Strategic Management Journal* **38**(13): 2647–2665.

Padhi SS, Wagner SM, Aggarwal V. 2012. Positioning of commodities using the Kraljic Portfolio Matrix. *Journal of Purchasing and Supply Management* **18**(1): 1–8.

Paoli M, Prencipe A. 1999. The Role of Knowledge Bases in Complex Product Systems: Some Empirical Evidence from the Aero Engine Industry. *Journal of Management & Governance* **3**: 137–160.

Park J-K, Ro YK. 2013. Product Architectures and Sourcing Decisions: Their Impact on Performance. *Journal of Management* **39**(3): 814–846.

Park J, Ro YK. 2011. The impact of a firm ’ s make , pseudo-make , or buy strategy on product performance. *Journal of Operations Management* **29**(4): 289–304.

Park WY, Ro YK, Kim N. 2018. Architectural innovation and the emergence of a dominant design: The effects of strategic sourcing on performance. *Research Policy* **47**(1): 326–341.

Parmigiani A. 2007. Why do firms both make and buy? An investigation of concurrent sourcing. *Strategic Management Journal* **28**(3): 285–311.

Parmigiani A, Mitchell W. 2009. Complementarity, capabilities, and the boundaries of the firm: the impact of within-firm and interfirm expertise on concurrent sourcing of complementary components. *Strategic Management Journal* **30**(10): 1065–1091.

Peteraf MA. 1993. The cornerstones of competitive advantage: A resource-based view. *Strategic Management Journal* **14**: 179–191.

Pil FK, Cohen SK. 2006. Modularity: Implications for imitation, innovation, and sustained advantage. *Academy of Management Review* **31**(4): 995–1011.

Polanyi M. 1962. Tacit knowing: Its bearing on some problems of philosophy. *Reviews of modern physics* **34**(4): 601.

Prencipe A. 1997. Technological competencies and proudct’s evolutionary dynamics: A case study from the aero-engine industry. *Research Policy* **25**: 1261–1276.

Pugh DS. 1983. Studying organizational structure and process. *Beyond method: Strategies for social research*. London: Sage : 45–56.

Puranam P, Raveendran M, Knudsen T. 2012. Organization design: the epistemic interdepencence perspective. *Academy of Management Review* **37**(3): 419–440.

Puranam P, Singh H, Chaudhuri S. 2009. Integrating Acquired Capabilities: When Structural Integration Is (Un)necessary. *Organization Science* **20**(2): 313–328.

Puranam P, Singh H, Zollo M. 2006. Organizing for innovation: Managing the coordination-autonomy dilemma in technology acquisitions. *Academy of Management Journal* **49**(2): 263–280.

Puranam P, Srikanth K. 2007. What they know vs. what they do: How acquirers leverage technology acquisitions. *Strategic Management Journal* **28**(8): 805–825.

Rabier MR. 2017. Acquisition Motives and the Distribution of Acquisition Performance. *Strategic Management Journal* **38**(13): 2666–2681.

Ramachandran K, Krishnan V. 2008. Design Architecture and Introduction Timing for Rapidly Improving Industrial Products. *Manufacturing & Service Operations Management* **10**(1): 149–171.

Ramsay J. 1996. Power measurement. *European Journal of Purchasing & Supply Management* **2**(2): 129–143.

Ranft AL, Lord MD. 2002. Acquiring New Technologies and Capabilities: A Grounded Model of Acquisition Implementation. *Organization Science* **13**(4): 420–441.

Ransbotham S, Mitra S. 2010. Target Age and the Acquisition of Innovation in High-Technology Industries. *Management Science* **56**(11): 2076–2093.

Reitzig M. 2004. The private values of ‘thickets’ and ‘fences’: towards an updated picture of the use of patents across industries. *Economics of Innovation and New Technology* **13**(5): 457–476.

Riordan MH, Williamson OE. 1985. Asset specificity and economic organization. *International Journal of Industrial Organization* **3**(4): 365–378.

Salvador F, Forza C, Rungtusanatham M. 2002. Modularity, product variety, production volume, and component sourcing: Theorizing beyond generic prescriptions. *Journal of Operations Management* **20**(5): 549–575.

Sanchez R, Mahoney JT. 1996. Modularity, flexibility, and knowledge management in product and organization design. *Strategic Management Journal* **17**(S2): 63–76.

Santos FM, Eisenhardt KM. 2005. Organizational boundaries and theories of organization. *Organizational science* **16**(5): 491–508.

Schilling M. 2000. Toward a General Modular Systems Theory and it's application to Inferfirm Product Modularity. *Academy of Management Review* **25**(2): 312–334.

Schmidt SK, Werle R. 1998. *Coordinating technology: Studies in the international standardization of telecommunications*. MIT press: US.

Sears J, Hoetker G. 2014. Technological overlap, technological capabilities, and resource recombination in technological acquisitions. *Strategic Management Journal* **35**(1): 48–67.

Shibata T, Yano M, Kodama F. 2005. Empirical analysis of evolution of product architecture: Fanuc numerical controllers from 1962 to 1997. *Research Policy* **34**(1): 13–31.

Simon HA. 1962. The architecture of complexity. *Proceedings of the American Philosophical Society* **106**: 467–482.

Smith A. 1776. *Wealth of nations*. Penguin Books: London.

Sorkun MF, Furlan A. 2017. Product and Organizational Modularity: A Contingent View of the Mirroring Hypothesis. *European Management Review* **14**(2): 205–224.

Sosa ME, Eppinger SD, Rowles CM. 2003. Identifying Modular and Integrative Systems and Their Impact on Design Team Interactions. *Journal of Mechanical Design* **125**(2): 240.

Sosa ME, Eppinger SD, Rowles CM. 2004. The Misalignment of Product Architecture and Organizational Structure in Complex Product Development. *Management Science* **50**(12): 1674–1689.

Sosa ME, Eppinger SD, Rowles CM. 2007. A Network Approach to Define Modularity of Components in Complex Products. *Journal of Mechanical Design* **129**(11): 1118.

Sosa ME, Mihm J, Browning TR. 2013. Linking Cyclicality and Product Quality. *Manufacturing & Service Operations Management* **15**(3): 473–491.

Steensma HK, Corley KG. 2000. On the performance of technology-sourcing partnerships: The interaction between partner interdependence and technology attributes. *Academy of Management Journal* **43**(6): 1045–1067.

Takeishi A. 2002. Knowlege Partitioning in the Interfimr Division of Labor: The Case of

Automotive Product Development. *Organizational Science* **13**(3): 321–338.

Takeishi A, Fujimoto T. 2001. Modularisation in the auto industry: interlinked multiple hierarchies of product, production and supplier systems. *International Journal of Automotive Technology and Management* **1**(4): 379–396.

Teece DJ. 1980. Economies of scope and the scope of the enterprise. *Journal of economic behavior & organization* **1**(3): 223–247.

Thompson JD. 1967. *Organizations in action: Social science bases of administrative theory*. McGraw-Hill: New York.

Toulmin SE. 2003. *The uses of argument*. Cambridge university press.

Tuertscher P, Garud R, Kumaraswamy A. 2014. Justification and interlaced knowledge at ATLAS, CERN. *Organization Science* **25**(6): 1579–1608.

Tushman ML, Rosenkopf L. 1992. Organizational determinants of technological-change-toward a sociology of technological evolution. *Research in organizational behavior* **14**: 311–347.

Ülkü S, Schmidt GM. 2011. Matching product architecture and supply chain configuration. *Production and Operations Management* **20**(1): 16–31.

Ulrich K. 1995. The role of product architecture in the manufacturing firm. *Research Policy* **24**(3): 419–440.

Ulrich KT, Ellison DJ. 2005. Beyond Make-Buy: Internalization and Integration of Design and Production. *Production & Operations Management* **14**(3): 315–330.

Venkatesan R. 1992. Strategic sourcing: to make or not to make. *Harvard Business Review* **70**(6): 98–107.

Wagner SM, Padhi SS, Bode C. 2013. The procurement process: refining inputs for kraljic matrix yields objective purchasing portfolio and strategies. *Industrial Engineer* **45**(2): 34–39.

Wasserman S, Faust K. 1994. *Social network analysis: Methods and applications*, Vol 8. Cambridge university press: UK.

Williamson O. 1985. *The Economic Institutions of Capitalism: firms, markets, relational contracting*. Free Press: New York.

Williamson OE. 1973. Markets and hierarchies. *American Economic Review* **63**(2): 316–325.

Williamson OE. 1991. Comparative Economic Organization : The Analysis of Discrete Structural Alternatives. *Administrative science quarterly* **36**(2): 269–296.

Williamson OE. 2008. Outsourcing : Transaction Cost Economics and Supply Chain Management. *Journal of supply chain management* **44**(2): 5–16.

Winter SG. 1998. Chapter 11 - Knowledge and Competence as Strategic Assets. In *The Strategic Management of Intellectual Capital*, Klein DA (ed). Butterworth-Heinemann: Boston: 165–187.

Worren N, Moore K, Cardona P. 2002. Modularity, strategic flexibility, and firm performance: A study of the home appliance industry. *Strategic Management Journal* **23**(12): 1123–1140.

Yu Y, Umashankar N, Rao VR. 2016. Choosing the right target: Relative preferences for resource similarity and complementarity in acquisition choice. *Strategic Management Journal* **37**(8): 1808–1825.

Zaheer A, Hernandez E, Banerjee S. 2010. Prior alliances with targets and acquisition performance in knowledge-intensive industries. *Organization Science* **21**(5): 1072–1091.

Zhou YM. 2013. Designing for Complexity: Using Divisions and Hierarchy to Manage Complex Tasks. *Organization Science* **24**(2): 339–355.

Zirpoli F, Becker MC. 2011. The limits of design and engineering outsourcing: Performance integration and the unfulfilled promises of modularity. *R&D Management* **41**(1): 21–43.

Zirpoli F, Camuffo A. 2009. Product architecture, inter-firm vertical coordination and knowledge partitioning in the auto industry. *European Management Review* **6**(4): 250–264.

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