Master thesis

"Ecosystem transformation in the industry 4.0 context: an investigation of changing interrelations and structural organizations"

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Abstract

The fourth industrial revolution or "industry 4.0" is often praised for its potential to impact different societal and ecological matters for the better. Even though an essential part of industry 4.0 is the digital integration across firm boundaries, only little is known about inter-firm collaboration from an organizational perspective. Therefore, this research investigates industry 4.0 induced ecosystem transformation in terms of system level interrelations and firm level reactions in terms of structural organization of ecosystems. To do so, this research uses an abductive research design and conducts a single case study in the industrial automation ecosystem. This research adds to our understanding by providing a theoretical lens through which ecosystems can be analyzed. This lens was developed through operationalization of interrelations by interdependence and co-specialization. Moreover, structural organization was operationalized by firm boundary setting, organizational coupling and modularity. Next, this theoretical lens was applied to the industry 4.0 context. From this analysis it appeared that ecosystem actors become increasingly reciprocally interdependent and increasingly co-specialized. As a response, actors appeared to react in different and contradicting ways of boundary setting. In terms of organizational coupling and modularity, opposing trends were observed as well. This could be explained by differentiating between commodity-based and specialism-based exchanges.

Keywords: industry 4.0, business ecosystems, strategizing, co-evolutionary logic, boundaries and compositions, case study research.

Preface

Seven months ago, I started to conduct the research for my master thesis. I had only a vague idea about what I wanted to do but seven months later I can proudly present my final thesis. Writing this thesis has sometimes been confusing and frustrating but above all it was an educational and inspiring process as well. Ultimately it made me realize that I was passionate about conducting research and therefore I decided to write a dissertation thesis as a Ph.D. candidate after finishing my master studies Business Administration and Innovation management, entrepreneurship and sustainability.

Even though I put a lot of effort in this project, I was not able to accomplish this result by myself and therefore I want to thank multiple persons who helped me the last seven months. First, I want to thank Dr. Ariane von Raesfeld Meijer and Dr. Raymond Loohuis for their moral and content-wise support. Next, I want to thank my friends and family for their support. Specifically, I want to thank Chelsea Veenstra and Max Thijssen for their help and support during this eventful process of writing this master thesis. I also want to thank Dr. Tamara Oukes and Dr. Biba Visnjicki for their help by collaborating on the assignment for Epsilon. Finally, I want to thank all respondents that provided me with the valuable and insightful data that enabled me to write this thesis. Next to talking about the research topics, I found it also very interesting to discover the companies and representatives that I visited and talk about their business and industry.

X. Stegehuis

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1. Introduction

In 2011, the German government presented the industry 4.0 plan at the Hanover Messe. The concept of industry 4.0 is currently one the most frequently discussed topics at manufacturing conferences, forums, and exhibitions (Liao, Deschamps, Loures, & Ramos, 2017). Industry 4.0 refers to the fourth industrial revolution as a follow up of the first three revolutions which were respectively driven by the steam engine, assembly line and electricity and automation of production through computational power (Kagermann, Wahlster, & Helbig, 2013). Industry 4.0 is technology driven, accompanied by increased organizational and market complexity and encompasses an end-to-end digital integration (Kagermann et al., 2013; Liao et al., 2017). The latter refers to integration between all business processes in the value chain across hierarchical levels and company boundaries (Liao et al., 2017). In other words, end-to-end digital integration refers to horizontal integration from sensor level to the ERP system and vertical integration of processes across firm boundaries. This research uses the following definition of industry 4.0: "*recent technological advances where the internet and supporting technologies (e.g., embedded systems) serve as a backbone to integrate physical objects, human actors, intelligent machines, production lines and processes across organizational boundaries to form a new kind of intelligent, networked and agile value chain*." (Schumacher, Erol, & Sihn, 2016, p.162). This definition has different implications for the understanding of the industry 4.0 concept. First, it implies the technology-driven character of industry 4.0. As well as the need for firm boundary-crossing integration of processes and the need for a flexible and agile value chain. In practice, this could lead to a situation where all machines and robots within a production environment communicate with and adapt to each other as well to the ERP system. Consequently, this could lead to a responsive value chain where all participants communicate on a real-time basis and adapt their production efforts to their partners accordingly. In short, industry 4.0 is characterized by three central implications; 1) change is technology driven, 2) processes are integrated both horizontally and vertically across firm boundaries, and 3) value chains need to be more flexible and agile. Even though these implications have far-reaching consequences for firms both on technological and organizational level, they do not fully explain the importance of studying industry 4.0.

Industry 4.0 is important to study because it has a positive impact on different societal dimensions. First, industry 4.0 will impact future production environment because firms expect 40 to 50 percent of all manufacturing equipment to be replaced by industry 4.0 driven technologies (Wee, Kelly, Cattel, & Breunig, 2015). Moreover, industry 4.0 puts humans at the center of all activities. On the one hand enables industry 4.0 firms to produce at batch size one so that customers can design their own products and realize an optimal fit between product and customer demand (Wee et al., 2015). On the other hand, industry 4.0 aims to realize a better work-life balance for employees in manufacturing industries (Gates, 2017). Even though, industry 4.0 will have significant impact on and could restructure required skill sets, it also increases quality of working conditions. This is done by taking away repetitive, heavy or other tasks that are unattractive for humans to execute. Finally, industry 4.0 contributes to pressing concerns regarding ecological sustainability. According to Gabriel and Pessl (2016), industry 4.0 supports current ecological concerns by the means of continuous energy and resource management, reducing CO_2 emission through production process optimization and decreasing used resources (e.g., through 3D printing). Moreover, industry 4.0 can give insights regarding energy consumption behavior by understanding energy consumption and production process behavior. To be more specific, the "who", "where", "when" and "how" questions are essential in evaluating and improving factory energy efficiency and can be answered by industry 4.0 (Shrouf, Ordieres, & Miragliotta, 2014). Evidently, industry 4.0 has big potential to positively impact pressing societal matters and should therefore be further investigated. However, what is already known about the industry 4.0 concept in the scholarly literature?

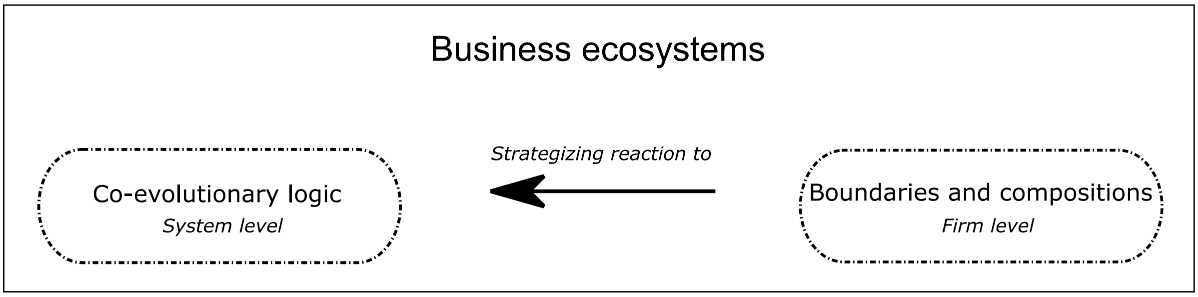
According to Liao et al. (2017), industry 4.0 is mostly researched in a manufacturing setting. Besides, the US and Germany have set up national-level initiatives involving billions of dollars to develop cutting-edge industry 4.0 technologies and secure competitive position of manufacturing (Kagermann et al., 2013; Rafael, Shirley, & Liveri, 2014). Together, these observations imply that understanding of industry 4.0 is highly valuable in manufacturing settings. Due to recent environmental, societal and technological developments like increasing customization requirements or pressures to reduce resource waste and CO_2 emission, manufacturing firms face substantial challenges. To overcome these challenges, firms need to gain capabilities to increasingly manage their value-chain in an agile and responsive way (Schumacher et al., 2016). More so, these challenges require firms to simultaneously increase efficiency, flexibility and quality which can be delivered by industry 4.0 (Kagermann et al., 2013). Schumacher et al. (2016) contributed to the understanding of industry 4.0 by presenting a maturity assessment model including multiple organizational dimensions. However, they hardly consider the end-to-end digital integration which includes collaboration and integration of processes and machines across firm boundaries. Only one of their nine dimensions mentions cross-company collaboration but only considers it from a cultural point of view. They do not consider inter-organizational collaboration from a strategic, operational or governance perspective, meaning that cross-company collaboration only plays a limited role within their maturity assessment. Underrepresentation of the end-to-end digital integration and the closely linked inter-organizational collaboration is widely recognized in the literature (Liao et al., 2017). Still, the firm boundary-crossing integration of processes within systems and how manufacturing firms should cope with them on a micro-level are essential features of industry 4.0 (Kagermann et al., 2013; Porter & Heppelmann, 2014). Firm level processes, to deal with increasing requirements to integrate processes and resources across firm boundaries, might differ from previous production settings (i.e., industry 2.0 and 3.0). All in all, literature on industry 4.0 mainly focuses on manufacturing settings. However, it only provides limited understanding about firm boundary-crossing integration and collaboration even though it appears a crucial part of industry 4.0. Literature on business networks and ecosystems may decrease this knowledge gap.

Firms in industry 4.0 are confronted with technical and organizational complexities and increased market dynamics. These complexities require firms to think on a system level instead of organizational level (Vargo et al., 2017). Within the marketing literature (e.g., IMP

Group), increasing complexity and dynamism that accompany technology are recognized. Vargo et al. (2017) state that marketing should stay on top of rapidly changing environments by adopting system thinking of markets. By adopting system thinking, marketing can better deal with the complex, dynamic and turbulent character of everyday life (Vargo et al., 2017). A concept that links processes of individual firms to system thinking is strategizing. This view originates from the IMP literature and strategizing is defined by Håkansson and Ford (2002) as: "*identification of the scope of action, within existing and potential relationships and is about operating effectively with others within the internal and external constraints that limit this scope*" (p. 137). This definition refers on the one hand to the execution of actions by individual firms but on the other hand, these actions are executed within a system of network partners. The combination of strategizing and system thinking is illustrated by Huemer (2017) who indicates that not only horizons, but also verizons (i.e., over and undercurrent exchange streams) should be the basis for strategizing. In other words, identification of the scope of action should not be limited to the linear value chain (i.e., horizons) but to over and undercurrent exchange partners (i.e., verizons) as well. To further highlight the connection between strategizing and system thinking, Vargo et al. (2017) state that system structures are the outcome of underlying processes. This means that strategizing is an essential concept in understanding system structures. This importance refers to the connection between identification of the scope of action and processes that underly structures where the former is the basis for the latter. The concept of strategizing is also considered relevant because it focuses on interaction across firm boundaries and could therefore contribute to the understanding about how manufacturing firms cope with firm-crossing digital integration of business processes. The context, that is used to identify the scope of action, includes the business ecosystem.

In this research, existing and potential relationships in which the scope of action is identified reside within business ecosystems. A business ecosystems refers to multiple actors that are connected by a shared fate and co-evolve around this shared fate (Aarikka-Stenroos & Ritala, 2017). Undoubtedly, complexity in industry 4.0 arises from substantial coordination efforts as well as from the need to integrate technology, customers and employees (Ostrom, Parasuraman, Bowen, Patrício, & Voss, 2015). These coordination efforts are called for by the nature of the industry 4.0 context, which is increasingly characterized by collaboration among various parties in different industries (e.g., ICT, machinery and plant manufacturers and mechatronics suppliers) to materialize a value proposition (Kagermann et al., 2013). Therefore business ecosystems are considered a relevant concept because it examines management that spans value chains, networks and industry boundaries (Aarikka-Stenroos and Ritala, 2017). A business ecosystem is defined as "*the alignment structure of the multilateral set of partners that need to interact in order for a focal value proposition to materialize*" (Adner, 2016 p. 40). This definition has different implications for the understanding of the business ecosystem concept. First, business ecosystems have an alignment structure existing of mutually agreed upon actor positions and activity flows between them. Second, business ecosystems exist of multilateral connections that cannot be broken down to individual dyadic relationships. Third, business ecosystems exist of a "set of partners" implying that these partners have a shared fate and have a joint goal of value creation. Finally, business ecosystems are focused on materializing on a value proposition meaning that they are organized around value creation activities. To deepen understanding on business ecosystems and how to interpret them, literature can be combined into a model as presented in figure 1.

Figure 1. Conceptual understanding of business ecosystems



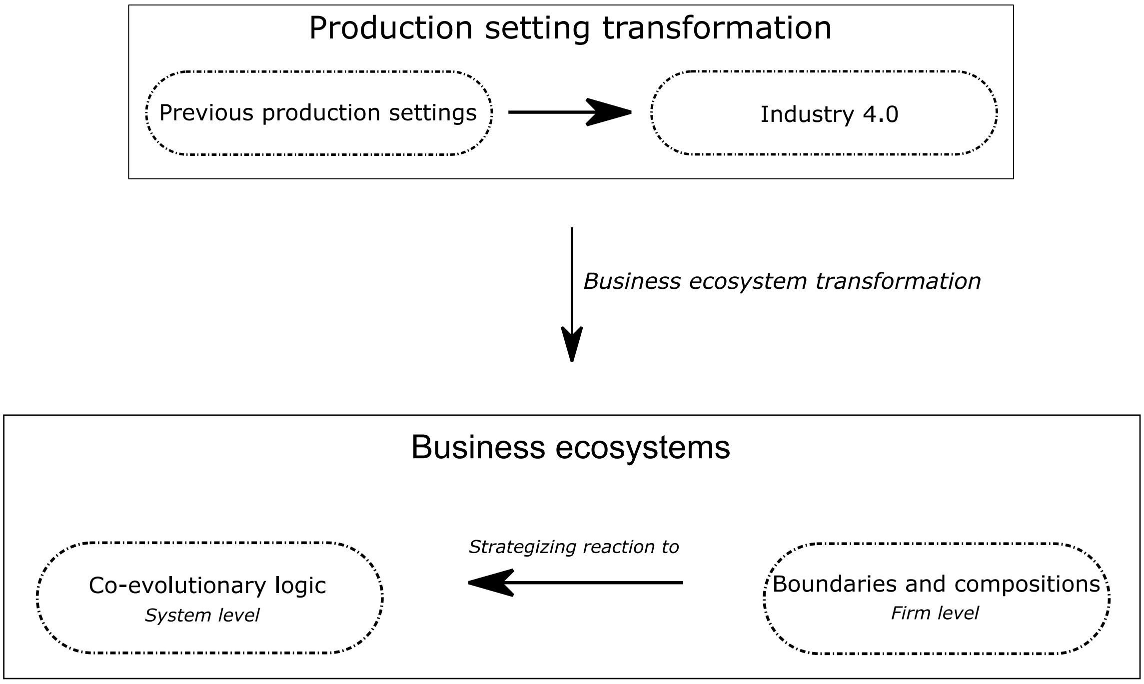
Aarikka-Stenroos and Ritala (2017) outline two different theoretical constituents for business ecosystems that can be considered conceptual tools for B2B and business network research: *co-evolutionary logic* and *boundaries and compositions*. The former entails interrelations between ecosystem partners (i.e., interpretations of interdependencies between business ecosystem actors and in which direction these interdependencies move). According to the IMP literature, network partners are interrelated in terms of activities, resources and actors (see: Ford, Gadde, Håkansson, Snehota, & Waluszewski, 2008). These dimensions can become interdependent in space ranging from pooled interdependency, sequential interdependency to reciprocal interdependency (Thompson, 2003) and move towards a specific direction over time (Ford et al., 2008). Boundaries and compositions are the second constituent of business ecosystems and can be considered the structural organization of a business ecosystem. According to Vargo et al. (2017), this structural organization is the representation of underlying processes meaning that is a concept analyzed on the firm level. Boundaries and compositions can be analyzed in terms of boundary setting (Gadde, 2014), organizational coupling (Brusoni & Prencipe, 2013), and modularity (Tsvetkova & Gustafsson, 2012). The relation between co-evolutionary logic and boundaries and compositions can be interpreted in the sense that the latter are outcomes of strategizing at the firm-level as a response to system-level developments in the former. This is connected to industry 4.0 in a way that co-evolutionary logic is affected by industry 4.0 and consequently, firms adapt their ecosystem structure-related processes accordingly. In other words, industry 4.0 might influence an ecosystem's co-evolutionary logic by altering the perspective on interrelations in the system leading to alternative in strategizing outcomes at the firm level.

Based on previously discussed literature, it appears that industry 4.0 is important to study in a manufacturing setting and is characterized by end-to-end digital integration. The latter includes collaboration and integration of processes and machines across firm boundaries. However, industry 4.0 related literature does not provide thorough knowledge regarding this end-to-end digital integration. It especially lacks insights from an inter-firm collaboration perspective including its developments relative to other production settings (i.e., industry 2.0 and 3.0). Some works, like the research of Brettel, Friederichsen, Keller, and Rosenberg (2014) come close but do not fully cover the topic at hand. They discuss end-to-end digital integration only from a technical perspective. To gain deeper understanding regarding inter-firm collaborations in an industry 4.0 setting, strategizing and ecosystems are promising concepts. Together, these concepts offer insights in developments of inter-firm collaborations on the system level (i.e., ecosystems) and how this affects processes on the firm level (i.e., strategizing). There are scientific papers that discuss strategizing on a system level but do only limited or failed to recognize a manufacturing context. An example is the work of Christopher (2000), who only focused on firm boundary setting and partly on organizational coupling. Besides, Rong, Hu, Lin, Shi, and Guo (2015) developed a 6C framework for assessing business ecosystems in an Internet of Things context. Even though they discussed dimensions that come close to the co-evolutionary logic and boundaries and compositions dimensions of Aarikka-Stenroos & Ritala (2017), they didn't apply it in a manufacturing setting. All in all, it leads to the conclusion that inter-firm collaboration in an industry 4.0 context is underexposed in the literature. This underexposure can be decreased by investigating business ecosystem developments and reactions of firms in terms of strategizing. Hence, the aim of this research is to explore the transformation of business ecosystems, in terms of co-evolutionary and its resulting strategizing outcome (i.e., boundaries and compositions), from older production settings to an industry 4.0 setting. This is reflected in the following research question:

"How do business ecosystems in terms of co-evolutionary logic and resulting strategizing, represented by boundaries and compositions, transform from older production settings to an industry 4.0 setting?"

This research question is visualized in figure 2, this representation is an extended version of figure 1 in which production setting transformation towards industry 4.0 and its possible effect on co-evolutionary logic and boundaries and compositions is added.

Figure 2. Transformation of co-evolutionary logic and boundaries and compositions to an industry 4.0 production setting



This research adopts a system perspective on markets that acknowledges the whole system and dynamics contrasting the mechanistic view of neoclassical economics (Vargo et al., 2017). This answers the call of Huemer (2017) and Vargo et al. (2017) who respectively claim that business environments should be considered from a multi-dimensional perspective and that system thinking increases rigor and relevance of future research. To adopt system thinking, this research uses the business ecosystem concept as an extended layer on top of business networks as indicated by Aarikka-Stenroos and Ritala (2017). This is done by adopting the *ecosystem-as-structure* approach of Adner (2016) which contrasts the *ecosystem-as-affiliation* approach. Consequently, business ecosystems concentrate around a value proposition rather than a keystone species and are activity centric instead of actor centric. Additionally, business ecosystems are approached through the "*stable business exchange*" lens of Aarikka-Stenroos and Ritala (2017). This is done because this lens focuses on the alignment structure and takes existing relationships and structures into account. The latter is important to consider because the research question aims to understand ecosystem developments from older production settings to industry 4.0. Within this category of Aarikka-Stenroos and Ritala (2017), business ecosystems are considered in terms of co-evolutionary logic (i.e., interrelations of ecosystem actors) and boundaries and compositions (i.e., structural organization of the ecosystem). The former dimension, interrelations, are considered on the detail level of activities, resources and actors using the ARA model of Ford et al. (2008). Finally, structural organizations are considered representations of underlying processes. Strategizing is considered the basis of these processes meaning that individual firms can influence the structural organization of their business ecosystem(s) in which they operate. To understand how influence is exerted, the research question implies a transformation view on business ecosystems meaning that they are in constant flux.

The research aims to present empirical evidence of industry 4.0 induced developments regarding co-evolutionary logic and how firms cope with these developments in terms of structural organization of the ecosystem. To realize this aim and answer the research question, a qualitative study design was adopted. To be more specific, a single case study was used because it enables the creation of a "thick description". This means that the research draws large conclusions from small but textured facts (Tracy, 2013). A thick description is important because the research does not only aim to understand how co-evolutionary logic and structural organizations of business ecosystems change. This research also aims to understand why these changes are observed, this makes it essential to understand the context of these changes. Within the case study, the research moves back and forth between the empirical context and the theory. In this sense, it uses an abductive research design as discussed by Dubois and Gadde (2002). Analysis started with an initial literature basis that developed when qualitative data emerged. An abductive research design was chosen because there is limited empirical research of business ecosystems in an industry 4.0 setting. However, there is a substantial literature body on business ecosystems outside this setting. Therefore, it is sensible to use this literature body as a starting point and let it gradually develop into an industry 4.0 setting. A business ecosystem in the manufacturing industry that revolves around the industrial automation value proposition was chosen as the case study context. This context was chosen because the author had the rare opportunity to get access to a varied set of ecosystem actors and the choice for this context is therefore based on the "revelatory case" rationale of Yin (2011). Within this context, data was collected by both archival data and in-depth interview data. These types of data are connected because the former complement the latter. Archival background information was used during the in-depth interviews to maximize participant output.

Theoretical contributions of this study are twofold and include the development of a theoretical lens to look at business ecosystems. Besides, this study contributes to the understanding of ecosystem development in an industry 4.0 setting. Regarding the former, this study operationalized the stable business exchange category of Aarikka-Stenroos and Ritala (2017). This is done through the concepts of firm boundary setting, organizational coupling and modularity. During this operationalization, it appeared that it is important to adopt a dynamic view on business ecosystems. Especially because business ecosystems gradually evolve into a new production context (i.e., industry 4.0) so that existing relationships and structures cannot be neglected. To theoretically contribute to our understanding of business ecosystems in an industry 4.0 context, this study observed an additional archetype for firm boundary setting next to the integrated hierarchy and the connected company archetype of Gadde (2014). Next to that, the discussion on organizational coupling and modularity is fueled by stressing the importance of recognizing intermediary platforms. Next to theoretical contributions, this research also provides insights for managerial decision making.

Results of this study inform managers how they can react on the firm level to industry 4.0 induced system level developments. To be more precise, managers can respond by means of boundary setting, organizational coupling and modularity. Next to providing understanding about how and why actors should act, results also indicate that managers need be bold and ready to take drastic actions to thrive in an industry 4.0 oriented manufacturing industry.

The remainder of this thesis is structured as follows. In the next section, the theoretical framework of this research is developed and presented. Then, the methodology to answer the research question is discussed. After this discussion, the results of the industrial automation case study are presented, and the research question is answered. The final part discusses the results, suggests possible directions for further research, outlines theoretical and practical contributions of this research and highlights the limitations of this study. First, the theoretical framework is discussed in the next chapter.

2. Literature review

2.1. From business networks to business ecosystems

In 1989, Håkansson and Snehota stated in their seminal work that "no business is an island" meaning that firms operate in networks which determine the distinctive capability and strategic fit of a firm. For years, the concept of business networks played a major role in the IMP literature but recently the concept of business ecosystems found traction as an extra layer that covers a broader societal system environment in which business networks are embedded (Aarikka-Stenroos & Ritala, 2017). The difference between business networks and business ecosystems refers to the reach of stakeholders that are acknowledged. Business networks often include more direct key relations like suppliers, customers and end-users (e.g., Lacoste, 2016), whereas ecosystems include more distant stakeholders like activist groups and competitors (Frow, McColl-Kennedy, & Payne, 2016). Still, this difference is not undisputed. In the work of Aarikka-Stenroos, Sandberg, and Lehtimäki (2014) for example, business networks include more distant stakeholders like governmental institutions, NGOs and complementors. However, the following definition of business networks from Ford and Mouzas (2013) illustrates the difference between business networks and ecosystems. Business networks are "*the conscious problem-driven attempts of one or more business actors to change or develop some aspect(s) of the substance of interaction in relationships in which they and other are involved*" (p. 436). Because this definition includes a conscious problem-driven connection between stakeholders, scope of business networks is limited to stakeholders that are consciously connected with each other. This means that business network boundaries are determined by network horizons of actors which refer to an actor's conscious view of its network (Anderson, Hakansson, & Johanson, 1994). Relative to this understanding of business networks, the ecosystem concept adds value by acknowledging more distant shareholders like competitors and complementors (Frow et al., 2016). This is considered interesting because firms, operating in the industry 4.0 context, need to integrate processes and cooperate across firm and industry boundaries. Therefore, they must consider more distant stakeholders. More so because ecosystems enables inclusion of partners that span value chains, business networks and industry boundaries (Aarikka-Stenroos & Ritala, 2017). Moreover, business ecosystems are considered an interesting alternative to business networks because it examines management that spans across value chains, business networks and industries (Aarikka-Stenroos & Ritala, 2017). Especially because firms, operating in the industry 4.0 context, need to integrate processes and cooperate across firm and industry boundaries they must consider more distant stakeholders.

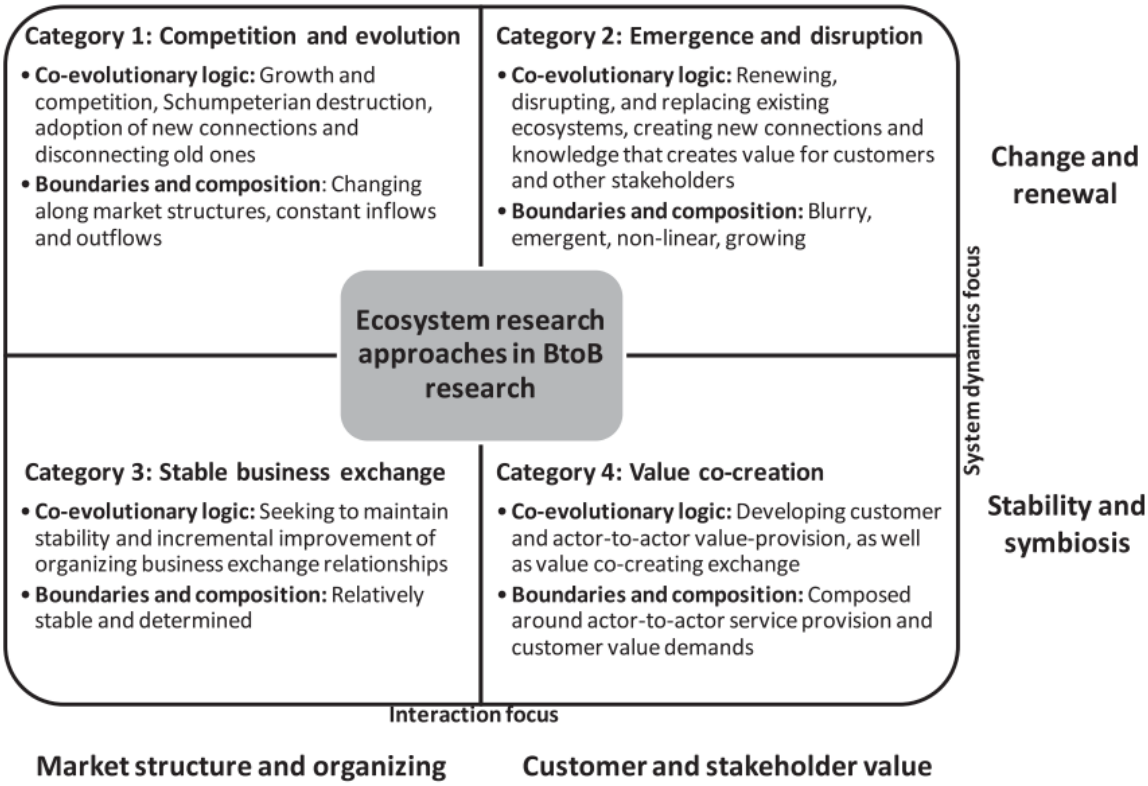
2.2. Business ecosystems

The term "*business ecosystem*" was first introduced in the seminal paper of Moore (1993). He viewed business environments from an ecological perspective where different entities form one system and rely on each other to survive; they have a shared fate. The business ecosystem of Moore (1993) increased understanding regarding strategizing in the sense that business ecosystems include business from various industries, firms co-evolve around innovations and face four different ecosystem lifecycles (i.e., birth, expansion, leadership and self-renewal or death). Every life cycle has different implications for the scope of managerial actions (i.e., strategizing). Iansiti and Levien (2004) add to this understanding by presenting three critical elements which ensure business ecosystem performance. These include that ecosystems must be able to 1) transform inputs (i.e., technologies and materials) into valuable outputs, 2) render long-term benefits to its member firms and be able to adapt to a continuous changing environment and 3) create niches which ensure variety. The final seminal paper that adds to the basic understanding of business ecosystems is the work of Adner (2006). His work is based on innovation ecosystems which are implicitly considered important by both Moore (1993) and Iansiti and Levien (2004). Because they respectively state that a business ecosystem should be able to renew itself and cope with an ever-changing external environment, they imply the importance of innovation within an ecosystem. Adner (2006) presents three risks that firms face and should deal with within an ecosystem. These risks are: *initiative risk* - the risk that a focal firm accomplishes its own targets and project goals, *interdependence risk* - the risk that suppliers and complementors within a system accomplish their targets and the system project goals and *integration risk* - the risk that every actor in the chain between a focal firm and the end-user adopts a specific solution. All these risks require substantial managerial actions that deal with them and therefore have an impact on the process of strategizing. Together, these three papers give a basic understanding of the business ecosystem concept and its important dimensions.

Over the years, the concept of business ecosystems faced increasing traction and it evolved in the literature. This evolution led to the identification of two different streams within the literature, these were labeled by Adner (2016) as the "*ecosystem-as-affiliation approach*" and "*ecosystem-as-structure approach*". The former approach stems from the work of Moore (1993) and Iansiti and Levien (2004) and can be considered actor-centric. The ecosystem-as-affiliation approach has a macro perspective on business ecosystems which means that it concentrates analysis on the network level and focuses on topics like inclusion, network density and network externalities. This approach might be well suited to increase understanding of strategic ecosystem policies that are deployed by keystone species to organize the ecosystem. However, it does not reveal patterns on the micro level referring to the interaction between ecosystem partners that is necessary to create value. The ecosystem-as-structure approach is activity-based rather than actor-based meaning that it starts from the value proposition and its necessary activities. Next, it considers all relevant actors needed to execute the necessary activities to materialize a value proposition. Because this research tends to gain understanding on the scope of action of firms within business ecosystems, the activity focused ecosystem-as-structure approach of Adner (2016) is considered most relevant. Within this approach the business ecosystem concept is defined as "*the alignment structure of the multilateral set of partners that need to interact in order for a focal value proposition to materialize*" (Adner, 2016 p. 40). This definition has various implications for the understanding of the business ecosystem concept. First, business ecosystems have an alignment structure existing of mutual agreed upon actor positions and activity flows between them. Second, business ecosystems exist of multilateral connections that cannot be broken down into individual dyadic relationships. Third, business ecosystems exist of a "set of partners" implying that these partners have a shared fate and have joint goal of value creation. Finally, business ecosystems are focused on materializing a value proposition meaning that they are organized around value creation activities.

This understanding of ecosystems is complemented by the work of Aarikka-Stenroos and Ritala (2017) by dividing ecosystem literature in four categories. To categorize literature, they introduced two constituents: *co-evolutionary logic* and *boundaries and compositions*. The co-evolutionary logic of an ecosystem refers to the interrelationships between actors in terms of co-specialization and interdependency. Next to that, boundaries and compositions refer to the structural organization of an ecosystem. Based on these constituents, four categories were established clustered by interaction focus system dynamics. The former discriminates between market structure and organizing whereas the latter includes change and renewal and stability and symbiosis. An overview of these four categories can be found in figure 3.

Figure 3. Four ecosystem approaches in B2B literature *(Aarikka-Stenroos & Ritala 2017)*



This research uses an ecosystem approach as described in the third category. This category implies that ecosystems stay stable over time and that interaction between actors focuses structural organization of markets and ecosystem stability. The former fits with the ecosystem-as-structure approach because it focuses on the alignment structure (i.e., ecosystem structure) as well. Besides, considering system dynamics as stable and symbiotic fits with the focus of this study on gradual developments from previous production settings to industry 4.0. This focus on gradual developments implies a certain degree of stability where existing relations and structures cannot be neglected. Moreover, these existing relations and structures gradually adapt to industry 4.0. The other categories were not chosen because they do not resonate with the aims of this research. First, category one considers ecosystem to revolve around dominant players (i.e., ecosystem leaders) whereas this study acknowledges value proposition as the gravitational center of an ecosystem. Second, category two focuses solely on a macro level which does not stroke with the micro level actions of individual actors that are ought to be understood. Finally, the fourth category only focuses on interaction regarding value co-creation whereas this study uses the value proposition only to determine the boundaries of a business ecosystem. This category puts too little emphasis on the structure and alignment of ecosystem actors. Within the "stable business exchange" category of Aarikka-Stenroos and Ritala (2017), co-evolutionary logic and boundaries and compositions of ecosystems are analyzed. Besides, their interrelations are analyzed as well.

Since structures are the representation of underlying processes (Vargo et al., 2017), boundaries and compositions are considered structural representations of underlying processes (i.e., strategizing). Besides, these structural representations are considered strategizing reactions of managers to developments in the co-evolutionary logic of a business ecosystem. This stems from the rejection of the statement of Murmann (2013), that firms can influence co-evolution of their business ecosystem implying that this is considered as a given in this research. However, managers can react to developments in the co-evolutionary logic by influencing business ecosystem structures through strategizing because they are representations of underlying processes according to Vargo et al. (2017). This leads to the conceptual model as presented in figure 2.

The next sections add to the preliminary conceptual model by discussing the co-evolutionary logic and boundaries and compositions and their respective conceptualizations. This should give a more holistic and detailed understanding of the co-evolutionary logic and boundaries and compositions concepts and increase the detail of investigation.

2.3. Co-evolutionary logic

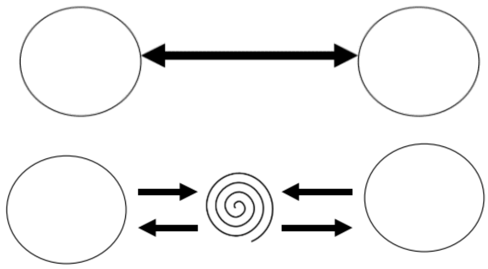
The concept of co-evolution stems from biology and claims that species adapt to their environment as well as to each other (Hackney, Burn, & Salazar, 2004). Therefore, co-evolution is defined as "*the successive changes among two or more ecologically interdependent but unique species, such that their evolutionary trajectories become intertwined over time*" (Hackney et al., 2004 p. 94). In the context of ecosystems, this means that two or more actors are interdependent through a common value proposition and share development paths over time. Co-evolution occurs through interaction and knowledge sharing that leads to the development of new competencies as a response to environmental changes (G. Liu & Rong, 2015). Besides that, co-evolution is inherently connected to business ecosystems due to the ecological perspective of business ecosystems on the business environment. Moreover, it was also mentioned in the initial business ecosystem definitions of both Moore (1993) and (Iansiti & Levien, 2004). For clarification, Murmann (2013) identified the difference between evolution and co-evolution including a reciprocal character of relations between environment and an evolving entity in case of co-evolution. Evolution is characterized by a one-way relationship (from environment to entity). This reciprocal relation between environment and entity in case of co-evolution implies that entities within specific industries can shape their environment to a certain extent. However, in the context of this research that view is not adopted since it investigates strategizing reactions of individual firms. It is assumed that individual actors in manufacturing industries, which are the focus of this research, do not hold enough power to direct the development or co-evolution of the overall industry 4.0 phenomenon. This also implies that individual firms cannot influence or alter co-evolutionary logic of their business ecosystem and that co-evolutionary logic is considered an external given. Because co-evolution refers to adaption of ecosystem actors relative to their environment as well to each other, actors face both interdependence and co-specialization. Interdependence considers how actors are mutually tied to each other. This dimension was mentioned in the co-evolution definition of Hackney et al. (2004) and gives understanding how dependence of unique species in a business ecosystem on complementary partner offers. Co-specialization aims to understand how individual ecosystem actors co-develop over time with other ecosystem actors share their development paths. Within the co-evolution definition, co-specialization concerns the *evolutionary trajectories of unique species* and the process of them *becoming intertwined over time*.

The concepts of co-specialization and interdependence complement each other and together offer holistic understanding regarding co-evolutionary logic. However, to investigate co-specialization and interdependence of firms in business ecosystems, a more detailed framework of the interpretation of organizations is presented. Firms that operate in business ecosystems engage in interaction which involves and affects people and things (Ford, Gadde, Håkansson, Snehota, & Waluszewski, 2008). Therefore, organizations are considered in terms of activities, resources and actors, this is represented in the ARA model of Ford et al. (2008).

2.3.1. ARA model

The ARA model is built on the perception that interaction is a process which occurs between companies and affects human and material assets located inside these companies. Besides, interaction is considered the main activity of a business through which it combines activities and resources with those of other companies. This differs from the traditional economic thinking that interaction is not a simple mechanism including independent actors that are free from friction. Within the IMP view, interaction always affects the people and things involved (Ford et al., 2008). The difference of perspective regarding interaction between traditional economic thinking and the IMP school is visualized in figure 4. The first illustration visualizes the invisible hand where exchange is considered a mechanism and exchange does not have content of its own, often referred to as market mechanism. The second illustration represents exchange that has content and develops over time. The spiral in the middle represents the process of interaction and arrows to the actors represent interpretations about what is received. Finally, arrows from the actors to the exchange represent approaches towards interaction (e.g., attitude, delivery of quality or lack of quality). This means that interaction is cumulated by previous gains and contributions which influence future gains and contributions. In other words, interaction is a time-spanning process that is influenced by former episodes rather than a phenomenon that occurs only once and on a transactional basis. The former represents the IMP view whereas the latter refers to traditional economic thinking regarding interaction.

Figure 4. Exchange vs. Interaction *(Ford et al. 2008)*



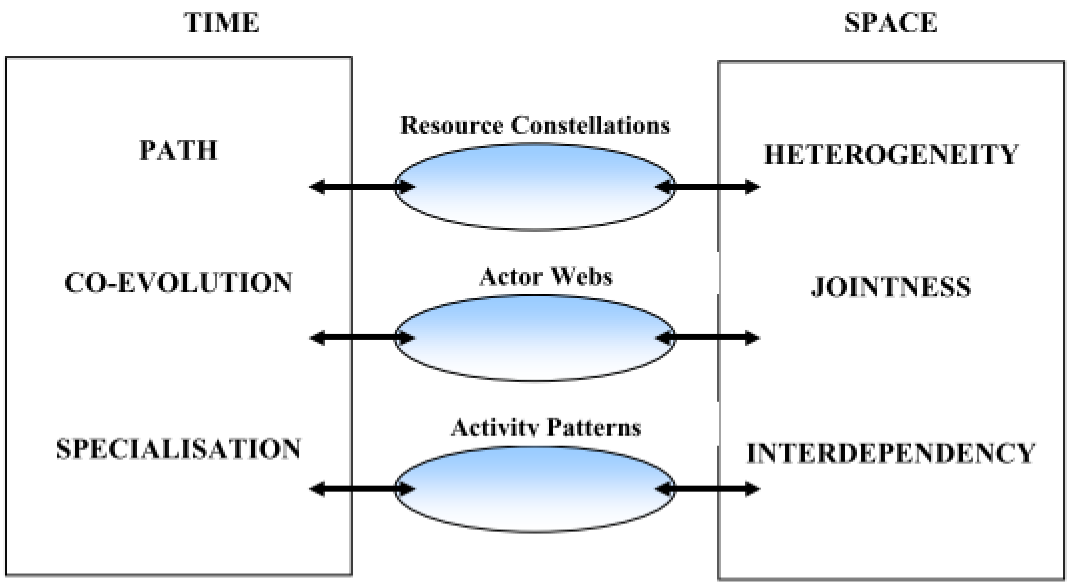
Content and outcomes of business interactions can be ascribed to three different layers that are inter-connected:

1. ***Activities*** like production, logistics, administration or information handling may be integrated. In this sense activities of companies may be more or less tightly linked to each other.
2. ***Resources*** could become adapted to each other and therefore mutually tied. This may concern tangible resources like machines but also intangible resources such as intellectual property and knowledge are recognized. The adaption of resources may lead to usage efficiency but also to new systematic combination of resources (i.e., innovations)

3. ***Actors*** incorporate interpersonal links that develop between individuals and companies. It incorporates the degree of trust, commitment and influence actors have each other and therefore form each other.

These three layers are considered to have specific locations in time and space. Time dimension assumes that a relation between two actors consists of multiple interaction episodes. Individual episodes are influenced by experiences from previous interactions and expectations from future interactions. Space dimension widens the view on interaction from a dyadic phenomenon to a network or system phenomenon. Accordingly, interactions between two actors (over time) not only influence interactions of these specific actors but they also influence interactions of these specific firms with other actors in their network. Conequently, actors can move in space over time so that they face tighter linkages with certain actors whereas they might face looser linkages with others. In this sense, firms face multilaterism meaning that interaction in a dyadic relation also affects interaction outside this dyadic relation. Therefore, analysis should focus on a system level rather than on the dyadic level. When the three layers, space dimensions and time dimension are combined, it results in the following outcomes which are visualized in figure 5.

Figure 5. ARA framework, a descriptive model of interaction ***(Ford et al., 2008)***



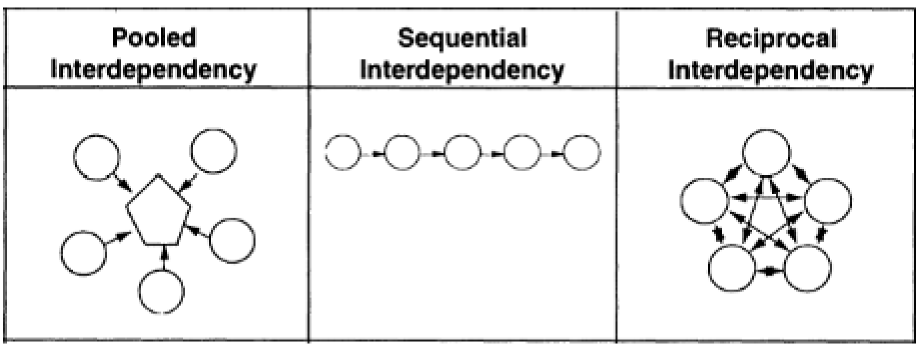
Because the ARA model recognizes firm interdependency and the involvement of people and things that develop in space and time, it resonates with the concept of co-evolution and the definition of Hackney et al. (2004). Therefore, the ARA model is considered appropriate as a conceptual tool that allows a more detailed analysis of co-evolution in terms of activities, resources and actors. Both co-evolutionary logic and the ARA model imply a temporal and spatial dimension (Aarikka-Stenroos & Ritala, 2017). Therefore, this separation is also made in this research, meaning that co-specialization relates with the time dimension of the ARA model whereas interdependence relates to the space dimension. The ARA model and its separation between time and space is used to holistically explain developments of co-evolutionary logic in an industry 4.0 production setting. Besides, it allows analysis of co-evolutionary logic on a more detailed level (i.e., level of activities, resources and actors rather than organizations). The next sections present a more detailed understanding of the interdependency and co-specialization concepts including their respective references to the ARA model.

2.3.2. Interdependence

Interdependence refers to the availability of other ecosystem partners to materialize a collective value proposition. It stems from both tangible technical sources (Adner & Kapoor, 2010) as well as social grounds, trust and commitment (Pulkka, Ristimäki, Rajakallio, & Junnila, 2016). However, these sources cannot be considered in isolation because they are inherently connected. Technical interdependence (e.g., alignment of machines and processes) may lead to the need to build trust and commitment. The other way around, trust and commitment may enable alignment of machines and processes. To explain the concept of interdependence, the framework of Thompson (2003) is used. He discriminated between three different forms of interdependence: pooled, sequential and reciprocal interdependence. These are now discussed and visualized in figure 6.

- ***Pooled interdependence*** refers to a situation characterized without direct interdependence. However, because entities within a system are connected through an overarching system (e.g., business ecosystem), they face interdependence. All entities collectively ensure the vitality of the overall system and if the overall system functions well, the individual parts do so too.
- ***Sequential interdependence*** includes a direct but asymmetric interdependence where entities depend on the actions of their upstream suppliers to be executed before they can execute their actions. However, this interdependence does not hold for upstream suppliers relative to their downstream customers.
- ***Reciprocal interdependence*** is the final form of interdependency where the output of one entity serves as input of all the other entities in the system. This can be considered both a direct and symmetric form of dependency.

Figure 6. Forms of interdependence according to Thompson (2003).
(Kumar & van Dissel, 1996)



The takeaway of this interdependence framework of Thompson (2003) is that business ecosystems can face different forms of interdependence. In this case, closer forms of interdependence (i.e., sequential and reciprocal) could lead to more harm inflicted among partners (Kumar & Van Dissel, 1996). This is observed because underperforming of single actors which are pooled interdependent has less negative impact on other actors compared to situation where actors are reciprocally interdependent. Therefore, closer forms of interdependence also lead to more complexity in communication and coordination. This framework is used to give a more detailed understanding of the nature of interdependence between business ecosystem partners in a manufacturing setting.

The concept of interdependence resonates with the space dimension of the ARA model. First, activities become more interdependent because they become increasingly distributed across the business landscape. Due to this increased distribution, a focal firm's dependence on external partners increases. The second layer of the ARA model concerns resources and in the spatial dimension, this involves the heterogeneity of resources. Because resources are heterogeneous meaning that they have different values in different contexts (Ford et al., 2008), firms face interdependence. This is because they seek an optimal constellation of resources to maximize exploitation of resource heterogeneity. To maximize exploitation, firms are dependent on external partners. Finally, actors face jointness within their ecosystem meaning that their actions cannot be isolated since it is inherently connected to its network or ecosystem (Ford et al., 2008). This concept of jointness also questions the meaningfulness of analyzing a single business or a single action and indicates that analysis should be executed on the system level as indicated by Vargo et al. (2017).

2.3.3. Co-specialization

Co-specialization refers to the specialization of individual actors in a business ecosystem on specific resources and capabilities over time resulting in increasing complementarities among ecosystem partners (Hienerth, Lettl, & Keinz, 2014; Pulkka et al., 2016). In other words, business ecosystem partners rely on increasing synergies over time for value creation. Co-specialization stems from the increasing need for heterogeneous and particular inputs for value creation (Normann & Ramírez, 1993). Something that can be observed in the industry 4.0 context due to its character of and increased complexity and crossing manufacturing industry boundaries. An example of co-specialization is presented by Hienerth et al. (2014). It illustrates that the synergetic and specialized cooperation of potential entrepreneurs, manufacturers and fan community in the context the LEGO ecosystem created more value over time than a situation without cooperation between these complementing entities. In this sense LEGO provides a platform for communication as well as resources and brand transfer. Potential entrepreneurs of new LEGO businesses contributed in terms of introducing new business ideas and commercializing them. Finally, the LEGO community acted as a source for new designs and content together with providing feedback of new business ideas. Together, these contributions synergized and drove value creation in the LEGO ecosystem by being locally adaptive, flexible in meeting customer demand but simultaneously use their world-spanning brand recognition.

Due to its temporal orientation, co-specialization can be connected to the time dimension of the ARA model. The first organizational layer that is analyzed in the context of co-specialization is activities. These adapt relative to others to reduce costs in daily business (Ford et al., 2008). Even though, reducing costs might be an important driver for co-specialization, it can also lead to increased speed and quality. These are also important to consider because industry 4.0 aims to realize increased speed and quality (Kagermann et al., 2013). Co-specialization does not only refer to activities but resources as well. Over time, resources adapt to each other to increase synergies created by the resources constellation (i.e., a combination of resources) so that a path can be observed (Ford et al., 2008). Within an industry 4.0 manufacturing setting, this can refer to resources like machines, software, technologies or data that are modified to solve relation specific problems and therefore follow identifiable paths. Finally, firms within an ecosystem face co-specialization on the actor layer meaning that actors within firms relate their problems to those of other actors within the business ecosystem. It also includes that actors of different ecosystem partners grow closer to each other and can build inter-organizational trust. These three layers are not independent because when actors grow closer to each other and build trust, this may enable them to align firm-specific resources resulting in mutually adjusted and specialized activities.

Still, interdependence and co-specialization are complementary in creating an understanding of co-evolutionary logic. Interdependence aims to deliver a static and general system level understanding mutual ties within the business ecosystem. Additionally, co-specialization aims to develop understanding of the dynamic development of these mutual ties. Together, these concepts give a complete picture regarding interrelations between ecosystem. Altogether, co-evolutionary logic in terms of interdependence and co-specialization is used to analyze interrelations of business ecosystem partners on the activity, resource and actor level. By analyzing the levels of individual ARA layers, it not only leads to more detailed results, it can also reveal interrelations between these different layers.

2.4. Boundaries and Compositions

Boundaries and compositions are the second constituent of business ecosystems and refer to the structural organization. Boundaries and compositions can be considered strategizing outcomes as response to developments in the co-evolutionary logic of a business ecosystem. Aarikka-Stenroos and Ritala (2017) use the concept of boundaries and compositions to refer to the contextual breadth of a business ecosystem as well as its structural organizations. Within this research, structural organization is focused on because it is assumed that contextual breadth cannot be influenced by individual ecosystem actors and therefore not relevant for this investigation. Because the view of Murmann (2013), consisting of the idea that firms in business ecosystems can direct their external environment, was rejected earlier, contextual breadth cannot be considered an outcome of the strategizing process of an individual firm. On the contrary, because structural organizations of business ecosystems are considered outcomes of underlying processes (Vargo et al., 2017), these can be considered outcomes of the strategizing process and are an interesting subject for investigation. As stated before, co-evolutionary logic is considered an external given for individual firms and can therefore not be influenced in the course of this research. However, individual firms can respond to changes in the co-evolutionary logic through strategizing which may result in alternative ecosystem organizations. In other words, the structural organization of business ecosystems are considered strategizing outcomes as response to developments in the co-evolutionary logic of a business ecosystem. Therefore, boundaries and compositions are considered outcomes of strategizing in response to developments in the co-evolutionary logic of business ecosystems. To give a more detailed understanding of the underlying processes regarding the structural organization of business ecosystem, three dimensions are considered. These are boundary setting, organizational coupling and modularity. Even though individual firms are assumed not to be able to influence the co-evolutionary logic business ecosystems, firms can react on the micro level through strategizing. These three dimensions are considered relevant in reacting to developments in the co-evolutionary logic, these are discussed more in-depth in the next sections.

2.4.1. Boundary setting

The first structural dimension that results from the strategizing process considered in this study is boundary setting. Firm boundary setting is a process that refers to the "*determination of what is inside the company in terms of operations and capabilities and sets conditions for the division of labor in relation to other firms*" (Gadde, 2014 p. 51). Boundary setting is considered an important strategizing endeavor because it is not only critical for efficiency and effectiveness of individual firms, but for larger systems like business ecosystems as well (Pisano & Shih, 2009). Firm boundaries can be considered in terms of broad and narrow which respectively refer to many operation and capabilities located inside the firm and few operations and capabilities located inside the firm (Gadde, 2014).

The roots of boundary setting lie within the transaction cost economics (TCE) which recognizes market-based and hierarchy-based coordination mechanisms (i.e., narrow and broad ownership boundaries). TCE is extensively discussed by Douma and Schreuder (2012). Based on the bounded rationality and opportunistic behavior assumptions, TCE recognizes three coordination mechanisms: markets (i.e., contracts), hybrid forms (i.e., joint-ventures or partnerships) and hierarchies (i.e., organizations). These coordination mechanisms can be associated with firm boundaries and range from narrow to broad. The most appropriate coordination mechanism is determined by the lowest transaction costs which depends on asset specificity, transaction uncertainty and complexity and frequency of transactions. Even though TCE is considered an important theory that explains organizational boundary setting, it focuses mainly on firm boundaries that are based on ownership neglecting activities and resources outside these ownership boundaries. It also assumes that firms have full control over their in-house owned resources and activities whereas they cannot exert influence over those outside the firm. However, from the ARA model of Ford et al. (2008) it appears that activities, resources and actors affect each other. This means firms can indirectly influence activities and resources across firm ownership boundaries. Still, firms also need to be aware that their activities and resources are subject to outside influence. Therefore, TCE and ownership boundaries are considered relevant but insufficient to understand the concept of boundary setting.

To complement ownership boundaries derived from TCE, Dubois (1998) identified two additional concepts of boundary setting: *awareness boundaries* and *influence boundaries*. Awareness boundaries refer to a firm's knowledge regarding resources and activities of other firms in its network. Influence boundaries refer to boundaries that indicate where a firm can influence ARA layers. This does not only occur within ownership boundaries but at other firms in networks as well, therefore it complements ownership boundaries. Based on this understanding of firm boundary setting, Gadde (2014) introduced two archetypes of boundary setting principles: *integrated hierarchy* and *connected company*. Using multiple case studies, he found that integrated hierarchies are characterized by broad ownership boundaries but narrow awareness and influence boundaries. This archetype was mainly adopted in the period of mass-production when organization tried to insource as many activities and resources as possible and tried to coordinate them through hierarchies resulting in vertical integrated firms. A famous example of such an integrated hierarchy is car manufacturer Ford which insourced many activities and resources to mitigate co-innovation risks and ensure activity alignment (Gadde, 2014). The second archetype, connected company, is characterized by narrow ownership boundaries but broad awareness and influence boundaries. This was found to be a strategizing reaction to the increasing knowledge base required to materialize a value proposition and increasing specialization. Because the complete knowledge base cannot be located at a single organization, the connected firm relies more on external partners and therefore needs strong resource and activity interfaces (Gadde, 2014).

The strategizing concept of boundary setting is linked to the co-evolutionary logic of a business ecosystem. Interdependence across organizations in terms of activities, resources and actors could lead to the observation of more integrated hierarchies as well as more interconnected firms. When firms face increasing interdependencies, they might react by establishing stronger resource and activity interfaces meaning that they must widen awareness and influence boundaries. However, increasing interdependence may also lead to broader ownership boundaries implying a shift towards vertically integrated organizations. This should be considered together with developments of ARA ties over time (i.e., co-specialization). An increase in synergies among ecosystem partners over time may lead firms to broaden both their awareness and influence boundaries whereas ownership boundaries may be narrowed.

This discussion provides a clear lens to analyze organizational boundary setting as a strategizing process in the empirical world. The next section builds and provides such a lens for organizational coupling.

2.4.2. Organizational coupling

The second dimension of the boundary and composition constituent is organizational coupling. Organizational coupling is about the trade-off between organizational distinctiveness and responsiveness (Brusoni & Prencipe, 2013). According to Orton and Weick (1990), coupling refers to the strength and intensity of actors within a network in terms of distinctiveness and responsiveness. The former relates to retaining one's own identity whereas the latter refers to the degree of consistency with the system. Organizational coupling is the relation between two actors that varies in strength and intensity along a continuum between organizational decoupling and tight coupling (Beekun & Glick, 2001). To give a more detailed understanding of inter-firm relations through the organizational coupling concept, four dimensions of Beekun and Glick (2001) are used. They state that inter-firm coupling exists of strength, directness, consistency and dependence. Strength is described in terms of frequency, intensity, probably and negligibly (i.e., significance) of interaction between network partners. Directness is determined by the number of actors through which parties communicate with each other. Consistency is about the reaction of coupled organizations to similar external stimuli; diverse reactions represent flexibility and therefore looseness in coupled systems. Finally, dependence is based on the magnitude of the exchange and the lack of substitutes for the exchange.

Literature suggests that loose coupling is desired when firms desire economies of scope, strategic flexibility (Lei, Hitt, & Goldhar, 1996) and adaptive capacity (Staber & Sydow, 2002). This need for economies of scope and strategic flexibility is driven by fragmentation of markets, new market segments and niches, increased flexibility and faster time-to-market (Lei et al., 1996). Adaptive capacity is relevant for firms that must cope with environmental complexity (i.e., problem structure is clear, but solution is unclear) because it is expected to increase variation in skills and competencies within a business network (Staber & Sydow, 2002). However, tight organizational coupling might be more desirable when the environment is ambiguous (i.e., dimensions are unclear ex ante) rather than complex (Brusoni & Prencipe, 2013). Next to that, organizations facing the initiation stage of a dynamic network might face tight coupling due to more frequent and direct interaction (Beekun & Glick, 2001). The observations of Beekun and Glick (2001), Lei et al. (1996) and Staber and Sydow (2002) regarding the occurrence of different forms of organizational coupling implies a connection with co-evolutionary logic. Fragmentation of markets and the increase of skills and competencies that need to be adapted to each other can be linked to co-specialization. Next to that, more frequent and direct interaction might be linked to interdependence between ecosystem partners. Because the organizational coupling concept consists of various dimensions (i.e., strength, directness, consistency and dependence), it gives a multi-faceted understanding of links between actors in business ecosystems. Therefore, organizational coupling and its dimensions are used to analyze inter-firm relations within industry 4.0 oriented business ecosystems. Organizational coupling is analyzed on a continuum between tight coupling and decoupling. The next section provides a more comprehensive understanding of the final structural dimension of business ecosystems: modularity.

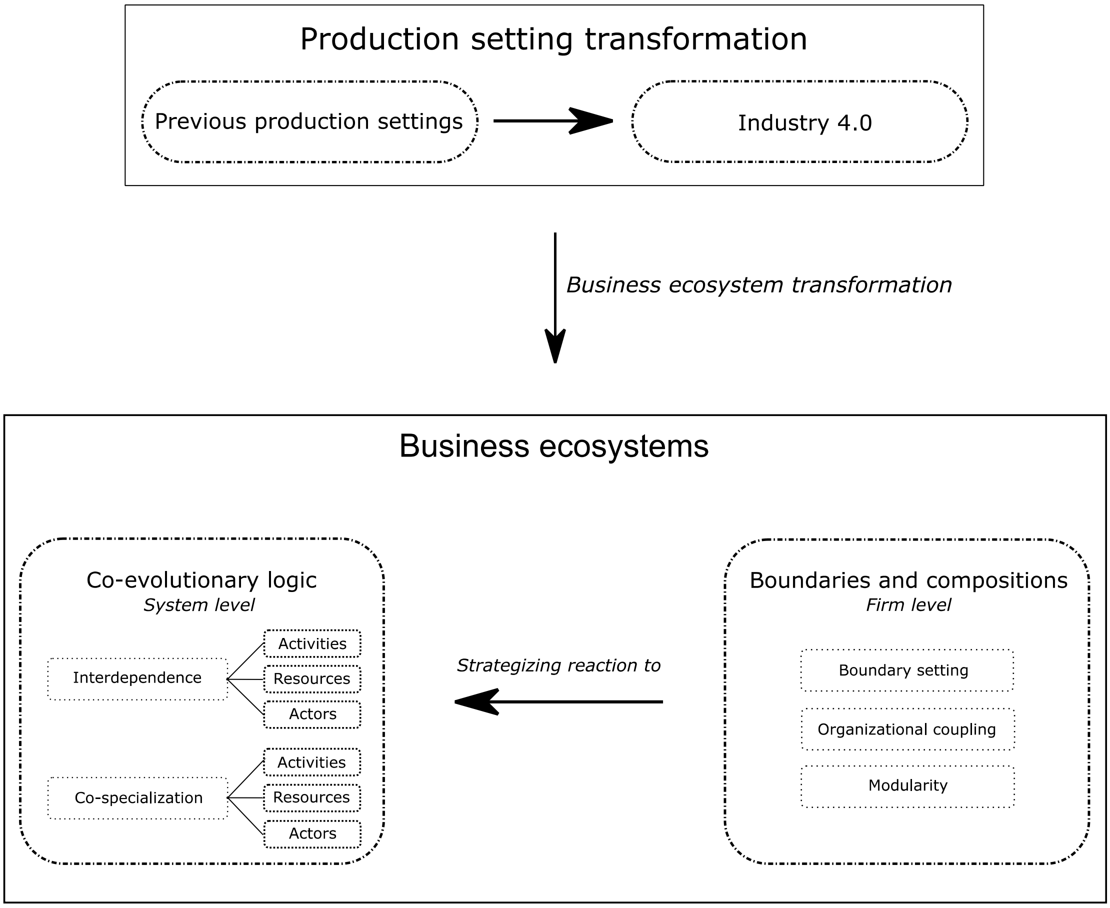
2.4.3. Modularity

Ecosystem modularity is the final dimension of the boundary and compositions constituent considered in this study. Modularity has long been an interesting research topic in terms of product modularity, because it is considered a helpful tool to cope with complex systems. Modularity copes with complexity by breaking up a system into various subsystems that interact through standardized interfaces (Baldwin & Clark, 2003; Langlois, 2002). Modularity is defined as "*a system that is composed of units (or modules) that are designed independently but still function as a whole*" (Baldwin & Clark, 2003 p. 3). Even though the concept of modularity is often considered on the product level, it has also been used on an industry and ecosystem level (Schilling & Steensma, 2001; Tsvetkova & Gustafsson, 2012). In the case of ecosystems, modularity is about actors that can be separated and recombined (Le & Tarafdar, 2009; Weiss & Gangadharan, 2010). In other words, modularity is about the interchangeability of ecosystem partners and is opposed by long-term relationships. This is a relevant operationalization of an ecosystem's structural organization because it provides understanding regarding composition. This is in the sense of whether an ecosystem's composition is dynamic and characterized by modularity or stable and characterized by long-term relationships. According to Schilling and Steensma (2001), the phenomenon of modularity is driven by heterogeneity of inputs and demands, standardization, level of technological change and industry competitiveness. These drivers match with various aspects of industry 4.0 such as the aim to achieve mass customization or its technological driven character. According to Baldwin and Clark (2003), modularity is achieved through shared architectures, interfaces and standards. The former determines what modules (i.e., functions) will be part of the system and what their position and role relative to the other modules is. Second, interfaces determine how different subsystems interact with each other (i.e., what are their relationships). And finally, standards comprise of the rules for testing design rules to ensure that various modules can interact with each other. The concept of ecosystem modularity can be considered a strategizing reaction to developments in ecosystem interdependence and co-specialization. Considering the work of Thompson (2003), ecosystem modularity would decrease when the interdependence between business ecosystem partners increase. According to him, the more complex interdependence becomes (i.e., interdependence moves more towards reciprocal interdependence), the more complex coordination becomes, and the less interdependence can be coordinated through standards. On the other hand, co-specialization and the dispersity of resources and capabilities across the business landscape may lead to increased diversity of inputs and demands (Ford et al., 2008). This would lead to a prediction of increased modularity.

Together, the concepts of boundary setting, organizational coupling and modularity give an extensive overview of structural organization of business. Since structures are seen as representations of underlying processes they are considered strategizing outcomes through which ecosystem actors react on co-evolutionary developments on the micro level. These three dimensions are used to gain understanding in the strategizing reactions of individual firms to possible developments of the co-evolutionary logic triggered by industry 4.0.

Now that both constituents of business ecosystems are discussed in-depth, the overall theoretical framework on business ecosystems can be drawn. The above discussion is visualized in figure 7.

Figure 7. Extended conceptual model



The next section discusses the methodological procedure that is used to execute the research and answer the research question.

3. Methodology

The aim of this research is to explore how business ecosystems, in terms of co-evolutionary logic and resulting strategizing outcomes (i.e., boundaries and compositions) transform from previous production settings to an industry 4.0 setting. This not only requires understanding about which dimensions of co-evolutionary logic and boundaries and compositions transform but also why these transformations are observed. The latter is necessary to connect transformational observations regarding co-evolutionary logic and boundaries and compositions to the industry 4.0 concept and transformation drivers that originate from it. Because the research aim implies a "why" dimension, the methodological approach must deliver a "thick description". This means that the research should draw large conclusions from small but textured facts (Tracy, 2013). Likewise, it must take the context of changes regarding co-evolutionary logic and boundaries, and compositions into account. These requirements determine the research design of this study.

3.1. Research design

This research adopts a qualitative research design because it can explain and gain a more in-depth understanding of the complex context behind actual observations (Sofaer, 2002; Tracy, 2013). This in-depth knowledge stems from the thick description that is given by case studies (Tracy, 2013). According to her, case studies enable researchers to immerse themselves into a situation and culture which leads to a thick description. To be more precise about the methodological approach, this research adopts a single case study because it is considered useful in dealing with "how" questions where the real-world context of an empirical phenomenon should be considered (Eisenhardt & Graebner, 2007; Yin, 2011). Furthermore, qualitative research and case studies can increase understanding regarding the emergence and change of interactions on a system level over time (Tracy, 2013; Yin, 2011). This is important to highlight developments regarding the co-evolutionary logic and boundaries and compositions over time. Finally, a case study as methodological approach is common in the contemporary literature regarding both business ecosystems and industry 4.0 since it deals with complexity that accompanies both phenomena and takes into account the context (e.g., Adner, 2016; Huemer, 2017; Schumacher, Erol, & Sihn, 2016).

Within the case study methodology, an iterative approach between literature and data is adopted. This approach was first introduced by Miles and Huberman (1994) and starts with a general research topic and literature base which evolve and become more specific when qualitative data emerges. This approach is also adopted within the IMP literature and was labelled as an abductive research design by Dubois and Gadde (2002). Abductive research refers to an iterative process where the researcher moves back and forth between theory and the empirical world. It includes that theoretical concepts are used for initial understanding of the empirical phenomenon but may change so that it resonates with the emerging qualitative data. In the context of this study for example, the initial focus was on the structural transformation of business ecosystems (i.e., boundaries and compositions). However, when qualitative data emerged, the scope of the research increased, and interrelations of ecosystem actors (i.e., co-evolutionary logic) was included as well. The inclusion of co-evolutionary logic represents an inductive approach and was motivated by the inextricable link with the structural organization of business ecosystems. After co-evolutionary logic was included during the data collection, the author returned to the literature to gain understanding of the topic that was used to interpret the data. This represents a deductive approach towards the data. Another example refers to the initial theoretical concepts regarding boundaries and composition. These originally included organizational coupling, ecosystem hierarchy and modularity. Over the course of the investigation, ecosystem hierarchy was dropped as a theoretical concept whereas firm boundary setting was included since this resonated better with the data. However, when boundary setting was included, the researcher returned to the literature again to gain knowledge that was used during data interpretation. In this case, excluding hierarchy and including firm boundary refers to an inductive approach whereas returning to the data for data interpretation refers to a deductive approach. The combination inductive and deductive approaches towards the data represents the abductive research approach. This approach was chosen because there was limited empirical research of business ecosystems in an industry 4.0 setting but a substantial literature body on business ecosystems outside this setting. Consequently, it was sensible to develop an initial theoretical lens based on existing literature but let it emerge during the investigation.

3.2. Case study context

The context of the case study is a business ecosystem in the Dutch manufacturing industry that revolves around the value proposition of industrial automation. Units of analysis are the industrial automation ecosystem and its actors which are used to analyze respectively co-evolutionary logic and boundaries and compositions. The former includes analysis of interdependence on a system level whereas the latter analyzes firm level responses. The industrial automation value proposition refers to the automation of production facilities by means of specialized machines, robotics and advanced IT applications. The business ecosystem exists of end-users (i.e., manufacturing firms), system integrators, machine builders and software developers. In 2017, a firm (hereafter: Epsilon[1]), that operated in the industrial automation ecosystem, started to cooperate with a consulting team. Epsilon wanted to introduce a new offering that aimed to increase empowerment and flexibility of manufacturing firms by providing robotics software. In doing so, Epsilon not only dealt with technological challenges but with organizational challenges as well. One of these challenges was to determine how the ecosystem for their new offering would look like and what Epsilon's position could and should be within the ecosystem. Initially, they fulfilled the system integrator function, but the introduction of their new offering pushed them to the software developer function. One of the reasons to choose this context was that the author participated in the consulting team that cooperated with Epsilon. Moreover, this cooperation gave the author a rare opportunity to gain access to different actors that operated or could potentially operate within this business ecosystem. Therefore, the choice for the industrial automation business ecosystem was based on the "revelatory case" rationale described by Yin (2011). Furthermore, the industrial automation business ecosystem existed of actors that had different perspectives towards business ecosystem and industry 4.0 developments (e.g., traditional, progressive and new entrants). Different perspectives towards business ecosystems and industry 4.0 led to different sentiments, preventing the data from becoming overly positive or negative but realistic instead. Ultimately, this led to a dataset that provides a comprehensive view of how industry 4.0 affects developments in the co-evolutionary logic and reactions of firms expressed in structural organization. However, before this dataset was obtained, a varied sample of firms that could give a complete view of the industrial automation ecosystem needed to be realized.

3.3. Sampling and sample

To ensure that all actors functions and perspectives were included in the case study, convenience and snowball sampling were applied. These sampling methods combined led to a sample that consisted of actors with different functional backgrounds (i.e., end-users, system integrators, machine builders and software developers). Also, these methods included different perspectives towards developments in business ecosystems and industry 4.0. First, convenience sampling is based on sources that are easily accessible by leveraging personal networks for example (Tracy, 2013). Within this research, networks of experienced colleague researchers, who cooperated with Epsilon, were leveraged. Additionally, sampling was done on conventions that were organized around the industry 4.0 theme. During these conventions,

[1] Epsilon is a pseudonym to ensure anonymity and confidentiality.

there were possibilities to interact and, more importantly, to confer with representatives of firms directly relevant for this research. Even though convenience sampling is often criticized for being adopted to avoid hard work, this sampling procedure respects the purposeful sampling rule of Tracy (2013). This rule includes that researchers should purposefully choose their data sources so that they fit the parameters of the research aim and question. The convenience sampling procedure in this thesis respects the purposeful sampling rule as follows. First, requirements of the sample were determined. These requirements consisted of the presence of all functional actors (i.e., end-users, system integrators, machine builders and software developers) as well as the inclusion of various perspectives towards business ecosystems and industry 4.0 (e.g., traditional manufacturing firms and progressive system integrators). Only after satisfying this requirement, sampling was started and firms were approached. Snowball sampling includes leveraging the network of other people by asking to suggest additional valuable case study participants. This research started with an initial sample derived through convenience sampling but leveraged the network of Epsilon to get in touch with complementary actors and case study participants. Together, these sampling methods led to a comprehensive and complete sample of business ecosystem actors.

The case study sample consisted of 13 participating firms, besides Epsilon, that fulfilled different functions and had different perspectives within the case study context. The participating firms fulfilled the following functions: end-user, system integrator, machine builder, software supplier or technology supplier. An overview and description of the sample, including interviewees and their respective functions, can be found in table 1. A sample size of 13 is considered enough for this research because it was the point where additional participants provided information that was very specific to a function. Since this research aims to increase understanding on the system level, this degree of specificity was considered outside the research scope. Additionally, such specificity would lead to incomprehensibility of the data. According to Tracy (2013), data redundancy and comprehensibility are the criteria to determine sufficient sample size. From this sample, data about developments in co-evolutionary logic and boundaries and composition regarding the industrial automation ecosystem was collected.

Table 1. Sample description

Firm	NAICS 2017	Description firm	Markets and competencies	Interviewee function
Epsilon	541330 541512	System integrator & software developer	Manufacturing	CEO Sales engineer
SI 1	238210 541330	System integrator	Industrial automation Installation technique Electrical engineering Process automation Machine control	Account manager
SI 2	333298 541330	System integrator	Utility Retail Manufacturing *- Industrial automation* *- Smart industry* *- Robotization*	Account manager & Department manager smart industry
SI 3	541330	System integrator	Identification Inspection & measurement Robot positioning	Technical sales / business developer
SI 4	541330	System integrator	Manufacturing industry Food industry Process industry	Improvement manager smart industry
SD 1	541512	Software developer	Manufacturing Machine builders	Owner / CEO & software engineer
TS 1	333298 333318	Technology supplier	High-tech systems Medical Industrial systems and vision Mechatronics Embedded systems	Business unit manager
SI 5	541330	System integrator	Laboratory	Owner / CEO & engineer
SI 6	541330	System integrator	Manufacturing *- Mechatronics*	Sales engineer
MB 1	333294	Machine builder	Food industry	Robotics sales manager & sales director
MB 2	541330	Machine builder & system integrator	Chemical industry Pharmaceutical industry Food industry Bio industry Metal industry	Owner/ CEO
OEM 1	3339	Manufacturer	Logistics	General manager operations
SI 7	3339	System integrator	Logistics	Head of robotics department
OEM 2	3345	Manufacturer	Liquid handling	Operations manager

3.4. Data collection

This case study relies on interview and archival data which were respectively collected through in-depth interviews and desk research. Regarding the former, archival data consisted of participants' background information and was collected through desk research. Background information aimed to give an understanding of topics and issues that were currently relevant for the participants. This had two benefits during the in-depth interviews; first, it enabled the interviewer to ask more specific questions regarding these topics and issues. Second, when participants noticed that the interviewer put the effort in the pre-research, he or she was more eager to share relevant data which therefore increased the quality of the interview data. Background information of participatory firms was collected from their respective corporate websites as well from news articles in which they were subject to analysis. News articles were extracted from the LexisNexis database. In this sense, archival data complemented interview data by providing background information that was used during the interviews.

Elaborating on the in-depth interviews, in this research interviews had a semi-structured character. This was decided because respondents required enough possibilities to express their ideas regarding the business ecosystem transformation in an industry 4.0 context. In this sense, respondents were not constrained by pre-defined theoretical concepts. This enabled respondents for example to express ideas which indicated that boundary setting is an important dimension of boundaries and compositions whereas ecosystem hierarchy appeared to be less relevant. Finally, semi-structured interviews enabled the interviewer to ask further questions when a response of an interviewee was unclear or showed inconsistencies. This refers to the interview practices of probing and interpreting that were mentioned by Tracy (2013). An outline of the interview can be found in Appendix A; this outline only represents a guide rather than a fixed path. To increase the value of interview data, it was complemented by archival data. Together, archival and interview data served an important factor in the overall data collection process.

This process of data collection consisted of different phases each fulfilling its own function. It started with searching for and collecting background information on participatory firms to get an initial idea what topics and issues were relevant for the firm. Before the interview was conducted, the interview outline (Appendix A) was distributed to the respondent(s) by email so that the respondent(s) could prepare for the interview. To prevent misunderstandings about the industry 4.0 concept, a common interpretation about content and context of the concept was created by means of discussion. This was necessary to have an interview where both interviewer and interviewee were on the same page regarding the topic at hand. This was also done for other concepts during the interview when the interviewer had the idea that there might be an incongruence about interpretation of a concept that was discussed. During the interview, the interviewer used an outline with additional annotations as a guide to steer the interview. The annotations acted as support for the interviewer during the conversation and are data collection tool derived from Yin (2011). When the author faced unclarities or inconsistencies during the interviewer, this was clarified by asking additional questions. When this occurred after the interview (e.g., during the processes of transcribing or data analysis), respondents were contacted and asked additional questions about these unclarities or inconsistencies. This was done by means of telephone or email contact and occurred four times. In total, this process led to a dataset derived from collecting background information on 13 firms and conducting 15 in-depth interviews. Table 2 presents an overview of the conducted interviews including firm number, interview duration and the function of the interviewee(s). To minimize biased data collection, data was gathered from subjects holding different functions at varying hierarchical levels. This principle increases construct validity of the research according to Yin (2011). The resulting dataset was then analyzed to gain an understanding how co-evolutionary logic and boundaries and compositions of the industrial automation business ecosystem transform into an industry 4.0 context. However, first ethical standards of data collection must be discussed to ensure that human subject were treated proper and fair.

Table 2. Overview interview sample

Interview	Firm	Duration	Function of respondent(s)
01	SI 1	01:23:51	**Account manager**
02	SI 2	01:07:45	**Account manager & department manager smart industry**
03	SI 3	01:09:45	**Technical sales / business developer**
04	SI 4	00:59:24	**Improvement manager smart industry**
05	SD 1	00:50:15	**Owner / CEO & software engineer**
06	TS 1	00:52:20	**Business unit manager**
07	SI 5	00:38:13	**Owner / CEO & engineer**
08	SI 6	01:06:29	**Sales engineer**
09	MB 1	01:38:43	**Sales area (robotics) manager & sales director**
10	MB 2	01:13:13	**Owner / CEO**
11	Log 1	01:05:23	**General manager operations**
12	Log 2	00:49:26	**Head of robotics department**
13	Epsilon	00:40:15	**CEO**
14	Epsilon	00:27:53	**Sales engineer**
15	LH 1	00:47:55	**Operations manager**

3.5. Ethics

To ensure ethical procedures in the process of this research, permission was granted by the ethical board of the University of Twente. Respondents were not asked to offer data that is considered unethical nor were respondents asked to perform unethical tasks. Furthermore, all data obtained by respondents during both formal and informal meetings is considered confidential. This means that participants were treated as anonymous, applying to both personal information and information regarding the content of this research. Before every interview or contact moment, the researcher asked permission to record the conversation and stressed that information is confidential and anonymous. Regarding archival data, the data that was gathered from public sources was made available with the consent of the owning party and therefore free to use.

3.6. Data analysis

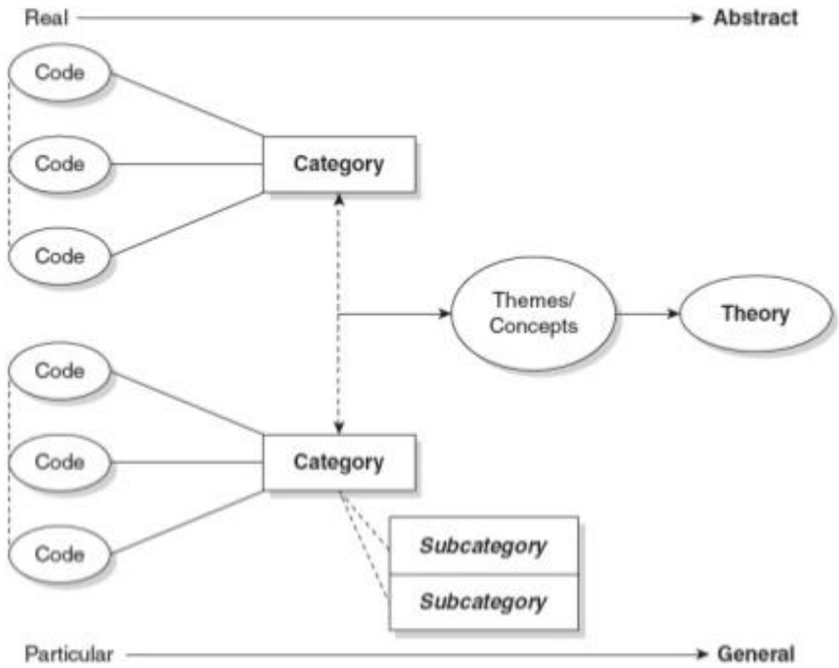
The data analysis has been carried out in multiple iterative steps which moved back and forth between data and theory. The first interaction with the data was transcribing it from audio to text format. During and right after the process of transcribing, significant data parts were highlighted, and initial comments were added[2]. This is called pre-coding by Saldaña (2013). Significance of data was based on the pre-established theoretical lenses including organizational coupling, hierarchy and modularity. During pre-coding, it was already discovered that hierarchy did not appear in the data and was therefore dropped from further analysis. The final step of data analysis included multiple rounds of data coding, which ultimately led to understanding how the co-evolutionary logic and boundaries and compositions of the case business ecosystem transformed into an industry 4.0 setting. Because the process of coding was essential within the data analysis stage and was extensive in its execution, it requires a more in-depth discussion.

3.6.1. Coding

The coding process consisted of three rounds which all had their own function. Together, these three coding rounds funnelled an extensive and unstructured cloud of data into a comprehensible dataset from which results could be extracted. In between the coding rounds, research moved back to the theory to reflect on both existing and new theoretical concepts. This was done to respect the abductive nature of the research design. During the first two coding rounds, the ATLAS.ti software package and Saldaña's (2013) coding handbook were used. The latter presents a streamlined codes-to-theory model for qualitative inquiry (p. 14) (figure 8), this acted as a basis for the coding process. Even though, this model was not yet adopted in the first coding round.

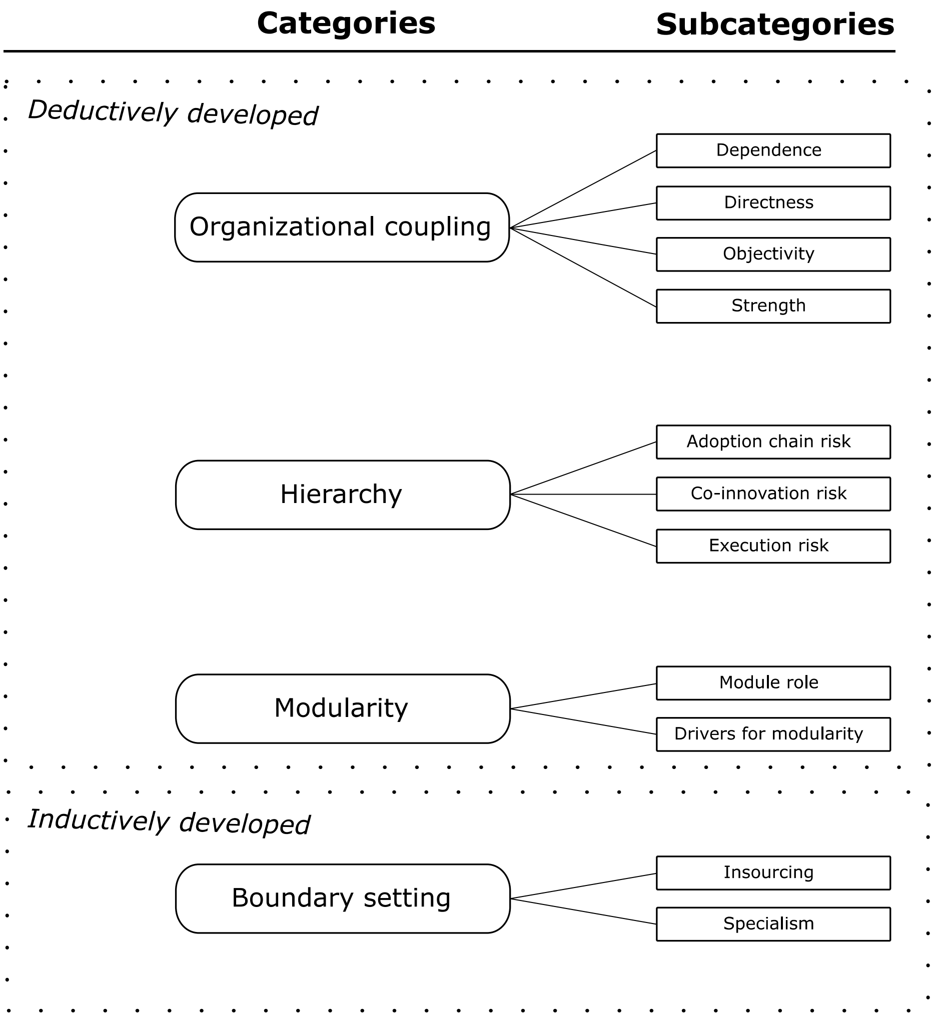
[2] This is called pre-coding by Saldaña (2013)

Figure 8. A streamlined codes-to-theory model for qualitative inquiry *(Saldana 2013)*



During the first coding round, data were coded according to broader themes and therefore deviates from Saldaña's (2013) coding model. The data was coded according to major themes and categories within these themes to separate the dataset in multiple datasets. This separation prevented the data to become overwhelming during the detailed analysis. An overview of these themes and categories is presented in figure 9. Some themes and categories were pre-established and derived from the initial literature base (i.e., organizational coupling, hierarchy and modularity). However, during the coding process, it appeared that not all data that discuss developments of co-evolutionary logic and boundaries and compositions fitted within these pre-established themes and categories. Therefore, an open attitude to coding was adopted meaning that extra themes and categories were established during the coding process (e.g., boundary setting). This refers to the abductive research design in the sense that, at this point, boundary setting was inductively included to the operationalization of boundaries and compositions. Boundary setting was not initially included in the model, but emerging data hinted towards the relevance of this concept. However, this stage did not yet provide the final operationalization as represented in figure 6. Eventually, the first coding round resulted in a dataset that was structured in general themes and categories suitable for more detailed coding.

Figure 9. Results first coding round

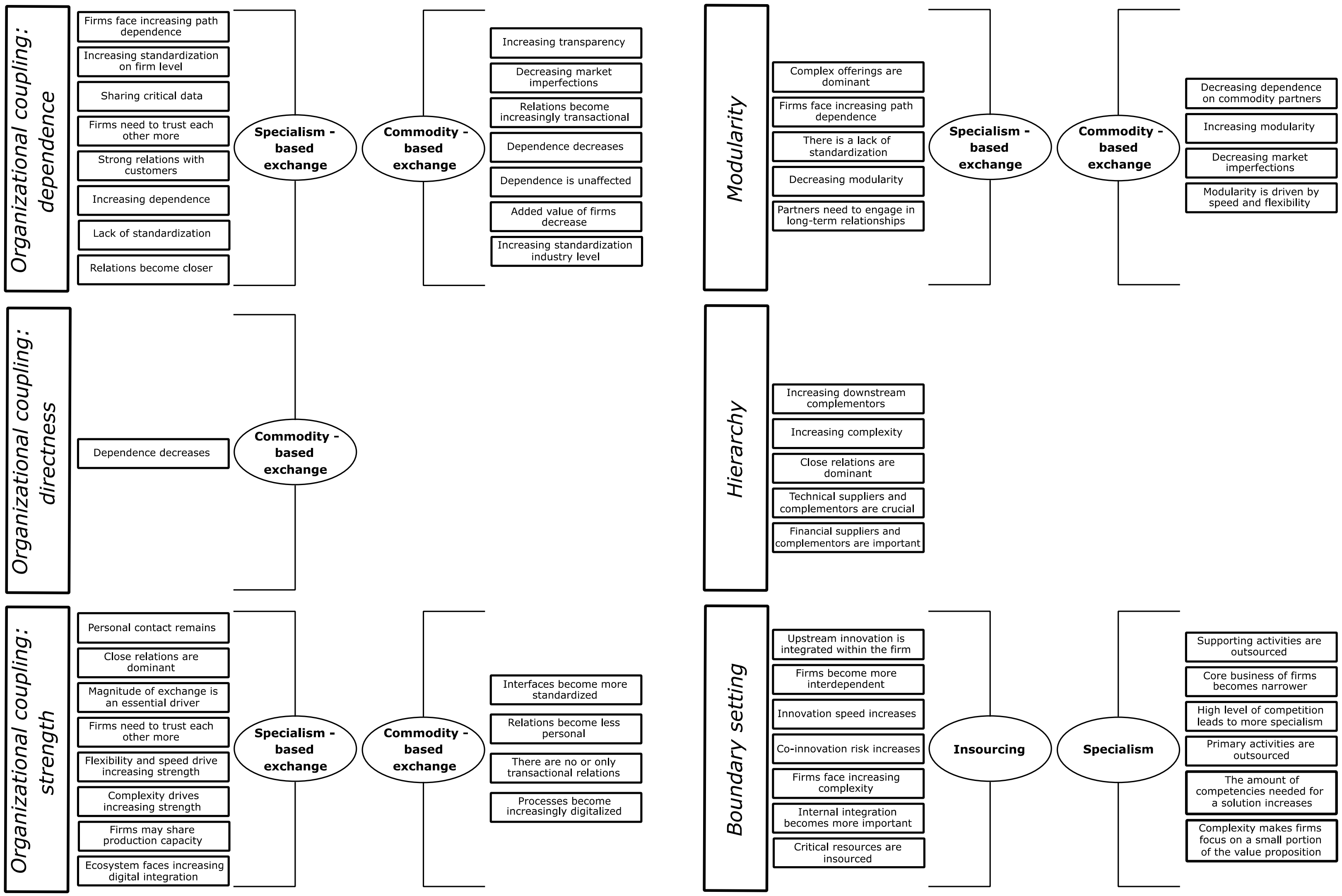


Note: this figure shows categories and subcategories that were used to categorize raw data segments during the first coding round. These categories differ in terms of origin where organizational coupling, hierarchy and modularity were drawn from the theory. Boundary setting on the other hand, emerged from the data.

In the second round of coding, individual data fragments were assigned (sometimes multiple) first-level codes. First-level codes are descriptive and focus on what is observed in the data. First-level codes were assigned by a process of open coding. This process was executed in the network view of ATLAS.ti and enabled network drawing between both data fragments and codes. These networks showed which individual codes were often co-occurring and a more in-depth analysis of these co-occurring codes led to the establishment of more general categories. The latter is often referred to as axial coding where data, that was fractured during open coding, is reassembled again (Tracy, 2013). After data pieces were coded and a network was drawn, individual data points were analyzed and interpreted. This led to deeper understanding regarding the meaning of data, and improved interpretation of the data. This includes that hierarchy was dropped as a structural concept for business ecosystems. This was decided because the data did not show any relevant observations or patterns concerning hierarchy. At the end of the second coding round, the research arrived at the final operationalization as presented in figure 6. A visual overview of the second coding round is presented in figure 10. Ultimately, this coding and analysis round resulted the final operationalization of an ecosystem and initial patterns on ecosystem transformation in an industry 4.0 context were obtained.

The final round of coding was done according to the operationalization which was constructed in the first two coding rounds. Original interview transcriptions were reflected against this operationalization. The third round was necessary because the understanding of the researcher, who was the main instrument of data analysis and sensemaking, developed over the course of the investigation. During the second coding round, patterns in the data through co-occurring codes were observed. During the third coding round, these patterns were confirmed, altered or rejected leading to the results of this study. Moreover, the third coding round acted as a tool to validate the established ecosystem operationalization in the first two coding rounds.

Figure 10: Results second coding round



Note: vertical boxes represent main categories established in the first coding rounds. Rectangle boxes and circles respectively refer to first-level codes and common themes.

4. Results

This chapter presents the results from the industrial automation case study. It starts with presenting results of industry 4.0 induced developments regarding co-evolutionary logic in terms of intercedence and co-specialization. When these developments are clear, the presentation continues with observed processes that firms adopt to deal with co-evolutionary logic developments. These processes include firm boundary setting, organizational coupling and modularity. Furthermore, these processes are executed at the firm level as response to co-evolutionary logic developments on the system level. Finally, all results together are used to answer the research question as formulated in the introduction.

4.1. Co-evolutionary logic

As was discussed in the literature section, co-evolutionary logic refers to inter-relations of actors in a business ecosystem. Moreover, co-evolution occurs over time through interaction and knowledge sharing. Co-evolutionary logic is discussed in terms of interdependence and co-specialization which respectively refer to ties between actors and development of these ties over time. Interdependence and co-specialization are discussed at the level of activities, resources and actors. This section discusses results regarding industry 4.0 induced developments in interdependence and co-specialization of activities, resources and actors. Developments in interdependence are first to be discussed.

4.1.1. Interdependence

Regarding interdependence, an overall observation in the data is the importance of production environment context in industry 4.0. This refers to the observation that within the production environment, machines and processes are interdependent because they form an intelligent whole. The following quotation illustrates this:

> *"A robot is never a stand-alone solution, it needs to be integrated within its surroundings (…) Collaborative robots are easy to configure but integrating them within the system often disappoints. This integration is often very complex in an environment with other machines, working orders, different sorts of products and stacking patterns."* (SI 4, interview 04)

This quotation refers to interdependence within firm boundaries because individual machines and robots need to be integrated with its surroundings. However, interdependence does not stop at the firm boundary but applies to the system level as well. One of the respondents (SI 1) stated that ecosystem partners need to be increasingly mutually integrated. This is necessary to be able to deliver more just-in-time. To achieve such an integration, partners must interact more which means that they become more interdependent. This hints towards a shift of more reciprocal interdependence as explained by Thompson (2003). This indication is illustrated by the next quotation:

> *"For me, cooperation is one of the core concepts of industry 4.0 and in that sense, open source belongs to cooperation (…) With open source I refer to a situation where firms can put data into a system and extract data from it as well. In other words, data must be available and accessible for everybody."* (SI 2, interview 02)

This quotation refers to increasingly reciprocal interdependence because firms, that operate within an industry 4.0 context, must work in collaborative systems where all data is freely accessible. In other words, the output of one party (i.e., production) serves as input for all other actors in the ecosystem (i.e., product or process adjustment). Representatives of SI 2 also indicated that universal access to data is essential to integrate systems and process within and across firm boundaries. This hints towards a reciprocal flow of data through a central portal which is accessible for all integrated firms. So, interdependence between manufacturing firms in the industrial automation ecosystem seems to increase and shift to a reciprocal character. Until now, interdependence of ecosystem actors is discussed on the organizational level. However, data revealed patterns regarding interdependence on the more detailed level of activities, resources and actors.

Activities

Different actors within the industrial automation ecosystem indicated that firms align their activities by coupling data streams of production processes. Especially because more business ecosystems rely on just-in-time delivery principles, production processes need to be fully aligned (SI 6). In practice, this means that there is not only a one-way stream of goods (i.e., sequential interdependence) but that production data moves into opposite directions indicating reciprocal interdependence. One respondent (OEM 1) gave an example of reciprocal interdependence of activities within firm boundaries. They desire to integrate production processes with its employee planning process and realize a dynamic planning mechanism. This example reflects reciprocal interdependence because progress data on the production process is input for the employee assignment process. This applies to the other way around as well because employee assignment data is input for the production process (i.e., employees executing production tasks). Reciprocal interdependence not only limits to the firm level but can be observed on the system level as well. One example would be that different ecosystem partners work together simultaneously instead of sequential by means of shared repositories (Epsilon). Another concrete example of increasing reciprocal interdependence on the system level is reflected in the following quotation of MB 1:

> *"With our new business model, we want to become the Amazon of our industry and eventually of other industries as well. With this new business model, we do not only want to sell our own products but also those of others. To do so, we collect customer data which' analysis provide us for example with an alert from the customer's production line: "beware, a motor must soon be replaced". To anticipate on this alert, we can link this alert to our warehouse as well as to the warehouse systems of our suppliers and complementors. (…) In that sense, we want to collect production data and based on that data we aim to integrate all players in the system."* (MB 1, interview 09)

This quotation illustrates how the firm collects production data from customers and how it is used throughout the business ecosystem by different actors. In this case, production data of the end-user serves as input for other actors in the ecosystem like machine builders or spare part suppliers for example. So, the data indicates that more activities throughout firms and business ecosystems in an industry 4.0 context become increasingly reciprocal interdependent. Next to interdependence development regarding activities, developments were also observed in the data in relation to resources.

Resources

In the ARA model of Ford, Gadde, Håkansson, Snehota, & Waluszewski (2008), resources refer to both tangible resources like machines as well as intangible resources. Regarding the former, data indicates that machines and robots become more interdependent because they are overarched by a central ERP system. Moreover, these ERP systems are connected and communicate with each other on the system level. The following quotation of MB 2 gives a representation of this development:

> *"With our ERP system, we can communicate with other firms and operate in their systems as well. Even though these connections are easy to establish, we currently do not make these connections that much. Still, it would be very valuable and necessary to couple these systems with each other on a larger scale."* (MB 2, interview 10)

This means that ERP systems of two interdependent ecosystem actors become reciprocal interdependent (through the exchange of data). As well as the machines that are connected to these systems. To be more precise, this interdependence stems from the data that resides in both ERP systems and machines and differs in value among different settings. For example, order data that resides in the ERP system of an end-user may hold more value when this data is located at or integrated with the supplier's ERP system. In realizing this connection, ERP systems become mutually adapted so that they can effectively communicate with each other. Reciprocal interdependence not only holds for tangible resources, but for intangible resources as well. Because data serves as input for product development, intellectual property becomes increasingly reciprocal interdependent (TS 1). Especially considering that it is not only a supplier-customer relation but that complementors are involved as well. So, it appears that resources become increasingly reciprocal interdependent. According to the data, this development together with interdependence developments in activities, affects interdependence as well.

Actors
Interdependence of actors is not discussed according to the typology of Thompson (2003). Instead, it is a prerequisite or co-occurrence of the development that activities and resources become more reciprocal interdependent and is reflected in the following quotation:

> *"It is possible to access machines of customers via the internet, but many customers do not trust it when we continuously monitor their machines. For now, we only access their machines in case of malfunctions."* (MB 2, interview 10)

This fragment stresses the crucial role of trust in realizing interdependence. This was backed by OEM 2 who stated that their customers didn't share much information because it involves chemical recipes. Since these recipes are the basis of competitive advantage, they only share this data in a fully safe environment. In other words, in a manufacturing context where activities and resources become interdependent, actors need to trust each other so that their actions cannot be considered in isolation. This section discussed developments regarding the nature and spatial orientation of ties between activities, resources and actor, the next section presents results regarding developments of these ties over time.

4.1.2. Co-specialization

Co-specialization is the second dimension of the co-evolutionary logic constituent. According to the data, actors in the industrial automation ecosystem head more into the same direction through co-specialization. As discussed in the previous section, activities, resources and actors become increasingly reciprocally tied. From a temporal perspective, it appears that organizations in the industrial automation ecosystem move towards the same directions resulting in increasing mutual adaptation. Like interdependence, co-specialization is discussed in more detail on the level of activities, resources and actors.

Activities
Because industry 4.0 is characterized by increasing connectivity and more process data is gathered, processes increasingly adapt to each other. An example was given by MB 1 which uses grading reports to realize an optimal fit between processes both within and across firm-boundaries:

> *"If we consider our new business model, it is advantageous for our suppliers that they are more able to deliver just-in-time. (…) We align our processes with our suppliers. We have specific programs in which we grade different aspects of our suppliers. These reports are shared with our customers so that they can anticipate on it. This is not only done externally but internally as well."* (MB 1, interview 1)

Even though grading reports are not a new phenomenon, firms within an industry 4.0 setting collect more data meaning that the grading reports become more detailed. To be more precise, data is collected on more dimensions and per dimension, data is collected in greater detail (i.e., real-time). This leads to more information on which the counterpart-firm can anticipate. This again leads to co-specialization of processes on a more detailed level. The increasing detail of measuring and grading ecosystem partner performance enables manufacturing firms to adapt activities on a more detailed level. This increasing co-specialization within an industry 4.0

context is observed both within and across firm boundaries. Still, adaption was not only observed on the activity level, but it is also relevant to the resource level.

Resources

In an industry 4.0 context, firms become increasingly connected by sharing data of various processes with the purpose of co-specialize resources. The representative of TS 1 has given an example by illustrating that it is essential to align directions of different technologies involved in a system offering:

> *"In the critical chain, one has to shift more towards partnerships and everybody must know exactly what customers want. Moreover, partners must share their own roadmaps, firms cannot escape this because they become too slow and inflexible otherwise."* (TS 1, interview 6)

The requirement to share roadmaps can be interpreted as the alignment of future technological development. In other words, development paths of resources become more adapted and co-specialized to cope with industry 4.0 induced speed and flexibility requirements. This holds for both tangible and intangible resources. Suppliers must align their offerings with customer directions. So, when a manufacturing firm heads towards a specific direction with their innovation, the machine builder must adapt its machine or robot so that it meets future customer requirements. This alignment with customer directions holds for complementors as well because the industrial automation is a system offering. This means that individual value propositions are only valuable in concert with complementing offerings. Therefore, the data hints to a development that resources become increasingly co-specialized in the sense that they share their development directions. This development appears to be driven to cope with increasing speed and flexibility requirements posed on manufacturing firm by the market.

Actors

Like interdependence, co-specialization on the actor level is considered a consequence or requirement of co-specialization developments on the activity and resource levels. This is for example illustrated in the following quotation of OEM 2:

> *"From a technical perspective, we can realize integration but, in the end, customers must accept on sharing data. Acceptation is achieved by creating a safe environment for the customer in which they can trust that no data leaks will occur."* (OEM 2, interview 15)

Together with the example of MB 2 on actors in the interdependence section, it appears that actors co-specialize in the industry 4.0 context by building up trust over time. Because trust is built over time, actors across the business ecosystem grow closer to each other and relate their own problems to those of their partners. This can also be observed by the statement of TS 1 that ecosystem partners must share and align their roadmaps. This not only leads to co-specialization of resources, but it also leads to a situation where actors in the business ecosystem agree on a shared direction including problems that must jointly be overcome. In other words, by sharing and aligning roadmaps, business ecosystem actors relate problems of their counterpart actors to their own problems. Co-specialization of actors is the final discussed aspect of co-evolutionary logic developments in an industry 4.0 context.

To conclude, the data hints towards industry 4.0 induced developments in co-evolutionary logic that are characterized by increasing interdependence and co-specialization. Regarding the former, it is observed that activities, resources and actors become increasingly tied together and reciprocally interdependent. It appears that increasing reciprocal interdependence of activities and resources was respectively driven by becoming 1) increasingly aligned to deliver more just-in-time and 2) increasingly connected so that they mutually adapt to each other. Next to that, as a prerequisite of these developments, actors also become more interdependent in the sense that they must trust each other before they start sharing data. Regarding co-specialization, analysis revealed that activities, resources and actors mutually adapt to each other over time. In other words, they head in the same direction and by doing so, they become increasingly aligned.

4.2. Boundaries and compositions

Individual firms, in the context of this study, cannot directly alter the co-evolutionary logic of business ecosystems. Instead, they can react on the co-evolutionary logic by altering ecosystem boundaries and compositions. This section presents results regarding structural developments of the industrial automation ecosystem. These structural developments are considered reactions of individual ecosystem actors to cope with industry 4.0 driven developments regarding the co-evolutionary logic. Besides, ecosystems structures are considered as representations of underlying processes. This means that individual ecosystem actors must identify a scope of action that lead to the structural organization on the business ecosystem. The structural dimensions considered in this research are boundary setting, organizational coupling and ecosystem modularity. Results regarding the former are first presented.

4.2.1. Boundary setting

Boundary setting includes not only ownership boundaries but also awareness and influence boundaries. Based on these three boundaries, Gadde (2014) introduced two archetypes: the integrated hierarchy and the connected company. In the data, shifts to both archetypes were observed which suggests that there is no uniform strategizing response towards increasing interdependence and co-specialization. Besides, data presented a development characterized by both broad ownership boundaries as well as broad awareness and influence boundaries. A detailed discussion per archetype is presented to create an in-depth understanding of these observations. These discussions include underlying drivers of strategizing reactions to connect findings with developments in the co-evolutionary logic of the industrial automation business ecosystem.

Integrated hierarchy

First, data shows situations where actors in the industrial automation ecosystem shift more towards an integrated hierarchy by broadening ownership boundaries and narrowing awareness and influence boundaries. Underlying drivers of this shift include internal integration, complexity and co-innovation risk, results regarding these drivers are now discussed individually starting with internal integration.

Data showed that insourcing of activities was driven by an increased integration requirement of both activities and resources. This driver is directly connected to an increasing reciprocal interdependence of activities and resources which was discussed earlier. Reciprocal interdependence regarding activities as a driver for insourcing activities was illustrated by OEM 1. They insourced the process of steel editing because the process had to be increasingly aligned with other processes (e.g., assembly). In other words, the process of steel editing and other manufacturing processes became more interdependent in the industry 4.0 context. Therefore, they decided to broaden their ownership boundaries and insource the process of steel editing. To refer again to the situation of MB 1, they stated the following:

> *"The reason for producing the software in-house is to establish full integration. That is the road we have taken, and we do not want to be dependent on an OEM that cooperates with many different firms."* (MB 1, interview 09)

With this quotation, they refer to the integration of software development resources with their own market knowledge. Because these two knowledge bases became more interdependent and co-specialized (i.e., had to move towards the same direction), they decided to insource software development. So, as a response to increasing reciprocal interdependence of activities and resources in the industry 4.0 setting, actors in the industrial automation ecosystem insourced activities and resources. Increasing integration requirements were not the only aspect that drives the shift towards an integrated hierarchy archetype, data revealed that complexity was an alternative driver.

Next to increasing need for integration, complexity was observed as a driver for shifts towards an integrated hierarchy archetype is reflected in the situation of MB 1. They decided to broaden their ownership boundaries by insourcing software development because involved knowledge was too complex to reside outside firm ownership boundaries:

> *"The coordination between various robots and vision applications makes it so complex. We have outsourced this at first, but this didn't go so well. This partner had experience with software and robotics but not with our specific application field, therefore this project didn't turn out well and we decided to integrate it."* (MB 1, interview 09)

This example indicates that resources (i.e., market knowledge and software development capabilities) that had to be combined for a proper offering (i.e., software for cutting machines) were too complicated to coordinate with external partners. Therefore, MB 1 decided to insource the software development function and broaden its ownership boundaries and narrowing its awareness and influence boundaries because they decreased cooperation with external partners. It appears that increasing interdependence of resources (i.e., market knowledge and software development capabilities) led to the complexity that could only be overcome through insourcing of knowledge. Consequently, this led to a strategizing response of insourcing software development shifting the firm towards an integrated hierarchy typology.

The final driver underlying a shift towards integrated hierarchy is co-innovation risk. Epsilon indicated that a major driver for insourcing activities and resources is the lack of movement in the market. This statement was also observed in practice at OEM 1:

> *"We want to go much further, we want to automate the whole process and every step within the process until the machine starts cutting. And because we have the capability of steel editing in-house, we are also able to shape this process. If we go to our supplier, why would he do that? If we are a big customer with for example 15 or 20 percent of the total revenues, we are still not big enough for them to redesign and automate their process. (…) So digital integration and the perfect alignment of processes did definitely drive the decision to insource this process."* (OEM 1, interview 11)

As mentioned before, OEM 1 aimed to achieve full integration between steel editing and other manufacturing processes. Besides this desire to realize full integration, another driver to insource steel editing is that their current suppliers were not able or not willing to provide this alignment. To put that differently, to anticipate on increased co-specialization requirements of industry 4.0, OEM 1 decided to broaden their ownership boundaries and insource the process. Relying on external parties, in this case, would not have led to the required degree of co-specialization of activities. Co-innovation risk is that final driver that was observed in the data that might explain shifting trends towards an integrated hierarchy archetype.

Altogether, increasing interdependence, resulting in complexity and co-innovation risk led firms in the industrial automation ecosystem to move towards an integrated hierarchy archetype. They did so by broadening their ownership boundaries and narrowing their awareness and influence boundaries through insourcing activities and cooperating less with external parties. Even though, it was also observed that firms increasingly moved towards a connected company archetype.

Connected company

Data showed multiple situations where firms in the industrial automation ecosystem moved towards a connected company archetype. These were driven by increasing number of necessary competencies and increasing specialization. The former includes that industry 4.0 requires more resources and capabilities for a value-proposition to materialize. However, firms cannot source all necessary resources and capabilities within its ownership boundaries in an economically viable way. Therefore, they must increasingly rely on external partners; this is exemplified by SI 2 in the following quotation:

> *"Everything mixes up and that results in complexity. For example, cybersecurity, how can the system be hacked? Cybersecurity is not part of our core business and we do not want to be occupied with it. However, we are aware that cybersecurity must be included in the value proposition. Therefore, we have third parties in our network that provide cybersecurity related expertise."* (SI 2, interview 2)

In this case, SI 2 does not integrate the process of cybersecurity and relies on external ecosystem partners to complement their offering. Industry 4.0 confronts SI 2 with an increasing number of activities and resources which cannot be sourced internally. Here, cybersecurity was mentioned specifically but other expertise areas like data science, networking machines and processes and software development were mentioned as well by other respondents. This increasing number of expertise areas needed to materialize a value proposition pushes ecosystem actors towards a connected company archetype of boundary setting. A closely related effect of this trend is that firms focus more on their core business.

The trend that manufacturing firms focus more on their core business is the second aspect that drives increasing shifts towards connected company archetypes. Increasing focus on core business means that manufacturing firms outsource non-core business activities and resources (e.g., supporting activities). OEM 2 indicated that they shifted from a culture of doing everything themselves to relying more on cooperation with external parties. The reason given included that it made OEM 2 faster and more flexible in the innovation process. TS 1 also indicated the latter by stating that owning the whole value chain is not desirable in an industry 4.0 setting because it makes firms too inert and slow. Moreover, OEM 2 did not only narrow their ownership boundaries, but they also broadened their awareness and influence boundaries as is illustrated in the next quotation:

> *"We insource our core technologies, the measuring principle, which we need to innovate. Because when we don't understand how the technology works or is developed, we cannot influence the innovation course of products. If we don't have this knowledge, we are dependent on external parties to innovate. It doesn't mean that we are producing all those technologies ourselves, we want to establish partnerships to increase knowledge and innovation possibilities. (…) And if we want to innovate, then we know how to do it."* (OEM 2, interview 15)

OEM 2 insourced technical knowledge not to execute the actual activity but to understand (i.e., become more aware) and influence activities and resources residing at external partners. Therefore, it appears that specialization has driven OEM 2 to a connected company archetype of boundary setting.

In the previous sections, it appeared that industry 4.0 is characterized by increasing interdependence and co-specialization between activities, resources and actors. Actors in the industrial automation ecosystem responded to and dealt with this development by insourcing activities and resources. As has been shown, however, insourcing attractiveness might be offset by increasing competencies to materialize a value proposition and specialization of ecosystem actors. These latter two are considered counterforces that push firms in the opposite direction from integrated hierarchies to the connected company archetype. Both opposing archetypes are characterized by conversed firm boundaries. This refers to that ownership boundaries are negatively related to awareness and influence boundaries. In case of the integrated hierarchy archetype, ownership boundaries are relatively broad whereas awareness and influence boundaries are relatively narrow. In case of the connected company, these trends are reversed. The data revealed a situation that was characterized by relatively broad ownership, awareness and influence boundaries.

Pooled ownership

One of the actors in the industrial automation ecosystem (SI 4) described a situation of firm boundary setting that included broad ownership, awareness and influence boundaries. By the end of 2017, development of Brainport Industry Campus started. At this campus, manufacturing firms as well as education and government institutions are physically located at the same location. Besides, they do not only share the same building but also integrate business processes like ordering, goods reception and mutual orders. SI 4 identified the following reasons how this is done:

> *"What we observe is that boundaries between firms are changing substantially. By working with good standards, digitalize processes, objects and connect these through the internet, one can organize business much easier with different companies."* (SI 4, interview 4)

When analyzing this situation from a firm boundary perspective, firms at the Brainport Industry Campus are considered to widen their ownership, influence and awareness boundaries. In this case, manufacturing firms pool ownership of processes like ordering, so these processes reside within the ownership boundaries of all firms. However, because these processes must be adapted to other processes with all firms, they also have wide awareness and influence boundaries. These wide awareness and influence boundaries stem from the requirement to be knowledgeable about processes of their counterparts and be able to influence them. This is necessary because shared processes to fit internal processes of all participating firms.

To draw a conclusion, from the data it appears firms respond to increasing interdependence and co-specialization in various ways. On the one hand, they move towards an integrated hierarchy by broadening their ownership boundaries and narrowing their awareness and influence boundaries. This is driven by increasing activity and resource interdependence, complexity and co-innovation risk. On the other hand, firms head towards a connected company archetype by narrowing ownership boundaries and broadening awareness and influence boundaries. This appears to be driven by increasing number of competencies needed to materialize a value proposition and increasing specialization of manufacturing firms. Aspects that might drive integrated hierarchies can directly be connected to increasing interdependence and co-specialization. Aspects that drive connected companies are considered counterforces to these co-evolutionary logic developments. Finally, it appears that industry 4.0 enables an alternative typology for firm boundary setting that is characterized by broad ownership, awareness and influence boundaries.

4.2.2. Organizational coupling

Organizational coupling represents the tension between firm distinctiveness and responsiveness among ecosystem actors. This tension implies that at least two independent organizations are involved and that not all activities and resources reside within the same ownership boundaries. Because at least two independent organizations are involved, organizational coupling is especially relevant in context of the connected company archetype of firm boundary setting. More so, because, organizational coupling gives a detailed understanding about structural processes that affect influence and awareness boundaries. As was discussed earlier, organizational coupling exists of strength, directness, consistency and dependency (Beekun & Glick, 2001). Data did not indicate anything about consistency but revealed industry 4.0 related insights regarding the other three aspects. Moreover, contradicting effects on the three aspects of organizational coupling were observed. In other words, both trends of shifts towards tight coupling and organizational decoupling were observed. This difference could, however, be explained by the nature of exchange, distinguishing between specialism-based and commodity-based exchanges. Referring to this difference, steel editing and hydraulics of OEM 1 is used to illustrate differences between specialism and commodity-based exchange. Specialism-based interaction (i.e., hydraulics) involves critical data that leaves the firm vulnerable when this data freely flows in the industrial automation market. Next to that, specialism-based exchanges are characterized by high complexity and include tacit knowledge that is highly concentrated and is difficult to transfer across firm boundaries. Commodity-based exchanges (i.e., steel editing) however involve non-critical data which can flow freely through the industrial automation market without affecting competitive advantage of OEM 1. Besides, commodity-based exchanges involve little complexity, include knowledge that is widely dispersed and can be easily standardized and transferred. Finally, commodity exchanges are characterized by purchasing processes based on lowest total cost (i.e., the sum of product price, search costs and other similar costs like ordering costs. Due to the differences between specialism-based and commodity-based exchanges, this section discusses industry 4.0 related effects on the organizational coupling of ecosystem partners for both types of exchange separately.

Specialism-based exchanges

In the industrial automation ecosystem, exchanges that were considered specialism-based included system integration, software development, machine building, flow handling and hydraulics. These are reflected on in terms of strength, dependence and directness to analyze organizational coupling regarding specialism-based exchanges.

Strength

Overall, the data assumes that relations between ecosystem partners engaging in specialism-based exchanges become stronger due to several reasons. First, it appears that these exchanges involve more critical data sharing in the industry 4.0 context. This leaves firms more vulnerable and exploitable in case of data leaks. Sharing of critical data and resulting vulnerability is an outcome of increasing interdependence between activities and resources. As stated before, a prerequisite for increasing interdependence and co-specialization between activities and resources is that actors also become increasingly interdependent and co-specialized. These increasing interdependence and co-specialization of actors is expressed in the need for actors to trust each other before they share critical data to relate each other's activities and resources. This is illustrated by Epsilon:

> *"It could be the case that technical issues are a bottleneck in sharing critical data, but I think it is mostly a trust issue. So, before a manufacturing firm shares data with a supplier, he wants to be sure that the other party is trustworthy. Therefore, it is mostly a relational issue."* (Epsilon, interview 13)

This quotation makes the connection between the willingness to share data and trust between two ecosystem partners. As was mentioned before, actors need to co-specialize in the sense that they must build trust. In the industrial automation ecosystem, this is done through personal contact:

> *"But in the end, there where you need each other and there is a need to cooperate, human contact is important. Especially when firms need to share critical information, they need to know that their information lands in a trustworthy place. And to create this trust, human contact between firms remains essential."* (TS 1, interview 06)

This quotation indicates that firms cope with increasing interdependence and co-specialization of activities, resources and actors by remaining personal contact. Because personal contact indicates the increasing strength of inter-firm relationships, this hints towards tighter organizational coupling as a response to increasing interdependence and co-specialization of activities, resources and actors.

Dependence

Dependence is an organizational coupling aspect that can be directly linked to co-evolutionary logic. As was mentioned earlier, ecosystems partners become more interdependent and face more co-specialization. As a reaction, they must increasingly share data and cooperate, this was mentioned by MB 2:

> *"In certain areas, relationships with partners will become stronger because firms will interact deeper within each other's organizations. This is because of the need to share data. When firms want to gain benefits from it, they must be able to process the data and therefore cooperate. This will be seen between partners that have a high magnitude of exchange."* (MB 2, interview 10)

In this situation, it appears that ecosystem actors that engage in specialism-based exchanges respond to increasing interdependence by tighten coupling with ecosystem partners. This means that their responsiveness towards partners increases whereas distinctiveness decreases.

Directness
Data revealed increasing directness between actors within the industrial automation ecosystem that engage in specialism-based exchange. One example in the data stated that digitalization empowers customers to interact directly with the production of its suppliers. This can be done without interference of humans (e.g., engineers) throughout the value network like the following quotation states:

> *"The process of acquiring our product will be increasingly digitalized, and we strive to outsource work preparation to our customers. So, when a customer configures its product, our factory already knows what should be done. (…) It should also be clear for our suppliers what materials are needed and how they should deliver and produce it. So, when a customer orders a product, our suppliers immediately know that and how the demand for a specific component will change."* (OEM 2, interview 15)

In other words, OEM 2 wants to connect their customers not only to themselves but also to their suppliers. This is considered a response to increasing interdependence of activities and resources. By facilitating direct interaction between ecosystem partners, activities and resources become more aligned and adapted to each other. Especially because alterations in activities and resources at one actor, are directly noticed by other firms in the ecosystem. This contrasts with the alternative that ecosystem actors notice alterations only after information crosses multiple ecosystem actors. This means that directness between their customers and suppliers increases because they do not need to communicate through the focal firm. Increased directness is a consequence of digitalization of the ordering process which is enabled by industry 4.0 technologies. Moreover, it is a response to increasing interdependence between activities and resources.

So, partners in the industrial automation ecosystem that engage in specialism-based interaction respond to increasing interdependence and co-specialization by tighten organizational coupling with their ecosystem partners. However, it is still unclear how this holds for interaction based on commodity activities and resources.

Commodity-based exchanges
Commodity-based exchanges imply a high level of standardization and codifiable knowledge, contrasting with complex products which are characterized by high levels of customized and tacit knowledge. The data indicates that ecosystem partners which engage in commodity-based exchange loosen their coupling despite increasing interdependence and co-specialization of activities, resources and actors. Discussing organizational coupling in terms of strength, dependence and directness provides understanding of the development of looser organizational coupling.

Strength
According to the data, ecosystem partners engaging in commodity-based transactions increasingly choose for transactional and weak relations. This trend is driven by the

digitalization of processes and decreasing personality of relations. The following quotation of OEM 1 exemplifies this observation:

> *"When I order stainless steel bolts, I do not need to know from whom I am buying or where the supplier is located, that is just not interesting. I do not need personal contact for buying a bolt because that is such a commodity meaning that I just want to have the cheapest one. And the cheapest bolt is located at the place which has the most automated processes in terms of both production and ordering."* (OEM 1, interview 11)

This quote implies that commodity exchanges are executed at the lowest possible price, where price is not only the purchasing price of the product itself but also the effort it takes to execute an order. This means that the process of ordering and production combined need to be as efficient as possible. Commodity offerings are often not distinctive in terms of product characteristics or price due to high standardization. Therefore, augmented services determine the lowest procurement price and unique capability of commodity offerings. This can be seen in the following quotation:

> *"Often I choose commodity products like bolts on price but sometimes the possibilities for digital connection is decisive because that could lead to significant time efficiencies and then price becomes less important. But that also depends on the magnitude of exchange between partners."* (MB 2, interview 10)

Because commodity activities and resources are highly codifiable, they are suitable for standardization. Combined with industry 4.0 driven end-to-end digital integration, commodity-based exchanges increasingly apply far-reaching digitalization of ordering processes with the purpose to maximize ordering efficiency. However, this is at the expense of human interaction and might result in less personal relations between ecosystem partners. In other words, interaction frequency decreases and therefore relations between ecosystem partners engaging in commodity-based exchanges might decrease in strength.

Dependence

Evidently, the dependency between partners engaging in commodity-based exchanges decreases. For this type of exchange, dependency stemming from "lack of substitutes" decreases because industry 4.0 and digitalization lead to increasing transparency and decreasing search costs. This is observed in the following quotation of TS 1:

> *"Firms in commodity markets become less dependent on each other. The world becomes bigger and more transparent, so firms are better able to "shop". They only face the risk that the offering does not meet their quality or delivery requirements but that can also become transparent. So current technology can mitigate the risks of engaging in exchanges on a transactional basis."* (TS 1, interview 06)

When data becomes more widely available, searching costs for customers decrease because they can search easier and wider for suppliers that match their needs due to a more transparent market. This means that dependency of customers on suppliers originating from an increase in available substitutes decreases. Phrased alternatively, due to decreasing dependence driven by decreasing market imperfections, ecosystem partners that interact based on commodity knowledge loosen their coupling.

Directness

The final organizational coupling related aspect that was observed in data is directness. Through the introduction of platform business models, ecosystem partners that engage in commodity-based interaction decrease directness. Both TS 1 and Epsilon expect platform business models, which already dominate consumer markets, to be largely implemented in manufacturing industries. The latter stated the following:

> *"We notice it already in the consumer market where consumers do not communicate with taxi drivers anymore, but we communicate through a platform (i.e., Uber). This might also be observed in the manufacturing industry where firms can place a request for wood editing and this request gets fulfilled by the best matching supplier."* (Epsilon, interview 14)

Even though both TS 1 and Epsilon discuss an expectation, MB 1 showed that this expectation already becomes a reality. They developed and implemented a new platform business model which was already discussed in the co-specialization section. The following statement was made by MB 1 regarding this new business model:

> *"With our new business model, we want to become the Amazon of our own industry and eventually of other industries as well. With this new business model, we do not only want to sell our own products but those of others as well."* (MB 1, interview 09)

The introduction of platform business models in commodity markets increases the number of hierarchical communication levels between ecosystem partners which therefore leads to a decrease in directness. All in all, it appears that ecosystem actors that engage in commodity-based interaction decrease directness through industry 4.0 enabled platform business models. Despite activities, resources and actors become increasingly interdependent and co-specialized, partners that engage in commodity-based exchanges loosen their coupling.

Overall, it appears that ecosystem partners engaging in specialized-based interaction tighten their coupling. On the contrary, ecosystem partners engaging in commodity-based interaction loosen their coupling. The former has three central drivers: 1) ecosystem partners continue to have personal contact to build trust, 2) ecosystem partners must share critical data to anticipate on increasing interdependence and co-specialization and 3) ecosystem partners communicate more directly to anticipate on increasing interdependence and co-specialization. On the other hand, ecosystem partners that engage in commodity-based interaction loosen coupling because 1) they aim to increase efficiency and lower costs leading to less personal relations, 2) dependence decreases due to decreasing market imperfections and 3) directness decreases through the increasing introduction of platform business models.

4.2.3. Modularity

Overall, data shows contrasting trends regarding the development of ecosystem modularity in the industrial automation ecosystem. On the one hand, ecosystem actors increasingly adopt a modular ecosystem approach but, in some cases, they also expect increasing use of long-term relationships. Long-term relationships can be considered the opposite from a modular ecosystem approach. This contradiction of modularity and long-term relationships can be explained by making the distinction between specialism-based and commodity-based interaction. Therefore, this section discusses these different types of interactions separately starting with specialism-based interaction.

Specialism-based exchanges

Data shows that partners involved in specialism-based exchange are expected to increasingly engage in long-term relationships. According to TS 1, ecosystem partners need to engage in long-term relationships, this is represented in the following quotation:

> *"We are heading to an environment that is characterized by faster time-to-market processes, shorter PLC's and more personalized products. This means that firms need to partner with suppliers in the critical chain of such a product. Because when firms do not do that, and the supplier needs to know exactly what a customer needs, firms cannot place a tender, receive offers of six different firms and pick one. In that case, firms are just too slow. Firms need to head more towards partnerships and suppliers need to know exactly what their customers need, they need to share roadmaps. When firms do not do this, they are not fast and flexible enough. This holds only for a subset of the value chain (i.e., specialism-based exchanges)."* (TS 1, interview 06)

This quotation demonstrates why modularity decreases in parts of the business ecosystem that engage in specialism-based exchanges. Firms engage in long-term relationships instead of adopting a modular approach towards the industrial automation ecosystem to anticipate on increasing co-specialization of activities and resources. A concrete example of decreasing modularity in complex exchanges is observed at the Brainport Industry Campus which was mentioned earlier by SI 4. Brainport Industry Campus focuses on high-tech and knowledge-intensive manufacturing firms. It is said that at the Brainport Industry Campus, the whole value chain manifests itself as a single whole. This means that they closely cooperate in terms of sharing knowledge on product development and R&D. However, being located in the same building and align processes might also imply decreasing because firms become connected with each other on the long-term. A modular approach implies that firms seek partners that fit contemporary needs and establish new partnerships with firms that optimally fit these needs. However, establishing new partnerships also requires firms to transfer their knowledge, which is a complex and time-consuming task in case of specialized and tacit knowledge. In the case of industry 4.0, which is characterized by shorter product life cycles and more personalized products, this is not possible. Therefore, in case specialism-based interaction, a modular approach to business ecosystems appears to be inferior relative to long-term relationships.

Commodity exchanges

As discussed earlier, industry 4.0 and digitalization increase transparency and decrease market imperfections through platform business models. This leads to decreasing searching costs for customers meaning that it becomes easier for firms to compare the performance of different (potential) partners. Decreasing market imperfections could ultimately lead to increasing abilities for organizations to switch ecosystem partners that fit contemporary needs. In other words, decreasing market imperfections lead to increased ecosystem modularity. Because commodity knowledge is standardized and easily transferable, modularity appears to be a suitable way to cope with increasing interdependence and co-specialization of activities, resources and achieve speed and flexibility.

> *"We see it in the consumer market already, more platforms appear where you can easily compare different offerings. Interaction between firms becomes less personal and firms can just look into a database or on the platform. (…) We can see it at 24/7 Tailorsteel that there is almost no personal contact because we can just upload a digital drawing and they start producing. At this moment one firm operates like this but in the future, we will move more towards a platform approach meaning that different metal editing firms can be compared and the cheapest wins the tender."* (Epsilon, interview 14)

This quotation of Epsilon describes a future situation in which firms place a call for proposal on a platform with technical specifications for metalworking. Next, they will cooperate and engage in interaction with the best fitting partner. Consequently, long-term relations with a limited number of partners are replaced by multiple transactional relations within a certain functional position. Another trend in commodity-based exchanges, enabled by digitalization, is the usage of real-time data which makes the exchange more dynamic. This is demonstrated by the following evidence provided by SI 4:

> *"So, if you want to transport a pallet from A to B, firms can look for spare capacity of transportation. The way of working is based on real-time information, this leads to a more dynamic way of organizing logistics."* (SI 4, interview 04)

In this case, logistics is used as an example in which real-time data is used to match logistics spare capacity with logistics demand. This way of organizing logistics is increasingly modular relative to current ways of organizing logistics. All in all, ecosystems actors in the industrial automation ecosystem engaging in commodity-based interaction, appear to increasingly adopt a modular ecosystem approach. This was observed because related knowledge is easily codified and standardized. This enables platform business models to decrease market imperfections and realize an optimal fit between supply and demand. More so, codifiable knowledge and leveraging real-time data enable a dynamic and modular organization of activities and resources.

Overall, it appears that firms in the industrial automation respond differently to increasing interdependence and co-specialization of activities, resources and actors in terms of ecosystem modularity. In the case of specialism-based exchanges, ecosystem actors engage in long-term relations because involved knowledge is tacit and therefore not easily transferred. In contrast, commodity-based exchanges respond to these interdependence and co-specialization developments by increasingly adopt a modular ecosystem approach. This is due to the ability to standardize and easily transfer knowledge enabling relative fast and successful establishment of new exchanges. This means that firms that engage in commodity-based exchanges can match their contemporary needs with the best fitting partners without engaging in a long-term relationship.

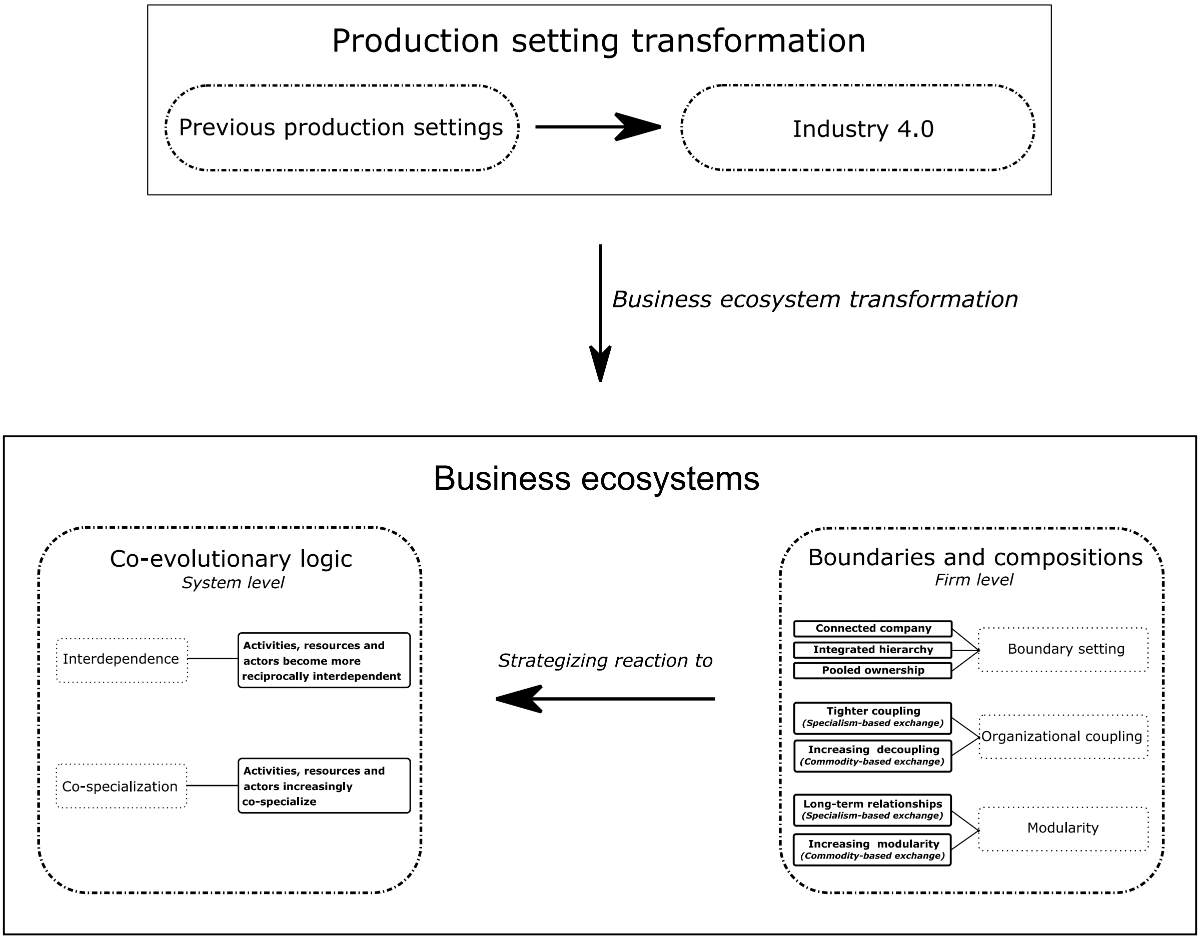
4.3. Conclusion

Based on the results that were presented in this section, the research question can be answered. The research question was formulated as follows:

"How do co-evolutionary logic and resulting boundaries and compositions of business ecosystems transform from older production settings to an industry 4.0 setting?"

Based on above presented results derived from the industrial automation ecosystem case, this research question can now be answered. In terms of co-evolutionary logic, activities, resources and actors in industry 4.0 oriented business ecosystems become more reciprocally interdependent and increasingly co-specialized. This means that input-output relations between activities, resources and actors become reciprocal. It also means that these three organizational layers increasingly share the same development direction. Ecosystem actors respond to increasing reciprocal interdependence and co-specialization by means of boundary setting, organizational coupling and modularity. Regarding the former, data revealed that firms responded in different ways by broadening ownership boundaries and narrowing awareness and influence boundaries but the other way around as well. Besides, one situation hinted towards a response that was characterized by broad ownership, awareness and influence boundaries. In terms of organizational coupling, ecosystem actors responded to co-evolutionary logic developments by both tighten and loosen coupling. This difference can be explained by differentiating between specialism-based and commodity-based exchanges. The final form of response that was observed in the data involved modularity. Again, contrasting trends were observed. On the one hand, firms increasingly adopted a modular approach towards ecosystems but on the other hand firms, in some cases, increasingly engaged in long-term relationships. These contrasting trends can also be explained by differentiating between specialism-based and commodity-based exchanges. These results are visualized in figure 11.

Figure 11. Overview of study results



5. Discussion

This chapter discusses the outcomes of the industrial automation ecosystem case study. Besides, it illustrates how these outcomes add to our theoretical understanding of industry 4.0 induced developments concerning co-evolutionary logic and resulting boundaries and compositions. This discussion is divided in two parts. First, the operationalization of ecosystem co-evolutionary logic and boundaries and compositions and its contributions are discussed. This is followed by a discussion of the outcomes concerning the application of the operationalization the industry 4.0 context.

5.1. Ecosystem operationalization

Overall, this study used the "*stable business exchange*" category from Aarikka-Stenroos and Ritala (2017) as lens towards business ecosystems. Their research aimed to systematically analyze usage of the ecosystem concept in B2B journals. Therefore, it was outside the research scope to provide a proper operationalization of interrelations and structures (i.e., co-evolutionary logic and boundaries and compositions) within business ecosystems. By means of an abductive research design, this research developed an operationalization of the co-evolutionary logic and boundaries and compositions. The former was broken down in interdependence and co-specialization whereas the former consisted of boundary setting, organizational coupling and modularity. The combination of interdependence and co-specialization to operationalize co-evolutionary logic captures both a spatial and temporal dimension. To be more specific, this combination provides on the one hand a holistic understanding of the nature of actor interrelations (i.e., interdependence). On the other hand, this combination provides understanding about the direction of these interrelations over time. Therefore, it appears to capture understanding of interrelations within business ecosystems. Next to co-evolutionary logic, structural organization of the business ecosystem (i.e., boundaries and compositions) is operationalized by the concepts of boundary setting, organizational coupling and modularity. From the data, it appears that these dimensions provide an in-depth understanding of processes through which firms can respond to system level developments (i.e., co-evolutionary logic). Boundary setting provides understanding of firm boundaries in terms of ownership, awareness and influence boundaries whereas organizational coupling aims to understand relations between two independent actors. Additionally, modularity focuses on the degree of actor interchangeability. This combination results in a comprehensive view on an ecosystem's structural organization. Overall, operationalizations of co-evolutionary logic and boundaries and compositions presented in this research provide scholars with a theoretical lens to look at business ecosystems and understand developments within these ecosystems. This research applied the operationalization in the case of industry 4.0 but future research may validate, adjust or elaborate on this operationalization by applying this model in other empirical contexts.

To develop the operationalization, this research firstly arrived at the IMP literature through for example structure ecosystems according the ARA model (Ford et al., 2008) and boundary setting (Gadde, 2014). However, IMP literature is often criticized for adopting a static approach towards networks by delivering structural snapshots even though dynamics are important to consider as well (e.g., Halinen, Salmi, & Havila, 1999; Medlin & Törnroos, 2012). From the work of Loohuis, von Raesfeld and Groen (2010), it appears that past experiences in business relations are important to consider because they impact future actions and developments. The combination of co-evolutionary logic and boundaries and compositions in the stable business exchange lens led to a balanced combination between structure and processes. Because co-evolutionary logic was operationalized through interdependence and co-specialization it included both a spatial and temporal dimension. These dimensions were reflected in the boundaries and compositions constituent as well. This constituent is inherently connected to structure but by considering the work of Vargo et al. (2017), structures are considered representations of underlying processes implying a process view on transformation. Having this balance between structure and process appeared to be important since firms incrementally develop their ecosystems to industry 4.0 meaning that they take existing structures and relationship into consideration. When this research would have solely focused on processes, results would have been fixated too much on firm level activities (e.g., Loohuis et al., 2010). This would have violated the system-thinking requirement of Vargo et al. (2017). On the other hand, over relying on structure would not deliver understanding how ecosystems change over time and relative to older production settings. Therefore, operationalization of business ecosystems used in this research is considered to deliver a complete understanding of business ecosystem development.

5.2. Ecosystem transformation in an industry 4.0 context

Co-evolutionary logic

Co-evolutionary logic was analyzed in terms of interdependence and co-specialization. Results showed that ties between activities and resources become increasingly characterized by reciprocity. This means that output - input relations are not one-way but that output downstream in the value network serves as input for other (upstream) ecosystem actors as well. Over time, these interdependences lead to increased co-specialization which means that activities and resources head towards a shared development direction and increasingly adapt to each other. Since activities and resources become increasingly tied, actors also become more interdependent and co-specialized because they need to trust each other before activities and resources are tied to each other. So, co-evolutionary logic of industry 4.0 based business ecosystems is characterized by increasing reciprocal interdependence and co-specialization.

5.2.1. Boundaries and compositions

To cope with these co-evolutionary logic developments, individual actors reacted through structural organization processes of the ecosystem. To be more specific, these processes refer to firm boundary setting, organizational coupling and modularity.

Firm boundary setting

Regarding boundary setting, results showed shifts to both archetypes of integrated hierarchy and connected company. This resonates with statements of Gadde (2014) that relying on a single archetype (i.e., integrated hierarchy or connected company) might be problematic because firms should not over rely on a generic business recipe. Instead, firms should maintain a dynamic approach to strategizing and constantly recreate and redraw firm boundaries that fit contemporary environment. Underlying drivers to in or outsource that were observed in the case study also complied with observations of Gadde (2014). This means that a shift to integrated hierarchy is observed when ecosystem actors try to realize increasing integration between processes, cope with complexity that accompanied these integration requirements and solve co-innovation risks. On the other hand, shifts to a connected company archetype was driven by increasing number of competencies needed to materialize a value proposition and increasing specialization of firms on core business. Even though observations regarding integrated hierarchies and connected companies fitted well with underlying drivers, an alternative typology was observed that was not discussed by Gadde (2014). He discussed these two typologies as a continuum in between which firms are located. Within these typologies, ownership boundaries are negatively related to awareness and influence boundaries. In other words, when ownership boundaries become broader, awareness and influence boundaries become narrower and the other way around. However, observations in the data could not be fully explained by the model of Gadde (2014). The observation at Brainport Industry Campus was characterized by broad ownership boundaries as well as broad awareness and influence boundaries. This observation included sharing of processes like ordering, receiving and mutual deliveries. This means that ecosystem actors pooled ownership (i.e., broad ownership boundaries) which had to fit every firm’s internal processes (i.e., broad awareness and influence boundaries). Future research could increase understanding regarding ownership, awareness and influence boundaries and their interrelations in the context of this industry 4.0

enabled process sharing. Additionally, further research endeavors might investigate which archetype, including the alternative archetype mentioned before, is most attractive in which situation. These directions would be valuable to managers in the sense that it adds to their understanding to insource, outsource or share processes with partners and make an optimal decision. Besides, understanding strong and weak points of these archetypes in different environments may support managers in their strategizing processes of boundary setting, now and in the future.

Organizational coupling

Besides boundary setting, data revealed shifting trends to both tight organizational coupling and organizational decoupling. The latter seems a counterintuitive response to a trend of increasing interdependence and co-specialization of activities, resources and actors. Brusoni and Prencipe (2013) expect tight organizational coupling in situations where a common frame of reference needs to be created and activities and resources must be tightly coordinated. Both were observed in co-evolutionary logic developments in the form of increasing interdependence and co-specialization of activities, resources and actors. However, counterintuitive findings of increasing organizational decoupling might be understood by zooming in on the underlying drivers. Decoupling was driven by 1) decreasing strength because human contact diminished to maximize ordering efficiency, 2) decreasing dependence because digital platform business models reduce market imperfections and 3) decreasing directness because firms do not communicate directly with each other but through platforms instead. So, digitalization of communication and increased introduction of platform business models appears to result in more decoupling.

The latter was discussed by Brusoni and Prencipe (2013) by identifying that platforms enable automatic responsiveness through standardized interfaces. However, they discussed platforms which fit the typology of platform ecosystem instead of market intermediary (Thomas, Autio, & Gann, 2014). Platform ecosystems are based on products or technologies around which a platform has developed whereas market intermediary platforms purely focus on brokerage tasks that connect multiple sides of the market (e.g., 4PL actors focusing on information-based exchange streams as mentioned by Huemer, 2017). This research theoretically contributes by adding the concept of intermediary platforms to the discussion concerning organizational coupling. To fuel this discussion, findings from this study found that introduction of multi-sided platform business models in the manufacturing industry drove shifts to organizational decoupling in commodity-based exchanges. This was possible due to the nature of involved knowledge which is highly codifiable and relatively easy to standardize. However, this study was only able to state whether introduction of multi-sided platforms would lead to tighter coupling or more decoupling. Future research may investigate this relation more in-depth by studying organizational coupling in the context of multi-sided platforms. This study has not had this as focus context and would therefore be a valuable contribution.

Modularity

Concerning ecosystem modularity, data revealed increasing modularization regarding commodity-based exchanges whereas the opposite was observed for specialism-based exchanges. The latter seems to contradict with literature because industry 4.0 is characterized by mass customization, high levels of technological change and competitive intensity. This seems contradictive because these characters are three aspects that drive ecosystem modularization according to Schilling and Steensma (2001). This leads to the expectation that ecosystems become increasingly modular in an industry 4.0 setting. However, Baldwin and Clark (2003) mentioned three prerequisites for modularity including architectures, interfaces and standards. Apparently, these are not satisfied in the case of specialism-based exchange in an industry 4.0 setting because involved knowledge is complex and tacit by nature. This nature prevents knowledge to be easily transferred and therefore interfaces and standards are hard or cannot be established. This study theoretically contributes by illustrating that nature of knowledge involved in exchanges may affect the relation between drivers of modularization, mentioned by Schilling and Steensma (2001), and ecosystem modularity. This adds to the discussion by considering that complexity matters when choosing for a modular ecosystem approach (e.g., Vickery, Koufteros, Drö, & Calantone, 2015). However, illustrating the relevance of knowledge nature was not the only finding regarding ecosystem modularity.

As mentioned before, industry 4.0 is increasingly characterized by market intermediary platforms. These platforms drive modularization of ecosystems because they facilitate standardized communication and decrease market imperfections making it easier for firms to "shop". Literature discusses how platforms can be used as a tool to achieve product and process modularity (e.g., Liu, Wong, & Lee, 2010; Pekkarinen & Ulkuniemi, 2008). Still, it is not yet clear how platform business models impact ecosystem modularity. This study adds to this understanding by illustrating that multi-sided platforms drive ecosystem modularity by decreasing market imperfections and increase transparency. However, future research could add to this understanding by investigating ecosystem modularity in market intermediary platforms dominated industries or settings. This research has not specifically focused on modularization in context of market intermediary platforms. Therefore, research that is focused on this setting would give a more detailed understanding of the influence that market intermediary platforms might have on ecosystem modularity developments. For managers this would be valuable to know since it could help them organizing an ecosystem that is aligned with the new industry 4.0 setting.

6. Managerial implications

This research provided several practical contributions that help managers to adapt to the upcoming industry 4.0 manufacturing context. Overall, managers should understand that organizations become increasingly reciprocally interdependent and become more co-specialized in terms of activities, resources and actors. This is important to understand because it forms the basis for ecosystem strategizing on the firm level. Based on these co-evolutionary logic developments, it appears that firms can respond in terms of boundary setting, organizational coupling and modularity. However, results hint that there is no uniform response to co-evolutionary logic development in terms of three aspects. Therefore, they need to be discussed more in-depth separately.

According to the results, the decision to in or outsource should still be based on a business case in which benefits, and costs must be weight against each other. Even though it appears that industry 4.0 does not change this phenomenon, outcomes of business cases may be different in the industry 4.0 context. Managers must be aware that organizations become increasingly interdependent and that their activities and resources must increasingly share development paths. This requirement for increased integration may increase costs of coordination stemming from sourcing these activities and resources outside the firm boundaries. As a result, it may be wise for managers to insource activities and resources that previously resides outside the firm. However, it may also apply to the other way around. Results indicate that more competencies are needed to materialize a value proposition and that firms become more focused on their core business. This could lead to increasing costs for coordinating activities and resources in-house meaning that is more sensible to rely on external partners for these activities and resources. All in all, managers need to reconsider which activities and resources are required to materialize a value proposition and how these activities and resources become connected in the industry 4.0 paradigm. This connection should especially be considered in terms of interdependence and co-specialization. Based on such a reconsideration, managers may decide to insource activities and resources previously sourced outside the firm and the other way around. In other words, industry 4.0 may have consequences for the activity and resource constellation of manufacturing firms. Managers are required to attend to these developments and make bold decisions involving far-reaching reconfiguration of the firm's activity and resource constellation. Next to considering activity and resource constellations, managers may also need to reconsider their orientation towards ecosystem partners in terms of coupling.

According to the results, managerial strategizing decisions on boundary setting are different in specialism-based and commodity-based exchanges. In case of the former, managers must be aware that they need to be increasingly flexible and agile, but that involved knowledge is tacit and hard to transfer. The data appears to advice managers to tighten coupling with ecosystem partners with whom they engage in specialism-based exchange. The opposite holds for ecosystem partners that engage in commodity-based exchange. In this case, information is codifiable and easy to transfer. Within this type of exchange, firms seek to minimize total costs of exchange. Within the industry 4.0 context, firms can respond to this by digitalizing interaction as much as possible and that communication is increasingly done through mediating platforms. In other words, managers can choose to increasingly decouple ties with ecosystem actors with whom they engage in commodity-based exchange. These findings are not only relevant for managers to understand how they should actively engage their partners. These findings should also provide understanding about how managers will be engaged by ecosystem partners in the industry 4.0 context. This is important to understand when interacting with partners and be able to understand changes in their attitude towards the firm. Ecosystem partners may alter their orientation to the firm in the industry 4.0 context, managers should be prepared for these developments.

As was the case for organizational coupling, managerial recommendations differ whether ecosystem actors engage in specialism or commodity-based exchange. In case of the former, managers are expected to increasingly engage in long-term relationships with their ecosystem partners. However, in case of the latter, dynamics among ecosystem actors might drastically change. Especially because market imperfections might decrease in the industry 4.0 context, competition might become fierce and actors increasingly become replaceable. Firms that source commodity products or services need to consider ways to increase their uniqueness. Relying on information asymmetry and convenience drivers become less attractive due to platform business models and increased and easier possibilities to integrate inter-firm processes. In other words, preferring the supplier on the corner of the street because he knows exactly what you want may not be relevant because in a digital world, virtually every supplier knows exactly what you want. Therefore, industry 4.0 may have far-reaching consequences for firms that operate in a commodity-based area. Moreover, these developments may even threaten the continuity of firms in case of inadequate responses.

7. Limitations

This paper acknowledges that it had some limitations which are important to recognize and discuss. First, this study had an abductive character to include unexpected findings not initially recognized in the literature. Even though this fits with the explorative character of the study, measuring instruments (i.e., interview questions) were not purposefully geared for measuring unexpected observations, this could harm construct validity. In other words, some themes (e.g., boundary setting) were only considered after data collection was started. Therefore, interview questions were designed to measure organizational coupling, hierarchy and modularity but not firm boundary setting. Future research may use an inductive approach toward the operationalization of business ecosystem transformation which allows for pre-established measuring instruments. This could strengthen the findings of this research or adjust findings to overcome construct invalidities of this research.

The second limitation originates from the difference between business networks and ecosystems. In the literature review, this difference was illustrated by the level of awareness regarding connection. Business network boundaries reach to subjective awareness boundaries of actors participating in them. However, ecosystems also consider actors that are included even though not all actors are aware of them (i.e., through the value proposition). This study used interviews (i.e., subjective perspectives of actors) as main data collection method. This enabled inclusion of ecosystem actors of which interviewees ware actively aware off, or in some cases when the interviewer gave an indication of alternative actors possibly involved in the ecosystem. However, data collection could have led to exclusion of relevant ecosystem actors because interviewees were not aware and knowledgeable of them. Future research may rely more on observational data which might be collected through participatory case study research. This could provide more detailed insights including more unaware actors and dimensions of the ecosystem.

The third limitation considered in this paper refers to the time span of data collection. An interviewee was only interviewed at one point in time and asked to reflect on the development of ecosystem developments in the future relative to the present. However, this might have led that longitudinal effects are not considered. Since humans cannot predict the future, they can only have an idea how the future may differ from the present. Even though there is no alternative way of researching the future in the present, a longitudinal study with multiple data collection points could be valuable to review these findings. This would consent with the work of (Sofaer, 2002). Other research potential may include conducting longitudinal process research at manufacturing firms that already more developed in the industry 4.0 context. However, findings from early movers may not be generalizable to the late majority. Still, it could give a proper understanding about what to expect from ecosystem developments and provide managers with grip to deal with the new phenomenon.

A final limitation concerns different understandings of the industry 4.0 concept. The term is often used as a buzzword meaning that there are many different views on what it includes or excludes. This study tried to mitigate this problem by informing respondents of the meaning of industry 4.0 as considered in this research before interviews took place. However, during interviews it still appeared that some respondents has a strong (alternative) belief of what industry 4.0 meant to them. Especially when respondents had a very narrow idea of what industry 4.0 is, it might have prevented them from providing valuable results. Future endeavors of scholars and practitioners alike need to establish a clear definition of what industry 4.0 is and what it is and what it is not. This should result in a consistent language when discussing industry 4.0 which increases quality of discussions.

8. Conclusion

This paper started off from the literature gap that referred to a lack of understanding regarding inter-firm collaboration in an industry 4.0 setting to realize end-to-end digitalization. Using a single case study in the industrial automation ecosystem, this paper has extended and operationalized the stable business exchange approach to ecosystems of Aarikka-Stenroos and Ritala (2017). This was done by dividing co-evolutionary logic in interdependence co-specialization whereas boundaries and compositions were operationalized by boundary setting, organizational coupling and modularity. These operationalizations provided a balance between temporal and spatial dimensions making it an appropriate approach to analyze business ecosystem development. Regarding the development of co-evolutionary logic, it appeared that activities, resources and actors become more reciprocal interdependent and increasingly co-specialize. To cope with these developments, firms responded through strategizing on the dimensions of boundary setting, organizational coupling and modularity. Results from this investigation hint on far-reaching consequences of industry 4.0 to interrelations and structural organizations of manufacturing business ecosystems. This requires managers to thoroughly understand what industry 4.0 means for their firms but it demands bold and radical decision-making as well. Even though industry 4.0 has the potential to disrupt manufacturing industries for the better, this potential will not be unlocked without a struggle. Managers should prepare for the storm that is coming both on technical and organizational aspects.

References

Aarikka-Stenroos, L., & Ritala, P. (2017). Network management in the era of ecosystems: Systematic review and management framework. *Industrial Marketing Management*, *67*, 23–36.

Aarikka-Stenroos, L., Sandberg, B., & Lehtimäki, T. (2014). Networks for the commercialization of innovations: A review of how divergent network actors contribute. *Industrial Marketing Management*, *43*(3), 365–381.

Adner, R. (2006). Match your innovation strategy to your innovation ecosystem. *Harvard Business Review*, *84*(4).

Adner, R. (2016). Ecosystem as Structure: An Actionable Construct for Strategy. *Journal of Management*, *43*(1), 39–58.

Adner, R., & Kapoor, R. (2010). Value creation in innovation ecosystems: How the structure of technological interdependence affects firm performance in new technology generations. *Strategic Management Journal*, *31*(3), 306–333.

Anderson, J. C., Hakansson, H., & Johanson, J. (1994). Dyadic Business Relationships within a Business Network Context. *Journal of Marketing*, *58*(4), 1.

Baldwin, C. Y., & Clark, K. B. (2003). Managing in an age of modularity. *Architectures, Networks, and Organizations*, *149*(1), 84–93.

Beekun, R. I., & Glick, W. H. (2001). Organization Structure from a Loose Coupling Perspective: A Multidimensional Approach. *Decision Sciences*, *32*(2), 227–250.

Brettel, M., Friederichsen, N., Keller, M., & Rosenberg, M. (2014). How Virtualization , Decentralization and Network Building Change the Manufacturing Landscape : *International Journal of Mechanical, Aerospace, Industrial and Mechatronics Engineering*, *8*(1), 37–44.

Brusoni, S., & Prencipe, A. (2013). The organization of innovation in ecosystems: Problem framing, problem solving, and patterns of coupling. *Advances in Strategic Management*, *30*, 167–194.

Christopher, M. (2000). The Agile Supply Chain Competing in Volatile Markets. *Industrial Marketing Management, 29* (1), 37-44.

Douma, S. W., & Schreuder, H. (2012). *Economic approaches to organizations*. Englewood Cliffs NJ: Financial Times Prentice Hall.

Dubois, A. (1998). *Organizing Industrial Activities Across Firm Boundaries*. Routledge.

Dubois, A., & Gadde, L.-E. (2002). Systematic combining: an abductive approach to case research. *Journal of Business Research*, *55*, 553–560.

Eisenhardt, K. M., & Graebner, M. E. (2007). Theory Building from Cases: Opportunities and Challenges. *Source: The Academy of Management Journal*, *50*(1), 25–32.

Ford, D., Gadde, L., Håkansson, H., Snehota, I., & Waluszewski, A. (2008). Analysing business interaction. *IMP Conference, Uppsala*, 1–37.

Ford, D., & Mouzas, S. (2013). Service and value in the interactive business landscape. *Industrial Marketing Management*, *42*(1), 9–17.

Frow, P., McColl-Kennedy, J. R., & Payne, A. (2016). Co-creation practices: Their role in shaping a health care ecosystem. *Industrial Marketing Management*, *56*, 24–39.

Gabriel, M., & Pessl, E. (2016). Industry 4 . 0 and Sustainability Impacts : Critical Discussion of Sustainability Aspects With a Special Focus. *Annals of Faculty Engineering Hunedoara – International Journal of Engineering*, *14*(2), 131–137.

Gadde, L.-E. (2014). Strategizing at the boundaries of firms. *IMP Journal*, *8*(2), 51–63.

Gates, B. D., & Head, G. (2017). Industry 4.0 : It ' s all about the people. *Kpmg*.

Hackney, R., Burn, J., & Salazar, A. (2004). Strategies for value creation in electronic markets: towards a framework for managing evolutionary change. *The Journal of Strategic Information Systems*, *13*(2), 91–103.

Håkansson, H., & Ford, D. (2002). How should companies interact in business networks? *Journal of Business Research, 55* (2), 133-139.

Håkansson, H., & Snehota, I. (1989). No business is an island: The network concept of business strategy. *Scandinavian Journal of Management*, *5*(3), 187–200.

Halinen, A., Salmi, A., & Havila, V. (1999). From Dyadic Change to Changing Business Networks: An Analytical Framework. *Journal of Management Studies*, *36*(6), 779–794.

Hienerth, C., Lettl, C., & Keinz, P. (2014). Synergies among Producer Firms, Lead Users, and User Communities: The Case of the LEGO Producer-User Ecosystem. *Journal of Product Innovation Management*, *31*(4), 848–866.

Huemer, L. (2017). Strategizing in horizons and verizons. *IMP Journal*, *11*(2), 274–288.

Iansiti, M., & Levien, R. (2004). Strategy as Ecology. *Harvard Business Review*, *82*(3), 68–81.

Kagermann, H., Wahlster, W., & Helbig, J. (2013). Recommendations for implementing the strategic initiative Industrie 4.0. *Final Report of the Industrie 4.0 WG*, (April), 82.

Kumar, K., & Van Dissel, H. G. (1996). Sustainable Collaboration: Managing Conflict and Cooperation in Interorganizational. *MIS Quarterly*, *20,* 279-300.

Lacoste, S. (2016). Sustainable value co-creation in business networks. *Industrial Marketing Management*, *52*, 151–162.

Langlois, R. N. (2002). Modularity in technology and organization. *Journal of Economic Behavior & Organization*, *49*, 19–37.

Le, T. T., & Tarafdar, M. (2009). Business ecosystem perspective on value co-creation in the Web 2.0 era: implications for entrepreneurial opportunities. *International Journal of Entrepreneurial Venturing*, *1*(2), 112.

Lei, D., Hitt, M. A., & Goldhar, J. D. (1996). Advanced Manufacturing Technology: Organizational Design and Strategic Flexibility. *Organization Studies*, *17*(3), 501.

Liao, Y., Deschamps, F., Loures, E. de F. R., & Ramos, L. F. P. (2017). Past, present and future of Industry 4.0 - a systematic literature review and research agenda proposal. *International Journal of Production Research*, *55*(12), 3609–3629.

Liu, G., & Rong, K. (2015). The Nature of the Co-Evolutionary Process: Complex Product Development in the Mobile Computing Industry's Business Ecosystem. *Group and Organization Management*, *40*(6), 809–842.

Liu, Z., Wong, Y. S., & Lee, K. S. (2010). Modularity analysis and commonality design: a framework for the top-down platform and product family design. *International Journal of Production Research*, *48*(12), 3657–3680.

Loohuis, R. P. A., von Raesfeld, A. M., & Groen, A. J. (2010). When Is It the Right Time To Change ? a Case Study of Implementing a New Activity in an Existing Business Relationship. *Proceedings of the 26th IMP Conference, Budapest, Hungary*, 1–20.

Medlin, C. J., & Törnroos, J.-Å. (2012). Time and process in business network research. *Industrial Marketing Management*, *41*(2), 215–223.

Miles, M. B., & Huberman, A. . M. (1994). *Qualitative data analysis*. Thousand Oaks, CA: Sage.

Moore, J. F. (1993). Predators and Prey: A New Ecology of Competition. *Harvard Business Review*, *71*(3), 75–86.

Murmann, J. P. (2013). The Coevolution of Industries and Important Features of Their Environments. *Organization Science*, *24*(1), 58–78.

Normann, R., & Ramírez, R. (1993). From value chain to value constellation: designing interactive strategy. *Harvard Business Review*, *71*(4), 65–77.

Orton, J. D., & Weick, K. E. (1990). Loosely Coupled Systems: A Reconceptualization. *Academy of Management Review*, *15*(2), 203–223.

Ostrom, A. L., Parasuraman, A., Bowen, D. E., Patrício, L., & Voss, C. A. (2015). Service Research Priorities in a Rapidly Changing Context. *Journal of Service Research*, *18*(2), 127–159.

Pekkarinen, S., & Ulkuniemi, P. (2008). Modularity in developing business services by platform approach. *The International Journal of Logistics Management*, *19*(1), 84–103.

Pisano, G., & Shih, W. (2009). Global competitiveness in the new world. *Harvard Business Review*, *87*(4), 114–125.

Porter, M. E., & Heppelmann, J. E. (2014). How Smart, Connected Products Are Transforming Competition. *Harvard Business Review*, *92*(11), 64–88.

Pulkka, L., Ristimäki, M., Rajakallio, K., & Junnila, S. (2016). Applicability and benefits of the ecosystem concept in the construction industry. *Construction Management and Economics*, *34*(2), 129–144.

Rafael, R., Shirley, A. J., & Liveri, A. (2014). Report To The President Accelerating US Advanced Manufacturing. *Report, Washington DC, US*.

Rong, K., Hu, G., Lin, Y., Shi, Y., & Guo, L. (2015). Understanding business ecosystem using a 6C framework in Internet-of-Things-based sectors. *International Journal of Production Economics*, *159*, 41–55.

Saldaña, J. (2013). *The coding manual for qualitative researchers* (Second edition.). Los Angeles: SAGE Publications.

Schilling, M. A., & Steensma, H. K. (2001). The Use of Modular Organizational Forms: An Industry-Level Analysis. *The Academy of Management Journal*, *44*(6), 1149–1168.

Schumacher, A., Erol, S., & Sihn, W. (2016). A maturity model for assessing Industry 4.0 readiness and maturity of manufacturing enterprises. *Procedia CIRP*, *52*, 161–166.

Shrouf, F., Ordieres, J., & Miragliotta, G. (2014). Smart factories in Industry 4.0: A review of the concept and of energy management approached in production based on the Internet of Things paradigm. *IEEE international conference*, 697-701

Sofaer, S. (2002). Qualitative research methods. *International Journal for Quality in Health Care, 14*(4), 329-336.

Staber, U., & Sydow, J. (2002). Organizational Adaptive Capacity A Structuration Perspective. *Journal of Management Inquiry*, *11*(4), 408–424.

Thomas, L. D. W., Autio, E., & Gann, D. M. (2014). Architectural Leverage: Putting Platforms in Context. *Academy of Management Perspectives*, *28*(2), 198–219.

Thompson, J. D. (2003). Organizations in Action: social science bases of administrative theory (1st ed.). *Taylor & Francis Inc*.

Tracy, S. (2013). *Qualitative research methods*. UK: Wiley-blackwell.

Tsvetkova, A., & Gustafsson, M. (2012). Business models for industrial ecosystems: A modular approach. *Journal of Cleaner Production*, *29*, 246–254.

Vargo, S. L., Koskela-Huotari, K., Baron, S., Edvardsson, B., Reynoso, J., & Colurcio, M. (2017). A systems perspective on markets – Toward a research agenda. *Journal of Business Research*, *79*, 260–268.

Vickery, S. K., Koufteros, X., Drö, C., & Calantone, R. (2015). Product Modularity, Process Modularity, and New Product Introduction Performance: Does Complexity Matter? *Production and Operations Management*, *25*(4), 751–770.

Wee, D., Kelly, R., Cattel, J., & Breunig, M. (2015). Industry 4.0 - how to navigate digitization of the manufacturing sector. *McKinsey & Company*, 1–62.

Weiss, M., & Gangadharan, G. R. (2010). Modeling the mashup ecosystem: structure and growth: Discovery Service for University of Alberta Libraries. *R&D Management*, *40*(1), 40–49.

Yin, R. K. (2011). *Applications of case study research* (5th ed.). SAGE Publications.

Appendix A - Outline in-depth interview (Dutch)

Beschrijving bedrijf

Kunt u een korte beschrijving geven van uw organisatie?

Trends in de markt m.b.t. industriële automatisering en digitalisering

Welke ontwikkelingen ziet u in uw markt m.b.t. adoptie industriële automatisering / Smart industrie?

Welke drivers (redenen voor adoptie van smart technologie) ziet u in uw markt? Waar zijn deze drivers op gebaseerd?

Trends in structuurverandering van de waardeketen

Hiërarchie

Kunt u een beschrijving geven van de waardeketen waarin u opereert en wat de rol van uw organisatie hierin is?

Zijn er aspecten in deze beschrijving die anders zouden zijn als u deze beschrijving vier jaar geleden zou geven?

Verwacht u aspecten in deze beschrijving die er anders uit gaan zien de komende vier jaren?

Modulariteit

Kunt u wat zeggen over de mate waarin uw organisatie afhankelijk is van andere spelers in de waardeketen?

Kunt u wat zeggen hoe deze mate van afhankelijkheid is veranderd door digitalisering de afgelopen vier jaren?

Kunt u wat zeggen over hoe u verwacht dat deze mate van afhankelijkheid zich zal ontwikkelingen door digitalisering de komende vier jaren?

Relaties in de waardeketen

Kunt u een beschrijving geven hoe de relatie en het contact met partners in uw waardeketen eruitziet?

Op basis van uw zojuist gegeven beschrijving, hoe is de relatie met waardeketen partners de afgelopen vier jaren door digitalisering veranderd (en waarom)?

Kunt u ook een beschrijving geven hoe u verwacht dat deze relatie met uw waardeketen partners zich zal ontwikkelen door digitalisering de komende vier jaren (en waarom)?