Collaborative Innovation, Collaborative Capabilities and Value Co-creation in an Industry 4.0 Context: An Empirical Evidence

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Abstract

Digitalization and Industry 4.0 present a fundamental technological disruption, requiring the industry, research and government institutions to revisit their roles in the triple helix of innovation ecosystems. In particular, actors in this environment need to understand the logic of value co-creation and alignment of value-systems during interaction and collaboration. The purpose of this study is to increase the understanding of these topics through investigating the triple helix and collaborative capabilities in the Industry 4.0 ecosystem context. It investigates the “Reboot IoT Factory” project, a 13-million-euro research project with seven leading manufacturers, four research partners, and tens of small and medium size enterprises (SMEs). This qualitative single case study presents the project’s novel, experimental operating model that can result in effective collaboration, but also establishes requirements for collaborative capabilities in order to co-create value and innovations in the innovation ecosystem. The results demonstrate that research projects can be conducted in a dynamical way to address quickly emerging research needs, to implement fast trials and to scale up developed solutions. Yet, this
type of operation requires adopting the ecosystem approach with mutual trust, intensive collaboration, and the identification of common aims among the project participants. The principles of the presented co-innovation model can be applied for designing innovation ecosystem projects.

*Keywords: Collaboration, capabilities, Industry 4.0, innovation ecosystem, Triple helix*

1. Introduction

Industry 4.0 is represented through a policy-driven innovation discourse in manufacturing industries, which can institutionalize innovations systems from the triple helix perspective i.e. businesses, academia and government (Pfeiffer 2017; Reischauer 2018). A huge body of benefits through Industry 4.0 adoption are provided in research (Fatorachian and Kazemi 2018), governmental reforms (Mexican Ministry of Economy, 2016) and practical reports (Kagermann et al. 2013). A key claim about technological dynamism and industrial advancements is that Industry 4.0 necessitates manufacturing and service-based industries to change and innovate their work and management structures (Li 2018; Reischauer 2018, Schwab 2016; Sung, 2018) hence creating a new competitive environment which requires new business models, improved processes, strategies and competencies from its participants (Camarinha-Matos et al. 2009). These organizational transformations shape the whole ecosystem and further empower the people with new capabilities at individual level, thus creating shared value (Kim 2017). Shared value-creation leads to the co-existence of multiple formal and informal collaborations and networks. A concurrent understanding of the involved organizations and their patterns of collaborations leading to effective manufacturing systems is crucial (Camarinha-Matos et al. 2013; Camarinha-Matos et al. 2009) and pleads further attention as an important research challenge (Camarinha-Matos et al. 2017).

Furthermore, the ongoing disruptions of Industry 4.0 in terms of emerging technologies and innovations call to re-think the role of companies, universities and government institutions forming triple helix of innovation ecosystem, to understand individual and aligned value-systems for collaboration (Camarinha-Matos et al. 2017). These changes require the triple-helix actors of the innovation ecosystem to explore and evaluate the utilities and risks associated with the emerging technologies (Kim 2017). Therefore, this paper aims to increase the understanding about value co-creation (i.e. creation of innovative solutions and business models with different stakeholders) in innovation ecosystems through the coalition of triple helix and their capabilities in the contemporary Industry 4.0 context. These concepts are examined in the framework of a large Finnish publicly funded national innovation ecosystem project called Reboot IoT Factory. The main scope of the Reboot IoT Factory project is to increase the productivity of participating factories by creating scalable digital solutions for the whole industry. The key element and the focal point of analysis is the project’s novel operational model, which is based on co-creation and experience sharing. The underlying innovative ecosystem environment of the Reboot IoT Factory project is analysed from three viewpoints: The conception of the initial Reboot IoT
Factory model, the operationalization of the model and the project result metrics and participants’ perceptions for effective collaboration.

The rest of this paper is structured as follows. In Section 2, a literature review on innovation ecosystem, value co-creation, triple helix and collaborative capability is presented. This is followed by the research methodology and materials in Section 3. Section 4 shows the key results of the research, which are then further discussed in Section 5. This is followed by a brief conclusion in Section 6.

2. Literature Review

2.1 Innovation Ecosystems and Value Co-creation

The ecosystem concept has become popular in industry, academic literature, and innovation policy debates (e.g. Majava et al. 2019; Rinkinen and Harmaakorpi 2019). An ecosystem viewpoint aims to develop “both the network-based organizational design and the collaborative organizational culture of the emerging innovation-led economies“ (Smorodinskaya et al. 2017). Ecosystems can be further classified; business ecosystems can be viewed value networks that cross regional and national boundaries, whereas knowledge or innovation networks typically are centred spatially around universities and public research organizations (Clarysse et al. 2014). In terms of focus, business ecosystems concentrate on value creation, knowledge ecosystems on the generation of new knowledge and technology, whereas innovation ecosystems integrate the knowledge and business ecosystems.

In a technologically disruptive setting, innovation can be nurtured in an ecosystem environment developed for value co-creation through collaboration (Smorodinskaya et al. 2017). These innovation ecosystems can be defined as e.g. “collaborative arrangements through which firms combine their individual offerings into a coherent, customer-facing solution” (Adner 2006) or “dynamic collaborative networks of people and organizations formed around projects with an innovation objective” (Smorodinskaya et al. 2017). Features discerning innovation ecosystems from other regional innovation-centric concepts include a greater appreciation for connections among actors, the vital role of information and communication technology (ICT), open innovation and the importance of market forces in comparison with government push (Oh et al. 2016).

In the birth phase of innovation ecosystems, actors can be divided into four roles (Dedehayir et al. 2016): leadership roles, direct value-creation roles, value-creation support roles and entrepreneurial-ecosystem roles. The role of research institutions can be vital during the birth phase, and actors can shift roles and assume multiple roles simultaneously (Dedehayir et al. 2016). Besides research institutions, large companies should have a bigger role in supporting innovative start-ups and the development of regional ecosystem (Clarysse et al. 2014). Clarysse et al. (2014) also mentioned public procurement as a possible stimulus for the creation of new ecosystems. Success factors for implementing innovation ecosystems also include continuous investments in infrastructure, systematic risk evaluation, assignment of clear roles and openness to chaos and failure (Durst and Poutanen 2013).
Modern economics literature implies that the process of co-creation enables collaboration between different actors, allowing them to co-create new values and goods contributing to innovations, resulting in an innovation-led economy (Smorodinskaya et al. 2017). Value co-creation is considered as a business strategy that focuses on an active relationship between producers and consumers where consumers can act as workers and design articulators of the organization. It can be defined as an active, creative and social process, based on collaboration between producers and users (Roser et al. 2009). Value co-creation targets the interaction mechanisms for collaboration, knowledge creation, sharing and transfer (MacGregor and Carleton 2012).

### 2.2 Industry 4.0 and Triple Helix Innovation Ecosystem

Adoption of digital technologies has tremendously increased during the last two decades. These technological developments are expected to bring up a long-term economic up-rise in terms of reshaping economic and social life (Ayres 1990; Korotayev et al. 2011). Digitalization has assumed a paramount role in shaping contemporary manufacturing industry (Reischauer 2018) and has resulted in a new industrial revolution known as Industry 4.0 (Schwab 2016). These technological disruptions challenge research institutions to move towards experimentation, learning by doing and design thinking which involves inter-disciplinary communication (Brown 2009; Kim 2017). Likewise, SMEs, typically with limited resources, need to collaborate with other private organizations and triple-helix actors to increase e.g. their access to wider expert pool and financial volume for new business opportunities (Camarinha-Matos et al. 2009). Furthermore, the changing nature of technological developments associated with Industry 4.0 calls for triple-helix actors to look for governance structures suitable for seizing these opportunities and co-creating value through collaboration (Kim 2017).

Reischauer (2018) argues that Industry 4.0 represents a comprehensive movement that enables policy-driven collaborative innovation through discourse, aiming for development of innovation ecosystems and sustainable growth. Industry 4.0 becomes, in this context, a platform where the actors co-evolve, enhancing the performance of one another, while assuming relative autonomy in the innovation space (Etzkowitz and Zhou 2018). Approaching Industry 4.0 from a triple helix viewpoint allows the actors to frame it according to their own interests, simultaneously ensuring mutual benefits from the collaboration (Reischauer 2018). This view is supported by Clarysse et al. (2014), who state that innovation policies should focus more on an ecosystem approach instead of bilateral connections between organizations. In a triple helix approach, academia becomes an enabler of entrepreneurship promoting firm formation, while the industry assumes a vital role in advancing research and providing high-level training. The responsibility of the government extends towards regulating the whole innovation process (Etzkowitz and Klofsten, 2005).

While the impact of Industry 4.0 on large enterprises has gained much attention, the effect on SMEs has been somewhat overlooked even though this effect and their contribution to value creation is crucial (Müller et al. 2018). Kagermann et al. (2013) provide a dyadic view: some SMEs act as consumers and some as suppliers of Industry 4.0 services. Müller et al. (2018)
provide another dyadic classification: internally and externally motivated SMEs. The former group is reported to actively engage in collaboration with new companies and academia, while the latter group is unaware of the potential of such partnerships and thus less prone to partake. Additionally, SMEs are slower in general to embark on digital transformation (Buonanno, 2005; Müller et al, 2018).

2.3 Collaboration and Collaborative Capability within an Innovation Ecosystem

Collaboration emerges as joint plan consisting of different entities which share information, resources and responsibilities to create shared value and achieve a common goal. In the process of collaboration, the entities forming the group can partake the role of one another, including mutual trust, positive competition, commitment, shared risks and rewards, problem solving and overall enhancement of collaborative capabilities (Blomqvist and Levy 2006; Camarinha-Matos et al. 2017). Collaborative capabilities are considered as paramount to collaborative innovation as they can manage, shape and develop the relationships with other partners on individual, group, departmental and organizational levels (Blomqvist and Levy 2006). Recent studies have found that digital integration in terms of Industry 4.0 benefits the whole value chain (Liao et al. 2017) and enhances decision-making process (Frand et al. 2019b), systematic learning capabilities and collaboration at all levels (Tortorella 2020). Therefore, it is significant to consider collaborative capabilities in an Industry 4.0 context as it entails a transformational capacity to continuously redefine itself with new technological advancements (Garud and Nayar 1994; Tyler 2008) leading to joint innovative solutions.

Collaboration capability can be defined as an “actor’s capability to build and manage network relationships based on mutual trust, communication and commitment” (Blomqvist and Levy 2006). Trust is a multi-faceted phenomenon (Blomqvist 2002) which potentially describes actor’ behaviour, their relationships and predicts the risk in their future collaborations (Seppänen et al. 2004). Commitment is measured in terms of solid actions and investments in the relationship (Cullen et al. 2000; Nummela 2003). The third major component of collaborative relationships is communication. Collaborative communication provides a major measure of partners collaborative intentions (Mohr et al. 1996, 1999). It accelerates collaborative processes by creating a smooth and supportive working environment which facilitates collaboration for the joint outcome (Morgan and Hunt, 1994).

3. Materials and methods

The environment examined in this paper is the Reboot IoT Factory project (Reboot IoT Factory 2020), a national innovation project aiming to speed up digital transformation of the manufacturing industry in Finland. More particularly, the primary focus is on the first phase of the project, which took place between June 2018 and October 2019. Phase I was funded by a national funding body and the project consortium initially consisted of five global manufacturing companies (ABB, GE Healthcare, Kongsberg Maritime, Nokia, Ponsse) and three research institutions (VTT Research Institute of Finland, University of Oulu, Åbo Akademi). The budget of Phase I was approximately 5 million euros. The project has also
received further funding and Phase II takes place between November 2019 and April 2021.

The project approached triple helix innovation in a non-traditional manner, which along with timeliness of digitalization and Industry 4.0 make it an interesting research case. From both the viewpoints of practice and the structuring of the results in Section 4, Reboot Phase I can be divided into conception, operations and evaluation phases as illustrated in Figure 1.

![Figure 1. Reboot IoT Factory timeline](image)

The development work of the initial collaboration model took place between 2015 and the project kick-off in August 2018 and its results are presented in Section 4.1. The operations of Reboot are based on a set of principles and practices that are presented in Section 4.2. The operations were monitored using a set of key performance indicators that are presented in Section 4.3. These results are based on the authors’ first-hand experience as well as on project documentation such as project plans, presentations and final reports. The empirical data included e.g. observations and notes in project meetings, sprint reviews, factory visits etc. The analysis was performed qualitatively by multiple researchers.

To further evaluate collaboration success, a self-administered questionnaire was distributed among the project participants during 08-10/2019. The survey questions were designed based on an actor-dependency model to understand the dependencies, problems and benefits the project participants encountered. The results of the survey are presented along with quotations from free text answers in Section 4.3.

4. Results

4.1 Conceptualization of the initial Reboot model

Finland possesses a high level of expertise in information and communication technology (ICT) and Internet of Things (IoT) in both the SME and research sectors. The key challenge has been in the agile integration of this expertise into manufacturing environments to enable fast industry transformation and global competitive advantage. The Reboot IoT Factory project was the first pilot within the Finnish digitalization program Reboot Finland. The initial starting points for the project were:

- Establishing grand challenges (GCs) based on companies’ digitalization strategies
• Co-creating Proof-of-Concepts (PoCs) based on factory business needs and utilizing research organizations' offering
• Actively sharing experiences of digitalization and co-creation within ecosystem.
• Creating possibilities for SMEs to scale-up PoCs through commercialization.

The project was designed involving participants from global Finnish manufacturing companies, multiple research institutes, governmental organizations and SMEs. Even though each factory has their own development focus, they would share best solutions and practices with others, facilitating quick learning through a shared effort in the ecosystem. On the other hand, research organizations would bring a wide range of new methods and technologies, research results, competence and innovation capabilities. Public funding from Business Finland shows strong government support and lowers the risk of testing new technologies.

4.2 Operationalization of the Reboot co-innovation model

The aim of the co-innovation model (Figure 2) is to align the partners towards the common goal of accelerated digitalization. It is operationalized by trying to solve GCs of the industry in a triple helix setting. The GCs of Phase 1 were data-driven supply chain and production, robotics fusion and labor at the digital work environment. Based on the factories’ needs, these GCs are further divided into PoCs, i.e. solution ideas. One factory act as an innovation platform for each PoC, while other factories can follow the progress and plan solution adoption. Research organizations identify and allocate suitable resources for each PoC. The best solutions are to be commercialized by SMEs and disseminated to global networks of the participants. Finally, experience sharing to outside the project, i.e. second wave factories, allows for further deployment of the developed solutions.
Each stakeholder in the project has a specified role and responsibilities as follows:

- Factories provide a platform for co-innovation by opening actual production environments for PoC trials. They co-lead GCs, propose development topics and create PoCs together with researchers and SMEs. Successful solutions are scaled up within the factory and scaled-out to factory networks utilizing existing pipelines.
- IoT solution providers (SMEs) offer digitalization services and products to factories via subcontracting, aiming for sustainable service business and products.
- R&D organizations co-lead GC teams, facilitate the ecosystem-level co-operation, carry out research in PoCs, help in business model creation and SME scouting, and educate future employees via university courses and in supervising master’s and PhD theses.

The operating model is based on a set of practices and principles. Adaptivity enables development based on changing factory needs and progress in digitalization. The work is planned and implemented in sprints, each lasting 3-4 months. Each sprint concludes with a Sprint Review, the most important meeting in the model. These regularly gather the entire consortium together in one of the participating factories to network, review progress and plan further. To review the project results, GC leaders present statuses of their PoC portfolios followed by showcasing workshops. Every sprint review includes a production tour, where PoCs and other digitalization solutions are seen in a production environment. Finally, next steps and new PoC initiatives are discussed in planning workshops for GC teams.

Experience sharing allows learning and testing a wide range of solutions with lowered risk. It is implemented through several planned actions. Besides sprint reviews, tech reviews are a series of online lectures where presenters come from research organizations, SMEs and/or factories to boost the awareness and co-operation between project participants. Publications, theses, blogs, fairs and innovation scouting are used to communicate scientific findings from the project to larger audiences and raise interest for research co-operation, global dissemination and state-of-the-art mapping. Finally, regular meetings e.g. by project administration are held.

Scale-up through SME co-innovation plays a key role of scaling up the inventions made in the PoC work. SMEs help companies in bringing the PoC solutions to their other factories, as well as to other project partners. For this goal, new processes and events for factory-SME matching such as hackathons and voice of the customer are used. SMEs can also get new products/services into their own offering for Finnish and global markets.

4.3 Results of the project

During Phase I of the project the results of the operational model were monitored. Key final metrics are presented in Table 1 below.

| Targets                                      | Key results from Phase I                                      |
|----------------------------------------------|--------------------------------------------------------------|
| 8 partners initiating ecosystemic collaboration | Trust created, 4 more partners join the ecosystem            |
Table 1. Key results of Reboot Phase I

The initial targets were met quite well and even exceeded in some cases. Several improvements to the project model were found and either implemented during Phase I or left for Phase II. Additionally, a survey was conducted to measure collaboration success. A total of 33 responses were received from industry partners (n = 11), research partners (n = 16) and from SME partners (n=6). Collaboration success was measured with 15 Likert-type scale questions, and the results are shown in Figure 3.

![Collaboration success measurement results](image)
Overall, collaboration success was rated quite high by the participants. The limited number of respondents per group poses challenges for between-groups comparisons, but they suggest that the researchers agree most strongly with questions regarding regular communication and collaboration. The SME respondents ranked questions related to alignment and co-operation very highly.

The survey also included two free text questions on collaboration and the project in general. Representative quotes from the answers are presented below along with the respondents’ affiliation (F = Factory, R = Research, S = SME). The first question posed was “How would your organization collaborate with other organizations in Reboot, if there were no project funding related rules/limitations?”

“Much more limited cooperation. One-to-one interaction mostly” (F4) “(…) there would be very little collaboration without project rules (…) it would be just another project where everyone does their own thing.” (R3)

The second question was for general feedback: “Do you have any other feedback about the Reboot project?”

“SME definition should be re-visited (turnover limit too low) as this limit greatly potential companies (…)” (F6) “(…) I feel it was still very much easier to collaborate and communicate with the companies than it has been in any of my other projects.” (R4) “(…) Smaller companies like us usually don't get a chance to work with bigger industry companies.” (S1)

5. Discussion

Dedehayir et al. (2016) point out the importance of the role of research institutions during the birth phase of an innovation ecosystem; while true for this case, here the enabling role has continued throughout the lifecycle of the project and ecosystem. Large companies should support start-ups and regional ecosystem development (Clarysse et al. 2014) and there should be openness to failure (Durst and Poutanen 2013), something the PoC structure and related funding aimed to achieve in this project. Joint target setting and experience sharing as well as basing the GC themes on participants’ market needs support the ideas of Oh et al. (2016) who emphasise the connections among ecosystem actors, open innovation and the importance of market forces. Continuous improvement was implemented within the operating model with factory guidance, enabling continuous investments in infrastructure; a success factor recognized by Durst and Poutanen (2013).

Mechanisms for both collaboration interaction and joint knowledge creation, sharing and transfer are essential for value co-creation (MacGregor and Carleton 2012). This project presents some practical ways to implement these in the Industry 4.0 context: e.g. sprint review days, tech review presentations and researcher and SME workshops.

The way that the participants were able to pursue their own digital strategies while sharing knowledge and co-evolving is an example of how Industry 4.0 provides a platform for such triple helix activities (Etzkowitz and Zhou 2018; Reischauer 2018). The PoCs allowed researchers to move from laboratories to a real-life factory context and to become familiarized
with the settings where PoC solutions will be deployed. This triple-helix type of boundary-spanning (Champenois and Etzkowitz, 2018) led to brainstorming that considered the solution deployment context and the factory’s market needs.

Collaborative capabilities are particularly important in the context of this study, as they relate to both project collaboration (Camarinha-Matos et al. 2017) and to the adoption of digital innovations (Liao et al. 2017). Key capabilities for effective collaboration and value co-creation include trust, communication and commitment (Blomqvist and Levy 2006). In the Reboot IoT Factory project, trust was enabled by selecting non-competing factories in the project. The absence of market-based competition among the factory partners significantly reduced the risk in disclosing needs for new innovations and sharing experiences.

The factories’ commitment was based on a CxO-level commitment from each participating factory, required at the beginning of the project. This enabled three crucial activities: allocating in-kind work from the factory towards the joint goals of the innovation ecosystem, disclosing the factory’s digitalization strategy to the ecosystem, and opening the factory floor as a controlled living lab environment for research. These in turn supported activities such as allocating research resources and defining the GCs around common themes. In terms of collaborative communication (Mohr et al. 1999), several activities such as joint meetings in different layers of corporate hierarchies were planned to co-create a collaborative environment for joint value (Morgan and Hunt 1994).

6. Conclusion

This paper focused on value co-creation in innovation ecosystems through a triple helix collaboration in the Industry 4.0 context. The case study was the Finnish publicly funded project Reboot IoT Factory, involving close collaboration of manufacturing companies, research institutions and SMEs. The analysis was done from three different viewpoints: the conception of the project model, the operationalization of the model, and the project results (metrics and participants’ perceptions on collaboration). The results presented in Section 4 not only demonstrate that the project has introduced a novel, experimental operating model that can result in effective collaboration, but also establish requirements for collaborative capabilities in order to co-create value in the innovation ecosystem.

Regarding practical lessons learnt from Phase I of the project, a few points regarding the success of the operational model can be highlighted. The results indicated that the co-innovation model based on experience sharing can accelerate digitalization of Finnish manufacturing industry. They also demonstrated that research projects can be conducted in a dynamical way to address quickly emerging research needs, implement fast trials and scale up the solutions that have been developed. Yet, this type of operation requires adopting the ecosystem approach with mutual trust, intensive collaboration, and the identification of common aims among the project participants.

It should be noted that the findings are based on a qualitative single case, setting limitations on generalizability. Replications of the Reboot model of similar models in different context could further refine the results presented in this study. Furthermore, Finland is a highly
developed countries in the world with a tradition for technological advancement, providing a unique co-creation space to implement the triple helix format. As Kimatu (2016) has pointed out, there is a great disparity among countries regarding the implementation of the triple helix. The national context should therefore be accounted for in transferring the results.

Furthermore, we did not look outside the triple helix, e.g. the quadruple helix and quintuple helix: including societal (Carayannis, 2009) and environmental factors (Carayannis, 2012). Integrating these perspectives in future research could advance a more holistic view of collaboration, innovation and value co-creation in Industry 4.0 ecosystems.

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