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Organizing for innovation in the digital age: outsourcing, collaboration, and platforms

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presented by

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Abstract

The innovation process, from the initial idea to the successful product, requires an orchestration among various sets of knowledge and capabilities. The single firm seldom has access to all of them in-house. Instead, it relies on the knowledge and capabilities of others, such as customers, suppliers, or universities. Which knowledge and capabilities to access externally and how to access them are important decisions of strategic management. In this dissertation, we are interested in how such decisions affect innovation outcomes.

Today, information technologies (IT) play a central role in the innovation of firms, both as part of the innovative products or services as such, as well as support of the innovation process. Thanks to IT, search, monitoring, and communication costs have fallen, facilitating more open and interconnected innovation. IT, therefore, have an important influence on when and how firms incorporate the knowledge and capabilities of others in the innovation process.

This dissertation is made up of three essays that are all based on empirical data, the first two using a quantitative methodology and the third using case studies. Each of them examines how decisions about a firm’s organization of the innovation process, such as outsourcing, collaborations, and engagements in platforms, affect innovation outcomes. The influence of IT plays an important role in two of the three essays. The first essay examines the effects of outsourcing, showing how the outsourcing of production activities, in particular, can harm a firm’s innovation performance. The second essay studies the role of IT investment in the context of collaborative innovation. The results suggest that the benefits of IT investment are most pronounced for firms that engage in intensive exchange with multiple external partners. The third essay investigates how firms join forces to develop and implement novel technology-based platforms. Using case studies of blockchain applications in a supply chain context, we examine the organizational requirements that enable such multiparty innovation projects.

Zusammenfassung

Der Innovationsprozess von der Idee bis zum erfolgreichen Produkt erfordert den Einbezug vielfältiger Kenntnisse und Fähigkeiten. Die einzelne Firma besitzt selten alle notwendigen Kenntnisse und Fähigkeiten selber. Sie ist deswegen auf Externe angewiesen, beispielsweise Kunden, Zulieferer oder Universitäten. Auf welche Kenntnisse und Fähigkeiten eine Firma extern zugreifen soll und wie sie den Zugang dazu schafft, sind wichtige Entscheidungen des strategischen Managements. Ziel dieser Dissertation ist es, zu untersuchen, wie solche Entscheidungen den Innovationserfolg der Firma beeinflussen.

Informationstechnologien (IT) spielen heute eine zentrale Rolle in der Innovation von Firmen, sowohl als Teil der innovativen Produkte oder Dienstleistungen an sich, als auch unterstützend im Innovationsprozess. Dank IT sind Such-, Kontroll- und Kommunikationskosten gesunken, was einen offenen und weitvernetzten Innovationsprozess fördert. IT haben deshalb einen wichtigen Einfluss darauf, wann und wie Firmen die Kenntnisse und Fähigkeiten Externer in den Innovationsprozess einbeziehen.

Diese Dissertation besteht aus drei Papers, die alle auf empirischen Daten basieren. Zwei davon nutzen eine quantitative und das dritte eine qualitative Methode. Jedes der drei Papers untersucht, wie sich Entscheidungen über die Organisation des Innovationsprozesses, wie beispielsweise Outsourcing, Kollaborationen und die Teilnahme an Plattformen, auf den Innovationserfolg auswirken. Der Einfluss von IT spielt in zwei der drei Papers eine wichtige Rolle. Das erste Paper befasst sich mit den Auswirkungen von Outsourcing und zeigt, dass insbesondere das Outsourcing von Produktionsaktivitäten den Innovationserfolg schmälern kann. Das zweite Paper untersucht die Rolle von IT-Investitionen im Kontext von Innovationskollaborationen. Die Ergebnisse legen nahe, dass die Vorteile von IT-Investitionen für diejenigen Firmen am stärksten ausgeprägt sind, die einen intensiven Austausch mit mehreren externen Partnern pflegen. Im dritten Paper wird untersucht, wie Gruppen von Firmen gemeinsam technologiebasierte Plattformen entwickeln und implementieren. Blockchain-Anwendungen im Kontext der Supply Chain dienen als Beispiel, um die organisatorischen Anforderungen an solche gemeinschaftlichen Innovationsprojekte zu untersuchen.

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The time that I spent with my colleagues at the Chair of Logistics Management has been enriching and uplifting. In particular, I thank Alexander Fink, Laura Heuser, Maximilian Klöckner, Maximilian Löffel, Sarah Schaumann, and Christoph Schmidt for the great friendship and all the inspiring exchanges inside and outside of the office.

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Chapter 1 Introduction and overview of the research

1.1 Motivation and research objectives

Organizing the firm for innovation is an important task of strategic management. This task includes decisions about the internal structure of the firm. It also includes decisions about when and how the firm engages with its environment, such as by outsourcing, collaborating, or participating in platforms. All these decisions shape the innovative capabilities of the firm and influence its innovation performance (Argyres & Zenger, 2012; Brass, Galaskiewicz, Greve, & Tsai, 2004; Cassiman & Veugelers, 2002; Macher, 2006; Novak & Stern, 2008; Teece, 1986). In this dissertation, we examine how such decisions, for which we use the term governance choices (Argyres & Zenger, 2012; Williamson, 1979), influence innovation performance.

We lay a particular focus on the role that information technologies (IT) play in shaping this relationship. IT allow firms to become more interconnected with other organizations, as they improve information availability and exchange (Goldfarb & Tucker, 2019; Menz et al., 2021). Many IT applications are important enablers of an open innovation process, providing firms with new opportunities to innovate in collaboration with others (Argyres, 1999; Dodgson, Gann, & Salter, 2006; Menz et al., 2021). Increasingly, IT are a constituting part of innovations. As such, they can place high demands on how firms organize the innovation process (Branstetter, Drev, & Kwond, 2019; Foerderer, 2020; Nambisan, Lyytinen, Majchrzak, & Song, 2017; Nickerson & Zenger, 2004). For these reasons, it seems necessary to reconsider the link between governance choices and innovation performance under the increasing influence of IT (Menz et al., 2021).

Each of the three essays in this dissertation is embedded in its own theoretical background and research stream. The purpose of this introductory chapter is to provide the bigger picture illustrating how the three essays relate to each other. To help us to carve out the interrelations between the essays and to help us navigate through this introductory chapter, we use the concept of the *governance choice*, which plays a key role in each essay, but is represented differently in each. The term governance choice is a standard term in research on the boundaries of the firm (Argyres & Zenger, 2012; Leiblein, 2003; Nickerson & Zenger, 2004). As we are examining different representations of governance choices and their relationships with innovation performance in this dissertation, it seems worthwhile to dig a little deeper into the meaning of this term.

A governance choice is a choice between governance structures, which, in a transaction-cost language is “the institutional matrix within which transactions are negotiated and executed” (Williamson, 1979). The firm and the market are the most prominent governance structures and theories of firm boundaries focus on the choice between these two (Williamson, 1975). There are other governance structures, however, such as a relationship or a network (Jones, Hesterly, & Borgatti, 1997; Williamson, 1981, 1991). All governance structures “govern” transactions with their own specific means – authority, price, trust, or a combination thereof (Bradach & Eccles, 1989).

Throughout this dissertation, we work with various representations of governance choices. We start in the first essay with a dichotomous governance choice between the firm and the market (Williamson, 1979), to examine how outsourcing affects innovation performance (Essay 1 / Chapter 2). We proceed with more refined governance options, which play a key role in the remaining two essays. A first focus lies on relational governance (Bradach & Eccles, 1989; Williamson, 1991) to investigate how different depths of collaboration influence innovation performance (Essay 2 / Chapter 3). Finally, we examine a hybrid governance structure that incorporates aspects of a firm and a network. We use the example of novel blockchain applications that are developed and implemented collaboratively by groups of firms (Essay 3 / Chapter 4).

This dissertation examines how certain governance choices help firms to improve their innovation performance, while others do not. It lays a special focus on the different roles that IT play in shaping this relationship. Although the three essays in this dissertation all examine the same general phenomenon, they each take a distinct perspective. Accordingly, they differ considerably from each other with regard to their research design and embedment in the respective relevant literature to which they contribute. The essays combine quantitative and qualitative methodologies, examine country- and project-level phenomena, and investigate dichotomous firm-market governance choices as well as intricate network governance approaches. Despite these differences, we believe that, in combination, they provide an interesting overview of the different viewpoints from which the link between governance choice and innovation performance can be studied.

The remainder of Chapter 1 is structured as follows. First, we introduce the conceptual foundation of the link between governance choices and innovation performance that underpins the three essays. We then discuss why IT matter for this link. Next, we provide a research outline that includes summaries of the essays. We close the chapter with concluding remarks.

1.2 The link between governance choice and innovation performance

1.2.1 The governance choice between the firm and the market

Given our interest in the link between governance choice and innovation performance of firms, we use a knowledge-based theory of firm boundaries as a theoretical lens to start with (Grant, 1996; Kogut & Zander, 1992; Nickerson & Zenger, 2004). This theory makes prescriptions on how to organize for knowledge creation, the fundament for innovation (Nickerson & Zenger, 2004). In this context, 'to organize' means to make a series of governance choices that determine the boundaries of the firm, i.e. what the firm makes and what the firm buys in the market (Nickerson & Zenger, 2004). Both options, organizing within the firm or organizing through the market have distinct strengths and weaknesses (Williamson, 1975). Depending on the type of knowledge to be exchanged and the type of innovation to be created, either one is more efficient (Grant, 1996; Kogut

& Zander, 1992; Nickerson & Zenger, 2004). Applied to innovation projects, the theory prescribes integration within the firm for projects that require tacit knowledge to be exchanged and intensive collaboration among many stakeholders (Grant, 1996; Nickerson & Zenger, 2004). For other projects that allow for a more modular approach with less intensive knowledge exchange, the market may be the more efficient governance choice (Grant, 1996; Nickerson & Zenger, 2004).

The purpose of this theory is to explain firms' governance choices, i.e. how they draw their boundaries, given the objective of knowledge creation. As such, it provides an excellent conceptual foundation on top of which we can examine our research interest, the link between governance choice and innovation performance. The theory's purpose, however, is not to explain innovation performance and its explanatory power in that regard is thus limited. In the following, we discuss important factors that influence the link between governance choice and innovation performance.

1.2.2 Strategic and constrained governance choices

Governance choices are embedded in a firm's strategy and tied to an objective (Argyres & Zenger, 2012; Madhok, 2002). The knowledge-based theory of firm boundaries makes an assumption with regard to the objective; it is efficient knowledge creation (Nickerson & Zenger, 2004). Firms are thus assumed to make governance choices in the pursuit of efficient knowledge creation. Although important for innovative firms, efficient knowledge creation may be just one among several strategic objectives, with potentially conflicting demands on resource utilization and allocation (Madhok, 2002; Zenger, Felin, & Bigelow, 2011). To illustrate why this strategic aspect of governance choices matters for the link to innovation performance, we can use the case of outsourcing. A firm that pursues the objective of efficient production may decide to outsource some production activities. A similar firm faced with the same governance choice, pursuing the objective of efficient knowledge creation, may decide to remain integrated instead. The effects on performance may differ depending on how performance is measured. Outsourcing may have a positive effect on production cost, but a negative effect on innovation performance. Remaining integrated may have the opposite effect (Novak & Stern, 2008).

Another aspect of governance choices that influences the relationship with innovation performance relates to the various constraints that firms have in making them. Some governance options may not be available, some options may be too costly or take too long to implement (Argyres & Liebeskind, 1999; Argyres & Zenger, 2012; Jacobides & Winter, 2005). Let us illustrate this with the outsourcing example. Outsourcing options are available for some of a firm's activities only, while for others they are not (Jacobides & Winter, 2005). At the same time, outsourcing may require organizational changes that are resource-intensive to implement (Barthélemy, 2001). Finally, the effects of outsourcing may only materialize after several years (Novak & Stern, 2008). As a result of these constraints, it is often not meaningful to make changes to the organizational structure of a firm for the pursuit of short-term goals. Instead, decisions on how to pursue such goals may be made contingent on the firm's current organizational structure (Argyres & Zenger, 2012). Firms may thus leave previous governance choices unchanged, even if these governance choices seem suboptimal for performance (Argyres & Liebeskind, 1999). Given that governance choices are path-dependent and not easily revertible, they can have important effects on how the firm creates value (Argyres & Zenger, 2012; Helfat & Campo-Rembado, 2016; Jacobides & Winter, 2005).

The prioritization between conflicting objectives, the constraints in making governance choices, and the delayed effects make governance choices strategic and their justification often subjective. Making governance choices is inherently tied to making trade-offs, such as between long-term evolution of capabilities and short-term profitability (Jacobides, 2005; Novak & Stern, 2008), between adaptability and efficiency (Macher, 2006; Weigelt & Sarkar, 2012), or between stronger systemic and stronger component innovation capabilities (Kapoor & Adner, 2012). These trade-offs illustrate how studying the performance effects of governance choices – even of simple ones, such as the one between the firm and the market – is important. Using this line of argument, in Essay 1, we examine how outsourcing affects innovation performance.

1.2.3 Alternative governance structures

Up to this point, we assumed a governance choice with two options only: the firm and the market. Alternative governance structures, such as a collaborative relationship or hybrid forms, are not explicitly treated in the dichotomous model. Such a simplification is valid to examine some phenomena related to governance choices and their effects, but it bars the examination of others. Particularly relevant for research on innovation are collaborative endeavors, be they dyadic or involve large networks of firms (Brass et al., 2004; Chesbrough, 2003; Teece, 1986). In the following, we take a closer look at those governance structures and how they shape the innovation output of firms.

A collaboration between two firms is different from pure market governance. To organize such collaborative relationships, firms use relational governance (Bradach & Eccles, 1989; Williamson, 1991). Absent a hierarchy, relational governance incorporates an informal component that is underpinned by mutual dependence and trust, which facilitates forms of collaboration that pure market contracts cannot facilitate (Bradach & Eccles, 1989; Geyskens, Steenkamp, & Kumar, 2006).

Collaborations play an important role in the management of innovation. The limited internal knowledge and local processes of search constrain a firm's ability to innovate on its own (Chesbrough, 2003; Dosi, 1988; Levitt & March, 1988; Teece, 1986). To overcome these constraints, firms seek access to the broad knowledge base and myriad of valuable ideas that lie outside of the firm; they engage in open innovation (Chesbrough, 2003). In order to efficiently exchange knowledge with external stakeholders, firms resort to relational governance to form collaborative relationships (Cassiman & Veugelers, 2002; Chesbrough, 2003; Teece, 1986). For research on open innovation, the simplification to a dichotomous governance choice is not meaningful. To capture how the governance choice matters for innovation performance in this context, we thus depart from the dichotomous view on governance choices and distinguish different aspects of relational governance instead. Embedded in the open innovation research, we examine aspects of the link between external knowledge search and innovation performance in Essay 2.

When we speak of relational governance, we usually address dyadic relationships. A network consisting of many firms, however, can also function based on relational governance, in which case we speak of network governance (Jones et al., 1997). With only relational governance at play and no authority or leadership in place, the pursuit of a common goal becomes difficult with growing network size (Provan & Kenis, 2008). To pursue a common goal, some form of authority may be necessary to provide goal-oriented leadership (Dhanaraj & Parkhe, 2006; Provan & Kenis, 2008). This is a case in which a hybrid or plural form of governance structure, combining aspects of a hierarchy (i.e. an authority that provides leadership) with aspects of a network (i.e. a group of independent firms), is appropriate (Bradach & Eccles, 1989; Provan & Kenis, 2008). With the rise in interorganizational information systems and platforms that involve networks of agents, questions surrounding the governance of those networks have immensely gained in importance in the recent past (Chatterjee & Ravichandran, 2013; Foerderer, 2020; Gawer, 2014; Shi, Li, & Chumnumpan, 2021). A lot of innovative activity is devoted to products or services that are shared in a network or developed and offered on platforms (Foerderer, 2020; Menz et al., 2021; Shi et al., 2021). Studying the relationship between the governance structures to facilitate such innovative activities and the innovation performance is therefore important. We take up this task in Essay 3 to study how firms jointly organize to develop and implement novel blockchain applications.

1.3 The influence of IT on governance and innovation

Having introduced the link between governance choice and innovation performance, we now examine the role that IT can play in influencing this link. We discuss three paths. First, IT can be an antecedent to changes in governance choices and as such, indirectly, affect firms' innovation outputs. Second, as a tool in the innovation process, IT can promote innovation performance contingent on a certain governance choice. Third, IT can be the object of innovation and as such, place demands on the organization of the innovation process.

IT have a direct impact on the governance choices that firms make (Bakos & Treacy, 1986; Brynjolfsson, Malone, Gurbaxani, & Kambil, 1994). By reducing search, monitoring, and communication costs, many IT applications contribute to reduced administrative and transaction costs (Bakos & Treacy, 1986; Goldfarb & Tucker, 2019; Ray, Wu, & Konana, 2009). Some technologies reduce the cost of hierarchical governance, others reduce the costs of market or relational governance (Ray et al., 2009). The direction of those shifts is therefore not always the same (Ray et al., 2009). The influence of IT can range from tipping an outsourcing decision to disrupting established market structures (Bakos & Treacy, 1986; Jacobides, 2005; Menz et al., 2021). As an antecedent to changes in governance choices, IT can thus indirectly influence the innovation output of firms (Jacobides & Winter, 2005; Menz et al., 2021).

IT can play a prominent role in the innovation process and drive innovation performance in general (Dodgson et al., 2006; Joshi, Chi, Datta, & Han, 2010; Kleis, Chwelos, Ramirez, & Cockburn, 2012). In certain cases, there is a complementarity between the IT application and the governance structure to jointly promote innovation outcomes (Argyres, 1999). For instance, IT applications can improve collaborative innovation, as they make knowledge exchange and joint knowledge creation more efficient (Alavi & Leidner, 2001; Dodgson et al., 2006; Kleis et al., 2012; Urbinati, Chiaroni, Chiesa, & Frattini, 2020). Using specific technologies in this context can provide collaborating firms with a competitive advantage over more closed forms of innovation (Argyres, 1999; Gómez, Salazar, & Pilar, 2017).

In many cases, IT are not just a facilitator of the innovation process, but a constituting part of the innovation (Branstetter et al., 2019; Nambisan et al., 2017). Aspects of an innovation determine how best to organize for it (Nickerson & Zenger, 2004). Characteristics of a technology can thus influence the governance choices firms make to create innovations that incorporate that technology. In this dissertation, we consider innovative applications of blockchain technology as one case of IT-based innovation that features strong network effects (Kumar, Liu, & Shan, 2020). It is a prime example of how the characteristics of the technology impose requirements on how the development and implementation of an innovative application is organized.

1.4 Research outline

In this section, we introduce the three essays that follow in chapters 2, 3, and 4. We start with an overview of the dissertation displayed in Figure 1 and Table 1. We then present the summaries of the three essays.

Figure 1 Overview of the essays

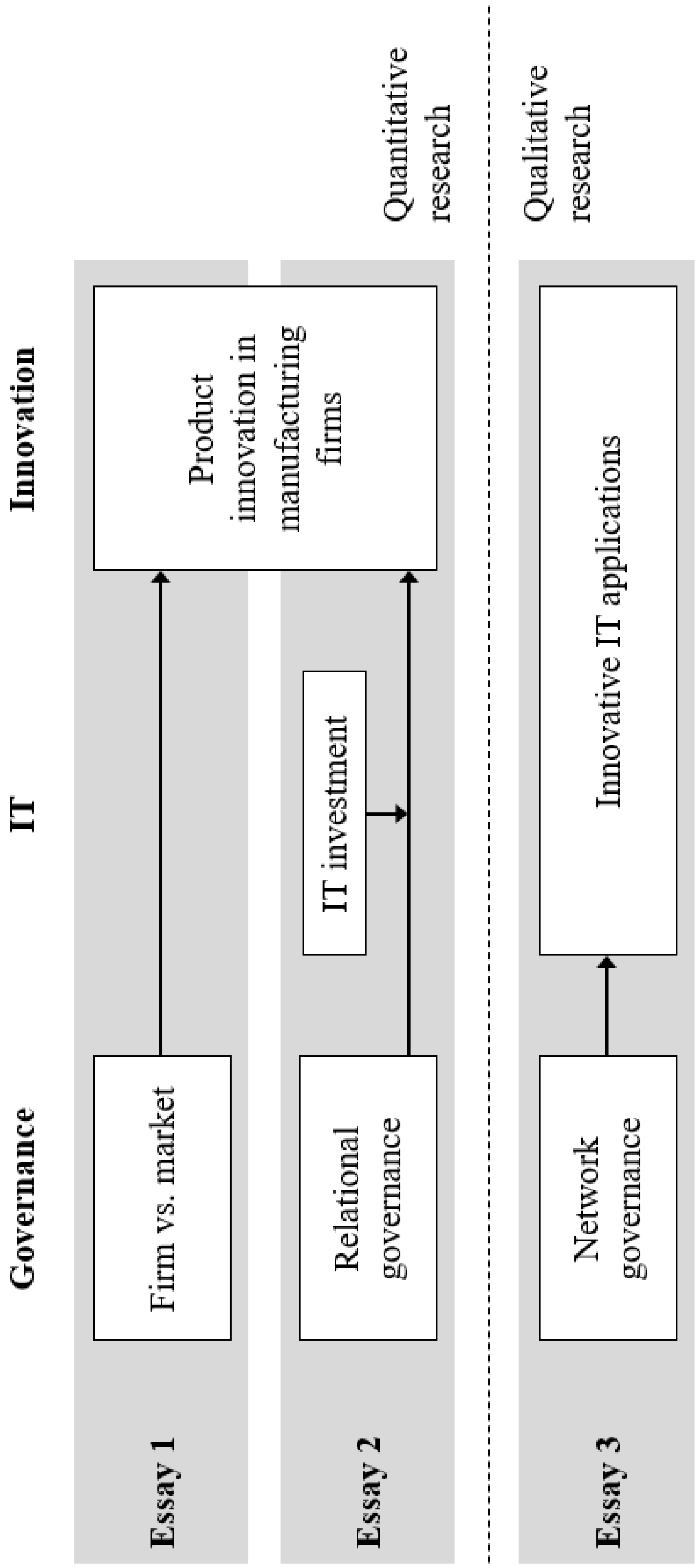

Table 1 Overview of the essays

	Essay 1	**Essay 2**	**Essay 3**
Title	When outsourcing threatens a firm's value creation from product innovation	Digitalization as a driver of open innovation: Influence of external knowledge search strategy and appropriability concerns	Blockchain and network governance: Learning from applications in the supply chain sector
Authors[1]	Stefan Naef, Mathias Beck, Martin Wörter, Stephan M. Wagner	Stefan Naef, Mathias Beck, Martin Wörter, Stephan M. Wagner	Stefan Naef, Stephan M. Wagner, Christian Saur
Research questions	How does outsourcing affect a firm's capabilities to create value from product innovations over time? What are the underlying mechanisms of the transformative effects of outsourcing?	Under which conditions can firms use IT to promote openness in innovation and increase innovation performance?	How do firms organize to jointly develop and implement blockchain applications in a supply chain context? What role does network governance play in supporting the development and implementation of blockchain applications?
Research stream	Boundaries of the firm	Open innovation	Interorganizational systems / Blockchain
Data	Swiss innovation survey; sample of 363 firm-year observations, 2005-2011	Swiss innovation survey; sample of 1,250 firm-year observations, 2005-2019	18 interviews with representatives of 5 blockchain projects
Methodology	First-differencing regression	Dynamic panel regression	Multiple case study
Key findings	Adverse effects of outsourcing on product innovation performance. They are driven by the scope and type of outsourcing and mitigated by investment in absorptive capacity.	Investment in IT can help firms to increase the openness of their innovation activities in terms of deep search. This is contingent on the firm's appropriability.	Blockchain projects install a centralized broker organization for management; oversight is shared among member firms. The combination of centralized and shared control has advantages over alternative forms
Publication status	Ready for submission	Working paper	Accepted for publication at Production Planning & Control

[1] Contribution of Stefan Naef to all essays: project lead, research design, literature review, data analysis, main authorship

1.4.1 Summary of Essay 1

Essay 1 is titled *When outsourcing threatens a firm's value creation from product innovation* and examines the effects of outsourcing on product innovation performance. Outsourcing makes a firm's boundaries constrict. As a result, the knowledge that remains within the firm becomes narrower. With the narrower set of knowledge available within the firm, the innovations that a firm creates may change (Argyres & Zenger, 2012; Jacobides & Winter, 2005). The expected effects of such a change may not be immediate and may also not be easy to reverse. As a result, outsourcing may transform how a firm creates value from innovations into the future. This hypothesis lies at the core of Essay 1. To test it, we thus ask the first research question: How does outsourcing affect a firm's capabilities to create value from product innovations over time?

We proceed to examine when and how the effects of outsourcing on value creation from product innovation appear by asking our second research question: What are the underlying mechanisms of the transformative effects of outsourcing? We aim to answer this question by first studying how the magnitude of the outsourcing drives the effects. We then compare the effects of different types of outsourcing, focusing on how closely related the outsourced activities are to the core activities of the firm. Finally, we examine investment in absorptive capacity as a possible strategy to mitigate adverse effects of outsourcing. Absorptive capacity is essential for the ability to integrate knowledge from external sources into the firm (Cohen & Levinthal, 1990), which gains in importance when the knowledge within the firm becomes narrower.

In line with the theory of the firm, we use the concept of a dichotomous governance choice between the firm and the market. Outsourcing can be represented as a shift from the firm to the market. We link such a change in the governance of the outsourced activities to innovation performance. In Essay 1, IT do not play an explicit role. Still, they can have an important influence on the outsourcing behavior of firms (Jacobides, 2005; Weigelt, 2009). With technologies that reduce search, communication, and monitoring costs available (Goldfarb &

Tucker, 2019), outsourcing options may become more numerous and more easily accessible (Brynjolfsson et al., 1994; Jacobides, 2005). This may drive specialization, as firms make use of the ample opportunities to outsource (Jacobides & Winter, 2005).

To test our hypotheses, we use data from the Swiss innovation survey covering 2002 to 2011. We focus on product innovations of manufacturing firms with more than twenty employees. Corresponding to the core idea of this study, to identify how a change in the boundaries of the firm (outsourcing) leads to a change in innovation performance, we apply a model that can represent such changes. We thus choose a first-differencing model, allowing us to focus on the relationship between changes in variables instead of levels.

The focus on a change in the existing structure of the firm, its delayed effect on innovation performance, and the underlying mechanisms differentiates our research from related research on the link between outsourcing and innovation performance (Hashai, 2018; Macher, 2006; Novak & Stern, 2008; Weigelt, 2009). Our results provide evidence that outsourcing can cause a decline in the performance of new products. Enriching this finding, we introduce a range of contingency factors. The effects of outsourcing depend on the scope of the outsourced activities, as well as the type of outsourced activities. While the effects appear for the outsourcing of production activities, which are closely related to the core activities of manufacturing firms, they do not appear for the outsourcing of services or IT. In addition, investing in the absorptive capacity helps to mitigate the negative effects of outsourcing.

1.4.2 Summary of Essay 2

In Essay 2, on *Digitalization as a driver of open innovation: Influence of external knowledge search strategy and appropriability concerns*, we examine the role that IT investment plays in promoting open innovation. There are two important limitations to a firm's openness in innovation. First, the limited absorptive capacity constrains the knowledge a firm can absorb from external sources (Grimpe &

Kaiser, 2010; Laursen & Salter, 2006; Salge, Farchi, Barrett, & Dopson, 2013). Second, unintended knowledge leakage can threaten a firm's ability to appropriate value from its own innovations, raising appropriability concerns (Cassiman & Veugelers, 2002; Teece, 1986). At high levels of openness, both the limited absorptive capacity and appropriability concerns can constrain the benefits that firms can draw from open innovation.

In this research, we are interested in how IT enable and constrain knowledge exchange across firm boundaries. IT can be an enabler of openness, as it facilitates the exchange and collaboration with external knowledge sources (Dodgson et al., 2006; Kleis et al., 2012; Trantopoulos, Von Krogh, Wallin, & Woerter, 2017; Urbinati et al., 2020). At the same time, IT also seem to promote the limitations of open innovation. Using IT to collect information from external knowledge sources can vastly increase the requirements for information processing, elevating the risk of cognitive overload (Dong & Netten, 2017; Gómez et al., 2017). In addition, many applications of IT in the innovation process force the codification of knowledge (Alavi & Leidner, 2001; Cowan & Foray, 1997). Therefore, IT may enable unintended knowledge leakage and, as a result, elevate appropriability concerns. To clarify the role of IT in open innovation as both a driver of the benefits and a driver of the limitations, we ask the following research question: Under which conditions can firms use IT to promote openness in innovation and increase innovation performance?

To answer our research question, we focus on openness in terms of external knowledge search depth. Sources of external knowledge can be other firms, such as suppliers or customers, as well as research institutions. In the context of open innovation, search depth refers to how intensively a firm draws from external knowledge sources (Laursen & Salter, 2006). Firms that pursue deep external knowledge search employ relational governance to develop intensive relationships with partners (Terjesen & Patel, 2017). Such relationships are characterized by high levels of trust and intensive communication, which facilitate knowledge exchange and joint knowledge creation (Terjesen & Patel, 2017). We argue that these relationships enable the use of IT applications for collaborative innovation, while at the same time also enabling the firm's absorptive capacity, thus increasing the benefits and mitigating the risks associated with open innovation.

To test the hypotheses, we use data from the Swiss innovation survey covering 2005 to 2019. We opt for a dynamic panel estimator to control for an autoregressive dependent variable, potential endogeneity in the explanatory variables, and firm fixed effects (Arellano & Bond, 1991; Blundell & Bond, 1998). This model is well adapted for the structure of the data set and allows for an examination of causality claims for the relationship between IT, openness, and innovation performance, while emphasizing the importance of appropriability concerns.

Essay 2 contributes to the open innovation literature as follows. Deep external knowledge search and IT investment have a complementary effect on innovation performance. Investment in IT allows firms to increase the benefits as well as the optimal level of openness in terms of external knowledge search depth. In addition, we show that appropriability is an important contingency factor for the positive effects of IT on open innovation. Firms that are threatened from imitation and exposed to ineffective protection mechanisms struggle to reap those benefits.

1.4.3 Summary of Essay 3

Essay 3, titled *Blockchain and network governance: Learning from applications in the supply chain sector*, examines how firms jointly develop and implement blockchain applications. Applications of this technology help to improve supply chain transparency, tracing and tracking, automation, as well as supply chain finance (Durach, Blesik, von Düring, & Bick, 2020; Gurtu & Johny, 2019; Hastig & Sodhi, 2020; Kurpjuweit, Schmidt, Klöckner, & Wagner, 2020; Saberi, Kouhizadeh, Sarkis, & Shen, 2019). With the broad range of potential benefits of blockchain applications being well-studied by now, the research interest shifts to questions of how these benefits can be reaped in practice.

A particular challenge in adopting blockchain applications seems to stem from two key characteristics of the technology. By design, blockchain technology is meaningful only under decentralized control (Lumineau, Wang, & Schilke, 2020; Nakamoto, 2008). At the same time, many applications have strong network effects, which require them to be adopted across a network of users (Babich & Hilary, 2020; Kumar et al., 2020). This entails that blockchain applications should be adopted by a network of users under decentralized control. This places high demands on the choice of governance, which neither a firm nor a market can appropriately fulfil. The successful pursuit of the objective to develop and implement a blockchain application is hardly possible in a network of firms without assistance and leadership. Hence, hybrid governance structures that incorporate aspects of networks, to include many users, and hierarchies, to provide targeted leadership, are necessary (Bradach & Eccles, 1989; Dhanaraj & Parkhe, 2006; Provan & Kenis, 2008). The choice of governance structure to develop and implement blockchain applications is a facet that has not yet been investigated. We thus ask: How do firms organize to jointly develop and implement blockchain applications in a supply chain context? What role does network governance play in supporting the development and implementation of blockchain applications?

We choose to answer the research questions by examining five blockchain projects that aim to develop and implement platform applications to improve operational efficiency and effectiveness in a supply chain context. The applications address problems with product tracking and tracing, trade finance, and supplier management. The blockchain projects each represent a case in a multiple case study. We collected data from multiple representatives of each case with semi-structured interviews. Research on interorganizational systems and the governance of such systems provided the foundation for us in structuring our data collection (Markus & Bui, 2012; Provan & Kenis, 2008).

In all of the studied blockchain projects, we find evidence of a struggle for balance between centralized and decentralized control. All of the projects have a dedicated management team with some decision-making authority on the development and implementation of the application. It coordinates member involvement, resolves conflicts, and builds consensus, providing the members firms with some of the benefits of hierarchy (Williamson, 1975). At the same time, however, several or all member firms are involved in strategic decision-making and oversight, ensuring some degree of decentralized control. The governance of these projects thus represents a hybrid form that combines a hierarchy with network governance (Provan & Kenis, 2008). We conclude that such hybrid governance structures are a requirement of the innovation, in this case a novel blockchain application.

This study is among the first that investigate the organizational aspects of developing and implementing a blockchain application. By highlighting how challenging it is to organize a blockchain project, we provide a contrasting perspective to the research that promotes the potential benefits of blockchain technology (Gurtu & Johny, 2019). A network governance that incorporates a hierarchy and thus balances decentralized oversight with centralized leadership is difficult to implement and maintain, but it has several advantages over more centralized or decentralized alternatives. On one hand, a dedicated management team provides target-oriented leadership, which a fully decentralized approach cannot offer. On the other hand, the shared control among member firms makes the project attractive for others to join, as dependency concerns are mitigated. In addition, the combined funding, expertise, and market power of the member firms is a key competitive advantage over projects that are driven by single firms.

1.5 Concluding remarks

1.5.1 Limitations of the research

Each of the three essays has its own specific limitations and suggestions for future research, which we do not repeat here. Instead, we discuss some general limitations of our research by comparing it to the manner with which similar phenomena are studied in related fields. The three essays all take a firm- or network-level perspective and do not consider many factors that are on either lower or higher levels of abstraction. In none of the essays do we look closely at relationships between specific firms or the internal lives of the firms that we study. Similarly, we do not consider effects that are greater than the firm (or the network of firms, studied in Essay 3), such as the competitive or institutional environment that might influence the behavior of the firm. Accordingly, our findings are addressed to the generic (manufacturing) firm.

This perspective is not necessary to study the relationship between governance choices and innovation performance or, more specifically, our phenomena of interest, outsourcing, collaborations in open product innovation, and collaborative technology innovation. The same phenomena are studied in related research with either a greater focus on the specifics of the firm, relationship, project, etc. or with a greater focus on the firm's environment. Accordingly, we formulate two general limitations of our research.

Phenomena related to outsourcing or collaborative innovation are often studied in specific dyadic relationships (Handley & Benton, 2013; Hoegl & Wagner, 2005; Wagner, 2012). The underlying data is specific to the dyad, specific to a single case of outsourcing, or specific to a single innovation project. In Essay 3, we use such case-specific data, in the other two essays, however, we use buyer-only firm-level data. In our approach to studying these phenomena, a lot of relationship-specific information, which can influence performance (Bstieler, 2006; Handley & Benton, 2013; Hoegl & Wagner, 2005; Kroes & Ghosh, 2010), is thus removed. This limitation is extendable to questions of implementation. While the implementation process is represented in Essay 3, in Essays 1 and 2, it is not. The success of outsourcing or any form of collaboration, however, depends on how firms implement it (Aksin & Masini, 2008; Barthélemy, 2001).

A second general limitation is related to aspects of the firms' environment, which we do not consider explicitly in our research. Although we control for the industry in the quantitative studies, this is no more than a dummy variable. The environment, however, does matter (Mauri & Michaels, 1998). Many contextual factors, such as competition and the distribution of capabilities among firms (Helfat & Campo-Rembado, 2016; Jacobides & Winter, 2005; Kapoor, 2013), industry dynamics and turbulence (Jacobides & Winter, 2005; Kapoor & Adner, 2012; Pavlou & El Sawy, 2006), or the geographical location (Asheim & Coenen, 2005; Belussi, Sammarra, & Sedita, 2010), matter for a firm's governance choices and their relationship with innovation performance.

In summary, examining the link between governance choice and innovation performance as we do it has inherent limitations. There are numerous influencing factors that we only cover rudimentarily, if at all, in our models. We believe, however, that there is value in studying the generic manufacturing firm in order to draw generalizable conclusions.

1.5.2 Conclusion

This dissertation examines different aspects of the relationship between governance choice and innovation performance. We lay a particular focus on the role that IT play in influencing this relationship. The results indicate how some governance choices that firms make help to improve innovation performance, while others do not. The contributions of all three essays are relevant in current research and still, each of the essays represents a different 'era' in the research of governance choices and their effects. The 'era' that Essay 1 represents is the earliest. Questions of outsourcing and its effects were of major interest in the 2000s and early 2010s. Research on innovation in alliances and collaborations has a similarly long history. Only from the late 2000s onwards, however, collaborative innovation has become a major topic as part of the research on open innovation, the stream Essay 2 is embedded in. With the rise of IT and its profound impact on innovation processes, the study of IT-related phenomena in innovation research has gained traction in the last two decades. Questions on organizational aspects of digital innovation, as we address in Essay 3, are of major interest today. We believe that studying the reciprocal influence of IT applications and governance choices are of major interest for research in the future.

Chapter 2 When outsourcing threatens a firm's value creation from product innovation

Abstract: The boundaries of the firm shape the development of the firm's capabilities and its accumulation of knowledge. Changes in the firm's boundaries therefore affect the way in which it creates value. Focusing on outsourcing, we explore the effects on value creation through product innovation. To substantiate our knowledge-based explanation for these effects, we identify knowledge relatedness of the outsourced activities and the firm's absorptive capacity as drivers of the effects of outsourcing on innovation performance. We test our hypotheses in a first-differencing model using panel data for Swiss manufacturing firms. Our results show that outsourcing can cause a decline in the subsequent performance of new products. The magnitude of the outsourced activities drives these effects.

2.1 Introduction

Firms outsource to gain access to the specialized capabilities of suppliers and to increase the focus on their own core capabilities (Hashai, 2018). In this way, firms become more specialized and value chains may become more efficient (Jacobides & Winter, 2005). Through outsourcing, the firm's boundaries constrict, the vertical scope shrinks, and the bundle of capabilities the firm controls becomes narrower. Firms innovate by searching for valuable combinations among capabilities within this bundle (Zenger et al., 2011). The inward shift in the firm's boundaries, induced through outsourcing, may therefore transform the way in which the firm creates value from innovations in the future (Argyres & Zenger, 2012; Jacobides & Winter, 2005). With this study we aim to describe and understand such transformative effects of outsourcing. We concentrate on the effects on value creation from product innovations.

Previous empirical research that links firm boundaries to performance has compared the performance of hierarchical and market governance, mirroring the make-or-buy decision (Williamson, 1975). This research generated valuable insights into the costs and benefits of the two governance options (e.g. Macher, 2006; Novak & Stern, 2008; Weigelt, 2009). Among these studies, some link innovation outcomes to outsourcing decisions (Hashai, 2018; Mihalache, Jansen, Van Den Bosch, & Volberda, 2012; Novak & Stern, 2008; Weigelt & Sarkar, 2012) or vertical scope (Helfat & Campo-Rembado, 2016; Kapoor & Adner, 2012; Macher, 2006). None, however, have examined how outsourcing transforms a firm's value creation from product innovation into the future. This is an important gap in the literature, as it identifies the long-term, less visible effects of a boundary change within the firm. Such effects underline the strategic nature of boundary choices (Argyres & Zenger, 2012; Kogut & Zander, 1992).

To close this gap in the literature, we turn to a theory that incorporates the time dimension into the interaction between firm boundaries and capabilities (Argyres & Zenger, 2012). Departing from an emphasis on the individual make-or-buy decision, this theory describes firm boundaries and capabilities as dynamically co-evolving (Argyres & Zenger, 2012; Jacobides & Winter, 2005, 2012). It can be costly to change firm boundaries and reverse these changes (Argyres & Liebeskind, 1999; Argyres & Zenger, 2012; Nickerson & Silverman, 2003). As a result, the development of a firm's capabilities and how it creates value is contingent on past boundary choices (Argyres & Zenger, 2012). In a recent empirical study, Zhang and Tong (2021) use this theoretical lens to examine the transformative effects of a boundary change; in their case, vertical mergers. They provide evidence that vertical mergers influence innovation outcomes for years to come. In the first part of this paper, we complement the work of Zhang and Tong (2021) by studying the inverse case to vertical integration, the effects of outsourcing on innovation outcomes. This leads to our first question: How does outsourcing affect a firm's capabilities to create value from product innovations over time?

In the second part of the paper, we expand our knowledge of such transformative effects to examine their underlying mechanisms and conditions. To do this, we study how the magnitude of the outsourced activities drives the effects on innovation performance by taking into account the change in vertical scope that accompanies the outsourcing. We then compare the effects of production outsourcing and other types of outsourcing that involve activities less closely related to the core capabilities of the firm, such as services and IT. Finally, we examine the investment in absorptive capacity as a possible mitigation strategy against adverse effects. This leads to our second question: what are the underlying mechanisms of the transformative effects of outsourcing?

To test our hypotheses, we base our analysis on a large-scale representative firm-level panel dataset of Swiss firms, derived from four waves of the Swiss innovation survey covering 2002 to 2011.[2] We apply a first-differencing model, which allows us to study the relationship between changes in variables instead of levels, as suggested for the study of the effects of boundary decisions (Lafontaine & Slade, 2007). The first-differenced form both corresponds to the phenomenon under study and allows us to control for unobserved time-invariant heterogeneity at the firm level (firm fixed effects). This is necessary to counteract potential inference problems. To identify outsourcing as the driver of the change in performance and rule out potential endogeneity issues, besides controlling for firm fixed effects, we introduce a time lag between dependent and independent variables and perform propensity score matching as a robustness check.

Our results show that the outsourcing of production activities adversely affects the performance of product innovations in manufacturing firms. These effects depend on the type of innovation. While production outsourcing weakens the performance of a firm's new products, it does not affect the performance of improved products. This suggests that production outsourcing is linked to a specialization of the firm's innovation capabilities. With these results, we complement Zhang and Tong's (2021) findings tying vertical integration to

[2] The survey waves are based on the KOF enterprise panel (https://kof.ethz.ch/en/surveys/structural-surveys/kof-enterprise-panel.html). This is a stratified random sample of about 6500 firms drawn from the Swiss business census provided by the Federal Statistical Office. We do not use more recent data because newer versions of the survey no longer include questions on outsourcing.

increased systemic innovation with the inverse case, showing that production outsourcing hurts systemic innovation. We substantiate the proposed effect by identifying when it occurs. Both the type and magnitude of outsourcing drive the adverse effects on product innovation performance. While the outsourcing of production activities affects innovation outcomes, the outsourcing of services and IT does not. The more the vertical scope of the outsourcing firm constricts, the more severe the effects on innovation outcomes. The interaction of the type and the scope of boundary change offers the most precise measure for the negative effects on innovation performance. This result improves the understanding and measurement of the link between boundary changes and performance outcomes. Ultimately, we provide evidence that impediments to knowledge transfer across firm boundaries drive the negative effects of outsourcing on product innovation performance. Investing in the internal absorptive capacity allows firms to counteract some of these effects. Overall, these findings underline that outsourcing can hurt a firm's long-term ability to create value from innovation.

In the following section, we introduce the theoretical basis for this study, discuss the empirical research that links boundary choices with performance, and derive a set of hypotheses about the effects of outsourcing on product innovation performance. After introducing the data and methodology, we present our empirical results and close the paper with a discussion of the implications.

2.2 Theoretical background

The relationship between firm boundaries and capabilities is important to explain differences in performance among firms (Argyres, Felin, Foss, & Zenger, 2012; Jacobides & Winter, 2012; Madhok, 2002; Zenger et al., 2011). Organizational economics (transaction cost approaches) and the capabilities-based view provide a rich theoretical foundation (Leiblein, 2003; Madhok, 2002; Williamson, 1975; Zenger et al., 2011). Attempts to integrate the two theoretical traditions have produced a dynamic perspective in which firm boundaries and capabilities coevolve (Argyres & Zenger, 2012; Bigelow, Nickerson, & Park, 2019; Jacobides & Winter, 2005, 2012). This is a departure from seeing firm boundaries merely as a result of firm attributes, such as capabilities. Instead, firm boundaries also affect the development of the firm, including its capabilities and how it creates value from innovation (Argyres & Zenger, 2012; Zhang & Tong, 2021).

We begin the next section with a review of the research on the effects of boundary choices. We then develop two sets of hypotheses. The first addresses possible direct effects of outsourcing on the innovation capabilities of the firm. In the second set, we focus on the mechanisms and conditions that drive the relationship between outsourcing and innovation capabilities.

2.2.1 Studying the effects of boundary choices

In research on boundary choices, the make-or-buy decision takes center stage. A decision maker is assumed to decide between two modes of governance, the firm and the market, each of which has its own strengths and weaknesses (Grant, 1996; Nickerson & Zenger, 2004; Williamson, 1975). Building on these theoretical foundations, many empirical studies present the make-or-buy decision as a trade-off between the respective strengths and weaknesses of the market and the firm. This trade-off is between long-term evolution of capabilities and short-term profitability (Jacobides, 2005; Novak & Stern, 2008), between adaptability and efficiency (Weigelt & Sarkar, 2012), between time-to-market and cost-effective manufacturing (Macher, 2006), or between stronger systemic and stronger component innovation capabilities (Kapoor & Adner, 2012). In summary, we know well what the distinct strengths and weaknesses of the market versus those of the firm are.

The relative benefits of the market and the firm play a dual role as drivers and effects of boundary choices. The knowledge of these benefits drives decision makers to choose one mode of governance over the other. In order to examine how boundary choices affect performance, the study design must be carefully selected (Lafontaine & Slade, 2007; Leiblein, Reuer, & Dalsace, 2002). Many empirical studies compare the performance of the market to that of the firm. This is often done by focusing on the make-or-buy decisions involving ‘new’ activities or assets to compare the performance of firms that chose the make option with the performance of firms that chose the buy option (Novak & Stern, 2008; Weigelt, 2009; Weigelt & Sarkar, 2012). In addition, these studies measure performance effects that are closely associated with the activities or assets involved in the boundary choice (e.g. Reitzig & Wagner, 2010). Such a study setting has certain limitations in regard to our phenomenon of interest, the transformative impact of outsourcing on a firm’s value creation from product innovation. Outsourcing in our case is not the same as choosing the buy option to organize a ‘new’ activity or asset; instead, it is a loss of control over an outsourced activity or asset. In addition, the consequences of outsourcing may affect the broader firm and not only the outsourced activity (Argyres & Zenger, 2012). Focusing on the evolution of performance over time after a boundary change allows to control for unobserved (time-invariant) characteristics of a firm that may influence both the outsourcing decision and the firm’s innovation performance. Thus, an important aspect of the ‘endogeneity’ of the outsourcing decision can be considered (Argyres, Rios, & Silverman, 2020; Zhang & Tong, 2021). In alignment with this logic, in the following paragraphs, we develop hypotheses that link a change in firm boundaries to a change in performance.

2.2.2 Effects of outsourcing on product innovation performance

For our first set of hypotheses, we apply the results from research on the relative benefits of the firm versus the market, on the transformative effects of outsourcing on the firm’s value creation from product innovation. Firms innovate through new combinations of knowledge (Cassiman & Veugelers, 2006; Galunic & Rodan, 1998; Teece, Pisano, & Shuen, 1997). To create value from product innovations, the integration of and coordination between a variety of complementary assets is necessary (Teece, 1986). Integrated firms control a broader range of complementary assets, possibly making them less reliant on knowledge transfer across firm boundaries.

Based on this argumentative logic, two research streams propose distinct associations between firm boundaries and innovation performance. For each, we formulate a hypothesis that adopts the logic from differences between firms to the performance effects within the firm. First, we have evidence that outsourcing firms are weaker at innovating than integrated firms in general (Weigelt, 2009). The outsourcing firm needs to transfer the knowledge from the outsourced activity across firm boundaries, making it more difficult to use the knowledge associated with the outsourced activity in the innovation process (Grimpe & Kaiser, 2010; Weigelt, 2009). If knowledge transfer between stages in the value chain is essential, integration offers performance advantages with regard to innovation and commercialization (Brusoni, Prencipe, & Pavitt, 2001; Kapoor & Adner, 2012; Reitzig & Wagner, 2010). This effect does not happen immediately; innovation and commercialization take time. Years may pass between the outsourcing and the market launch of the products developed under the new organizational form.

Hypothesis 1. *Outsourcing leads to a decrease in product innovation performance. This decrease in product innovation performance comes with a delay.*

A second set of studies argues that outsourcing firms are not generally less well equipped to innovate. Instead, depending on whether firms are more specialized or more integrated, the results of a firm’s innovation effort may differ. As Hashai (2018) shows, outsourcing may be beneficial as it allows the firm to increase the focus on its core strengths and to specialize. Instead of retaining non-core capabilities in-house, the firm gains access to specialized capabilities of suppliers, and may benefit from keeping up with the latest technological developments (Poppo & Zenger, 1998; Wolter & Veloso, 2008). Not all types of innovations require the same degree of knowledge transfer (Kapoor & Adner, 2012; Nickerson & Zenger, 2004; Teece, 1996). As a result, the competitive advantages of specialized and integrated firms differ by type of innovation (Kapoor, 2013; Kapoor & Adner, 2012; Macher, 2006). If interdependencies are weak and tasks decomposable, independent search and higher degrees of specialization may be important benefits of market governance (Nickerson & Zenger, 2004; Wolter & Veloso, 2008). In contrast, when tasks are more complex and more advanced coordination in the search effort is necessary, integration is more efficient (Nickerson & Zenger, 2004). Systemic innovations are more likely to require solutions to non-decomposable problems. In contrast, component innovations pose more decomposable problems (Nickerson & Zenger, 2004). As a result, in environments that require systemic innovations, integrated firms have a competitive advantage over specialized firms. Conversely, specialized firms may be at an advantage for creating component innovations (Kapoor, 2013; Kapoor & Adner, 2012; Macher, 2006; Teece, 1996).

Considering the performance differences between more integrated and specialized firms with regard to innovation type, outsourcing may influence the firm's performance by type of innovation. To explore how the effects of outsourcing on innovation performance differ by innovation type, we distinguish the effects on the performance of new and improved products. Relative to product improvements, the development of new products may be more of a non-decomposable problem and require closer interaction and coordination between knowledge sets or design choices. Product improvements may be limited to the exchange of components or modules, so less interaction and coordination will suffice (Nickerson & Zenger, 2004; Wolter & Veloso, 2008).[3] Through outsourcing, a firm may become less well equipped to create and commercialize new products, but better equipped to create and commercialize components of

[3] In certain innovation environments, where the technological base can be an obstacle to the development of (radically) new products, cooperation with several specialized firms can be advantageous. In the hypothesis, we distinguish only between new products and improved products, not between new and breakthrough innovations. It may be true that for highly novel products, established paradigms are a hindrance and collaborative forms of organization work better than integrated forms. We argue, however, that for the panel of firms we use and the breadth of innovations we consider, this case is of minor importance.

products, therefore improving existing products. We propose that there is a delayed negative effect of outsourcing on the performance of new products and a delayed positive effect of outsourcing on component innovation performance.

Hypothesis 2. *Outsourcing increases the performance of improved products and decreases the performance of new products. These effects come with a delay.*

2.2.3 Underlying mechanisms and conditions

Going beyond the mere effects of outsourcing on product innovation performance, we aim to improve our understanding of how and when these effects occur. To identify the relevant mechanisms and conditions, we reflect on the assumptions in the arguments leading up to hypotheses 1 and 2. In this paragraph, we introduce these assumptions and then develop a hypothesis for each.

Our first assumption concerns the magnitude of the outsourced activities in both hypotheses. For the knowledge associated with the outsourced activity to be relevant in the innovation process, the outsourced activity must have a certain magnitude. To test the effects of that magnitude, we include the change in vertical scope accompanying the outsourcing in our arguments. Second, we assume that the knowledge associated with the outsourced activity is complementary in the innovation process. We test this by comparing the effects of different types of outsourcing depending on how closely related the outsourced activity is to the core capabilities of the firm. Third, we assume more costly knowledge transfer across firm boundaries to be the driver of the effects on product innovation performance. Firms can influence their ability to absorb external knowledge (Caner, Cohen, & Pil, 2017; Weigelt, 2009). We can thus test, whether by changing the absorptive capacity, the firm can mitigate possible adverse effects of outsourcing. These are the three major mechanisms that underpin hypotheses 1 and 2. Our next step is to substantiate them.

The first mechanism addresses the influence of magnitude on the effects of outsourcing. In the derivation of hypothesis 2, we argue that the vertical scope of the firm matters for how it innovates. It is not the act of outsourcing in isolation that causes the described effects, but rather outsourcing in combination with a change in vertical scope. Similarly, the change in vertical scope matters for hypothesis 1: The scope of the outsourced activities determines the magnitude of knowledge transfer from the outsourced activity that will be necessary in the innovation process. Small outsourcing projects may have no effect at all on the innovativeness of the firm. Again, it is the combination of outsourcing and the change in vertical scope that accounts for the possible effects on innovation performance. In summary, we argue that outsourcing alone is not sufficient to capture the full impact on product innovation performance. Rather, the interaction with a change in vertical scope is a better explanation of the drivers of these effects. We formulate the hypothesis as a moderation of the effects described in hypotheses 1 and 2 by a change in vertical scope.

Hypothesis 3. *The change in vertical scope positively moderates the relationship between outsourcing and innovation performance. The more the vertical scope of the firm shrinks, the more the innovation performance changes, as predicted in hypotheses 1 and 2.*

Next, we address the requirement to integrate the knowledge of the outsourced activity into the innovation process as a driver of the effects described in hypotheses 1 and 2. We argue that only the outsourcing of activities that are related to the core capabilities of a firm may affect product innovation performance. As a form of outsourcing that affects activities closely associated with the core capabilities of manufacturing firms, we focus on the outsourcing of production activities. Production capabilities are important complementary assets in the development and commercialization of new products (Teece, 1986). That is why the governance choice with regard to production activities may influence a firm's innovation outcomes. As a current example of a highly innovative firm, Tesla fosters a vertically integrated production, successfully competing against traditional car manufacturers that rely on outsourced component manufacturing and vertically disintegrated supply chains (DeBord, 2020; Verpraet, 2020). There are other functions that firms can outsource, such as IT or services (Ang & Straub, 1998; Reitzig & Wagner, 2010; Weigelt, 2009). Although relevant to ensure the operations of the firm, we expect these functions to play a less important role than manufacturing in the innovation of new products because they are more peripheral to the core capabilities of the manufacturing firm. We propose that the effects of outsourcing on product innovation performance are only significant for the outsourcing of production activities, not for the outsourcing of peripheral activities such as IT or services.

Hypothesis 4. *The effect of outsourcing on product innovation performance depends on the type of outsourced activity; the negative effects are restricted to the outsourcing of core capabilities (i.e. production outsourcing).*

Last, we address the proposed mechanism that attributes the negative effects of outsourcing to a hampered knowledge transfer across firm boundaries. If a firm is to rely on the capabilities of the suppliers in the innovation process, it must have some knowledge of the supplied components or products (Brusoni et al., 2001; Takeishi, 2002). Firms can extend their boundaries of knowledge beyond their boundaries of production. Greater knowledge of the outsourced activity allows firms to better select and monitor suppliers, as well as exchange knowledge to mitigate the possible adverse effects of outsourcing (Mayer & Salomon, 2006; Poppo & Zenger, 1998; Wolter & Veloso, 2008). This ability hinges on the firm’s absorptive capacity (Cohen & Levinthal, 1990; Rothaermel & Alexandre, 2009). Investments in its absorptive capacity enable a firm to transfer knowledge more easily across firm boundaries (Grimpe & Kaiser, 2010; Sofka & Grimpe, 2010). Enabling knowledge transfer across firm boundaries can mitigate the proposed negative effects of outsourcing production activities on innovation. We propose that investments in the absorptive capacity moderate the relationship between outsourcing of production activities and product innovation performance.

Hypothesis 5. *Investments in the internal absorptive capacity of the firm positively moderate the relationship between outsourcing and product innovation performance. The more a firm invests in its internal absorptive capacity, the less the innovation performance changes, as predicted in hypotheses 1 and 2.*

2.3 Data and methodology

2.3.1 Data

The empirical analysis uses firm-level panel data of Swiss firms, derived from four waves of the Swiss innovation survey (2002, 2005, 2008, and 2011). The Swiss innovation survey is a postal survey conducted by the KOF Swiss Economic Institute, based on the KOF enterprise panel, a representative sample of approximately 6,500 firms randomly drawn according to the stratification characteristics (29 industries and three firm-size classes) from the governmental business register. In its setup, the Swiss innovation survey is aligned to the European Community Innovation Survey (CIS), which is based on OECD/Eurostat guidelines (OECD/Eurostat, 2018). Data from this survey has been used in many empirical papers (e.g. Beck, Lopes-Bento, & Schenker-Wicki, 2016; Trantopoulos, Von Krogh, Wallin, & Woerter, 2017). The survey provides detailed information on firms' R&D and innovation activities, their organizational structure, economic performance, other firm characteristics such as the number of employees, intermediate inputs, and qualification of the employees as well as information about the market structure. The response rates from the surveys are 39.6% (2002), 38.7% (2005), 36.1% (2008), and 35.9% (2011).

2.3.2 Measures

In line with our research question, we measure how a change in the organization of a firm's boundaries affects its performance. Therefore, the measures all represent changes in levels. Unless indicated otherwise, a change in levels is calculated as a variable's difference in value between two consecutive survey waves.

Product innovation performance: Our outcome variables measure a change in the firm's product innovation performance (*Δ PRODUCT*). *PRODUCT* is measured as the sales share of new and improved products. Measuring innovation as a share of sales allows capturing the market response to a firm's innovative products including commercialization and does not limit the focus on the generation of core technologies. To test hypothesis 2, the dependent variable *Δ PRODUCT* is split into a change in the sales share of new products (*Δ NEW*) and the sales share of improved products (*Δ IMPROVED*) to account for different types of innovation. All dependent variables indicate changes in the levels of the underlying measures.

Outsourcing: In the main models, we distinguish two types of outsourcing: the outsourcing of activities related to production of products or components that used to be performed in-house (*Production OS*), and the outsourcing of services and IT, combined to form the measure *Peripheral OS*.[4] In comparison to production activities, services and IT activities are more peripheral to the innovation process of most manufacturing firms, hence the name *Peripheral OS*. Combining the survey questions on outsourcing into those two outsourcing measures (*Production OS* and *Peripheral OS*) is supported by a factor analysis (see Appendix A). The survey questions ask whether a firm newly outsourced production of products, production of components, services, or IT in the past five years. The data resembles a treatment variable where 1 indicates that a firm was treated (it newly outsourced some activities) and 0 indicates that a firm remains untreated (it did not outsource any activities). The question on outsourcing is not part of the CIS in other countries than Switzerland. In the Swiss Innovation Survey, the question was asked in three consecutive waves only (2005, 2008, and 2011) and solely applies to firms with

[4] In the models for hypothesis 4, we test whether the coefficients differ between *Production OS* and *Peripheral OS*. To extend the analysis, we split up *Peripheral OS* and perform the same tests on the measures underlying *Peripheral OS*, namely *Services OS* and *IT OS*.

20 or more employees. We introduce *Production OS* and *Peripheral OS* both as lagged (t-1) and contemporaneous (t) variables in relation to the dependent variables. Lagging the main explanatory variable ensures that there is no temporal overlap with the main dependent variables, which strengthens the claim of a causal relationship. By introducing *Production OS* and *Peripheral OS* as contemporaneous variables, we control for any correlation between outsourcing and changes in innovation performance in the same time period. This is important, since we assume that the effect of outsourcing activities on the innovation performance changes over time.

Vertical scope: We measure *Vertical scope* as the log of the cost of purchased goods. This measure has been used in studies on the boundaries of the firm before (Kotabe, Mol, Murray, & Parente, 2012; Novak & Stern, 2008). As is the case for the other variables, *Vertical scope* enters the models as a change variable *Δ Vertical scope*, both in its lagged (t-1) and contemporaneous (t) forms. When a firm outsources activities that had formerly been performed in-house, the cost of purchased goods increases and the vertical scope decreases. *Δ Vertical scope* is coded such that a negative value indicates a decrease in vertical scope and an increase in the cost of purchased goods. Other factors, such as prices in upstream markets and (re-) integration may also influence the cost of purchased goods. To test hypothesis 3, we introduce the interaction term *Δ Vertical scope (t-1) * Production OS (t-1)* in the model. The former controls for the effects of changes in vertical scope on innovation performance, independent of outsourcing. The interaction term captures the effect of outsourcing with a simultaneous change in a firm's vertical scope on innovation performance.

Absorptive capacity: In hypothesis 5 we argue that absorptive capacity moderates the relationship between outsourcing and innovation performance. Although we cannot measure a firm's absorptive capacity associated specifically with the outsourced activities, we can use a proxy. We argue that changes in a firm's internal R&D expenditures (*Δ int. RD Input*) serve as a substitute for investments in absorptive capacity (Cohen & Levinthal, 1990; Grimpe & Kaiser, 2010; Sofka & Grimpe, 2010). Not all R&D expenditures contribute to the firm's absorptive capacity; R&D investments at external partners do not directly contribute to the knowledge within the firm and do not allow it to increase its absorptive capacity. In summary, we test, whether *Δ int. RD Input* moderates the relationship between production outsourcing and product innovation performance addressed in hypotheses 1 and 2.

Control variables: In our analysis, we use a set of control variables, which might influence changes in innovation performance of firms. Again, we introduce the variables as changes in their underlying measures. In order to construct the lagged control variables, we use the additional survey wave from 2002, which did not include the question on outsourcing. It is important to note that time-invariant control variables, such as industry affiliation, are automatically excluded in the first-differencing model. First, we control for changes in (the log of) firm size (*Δ Size*) as well as changes in the share of employees with tertiary education among the total workforce (*Δ HC Educ*), as these are often important firm characteristics affecting innovation performance. Second, as a major predictor of changes in innovation performance, we control for changes in a firm's general R&D input (*Δ RD Input*) in all models. We measure this variable as the logarithm of R&D expenditures. Third, we include the industry-level average of the change in product innovation performance (*Ind.-Ø Δ PRODUCT*) in the models in order to control for industry-specific trends in innovative activities. The focal firm is excluded from the industry average. We classify industries according to 2-digit NACE codes (European Communities, 2008). Finally, survey year dummies complement our set of control variables.

2.3.3 Estimation strategy

In the previous section, we introduced the measures as changes in levels. In line with how we introduced the measures and corresponding with the study's purpose to investigate how a change in one variable leads to a change in another, we apply first-differencing (FD) estimations. The FD transformation eliminates the time-invariant unobserved effects (Wooldrige, 2016). The FD estimation approach not only allows us to analyze the research questions by linking changes in explanatory variables to changes in dependent variables; it also strengthens the precision of the inference. Eliminating time-invariant effects allows controlling for firm-specific factors that influence firms' performance levels and outsourcing activities but that are not observed. This addresses another potential endogeneity bias – aside from reverse causality. Focusing on within-firm changes is an effective way to resolve the inference problem inherent in estimation procedures that study between-firm differences. In other words, the FD equation (3) eliminates c_i, which would bias our results, if it were correlated with u_{it}:

$$y_{it} = X_{it}\beta + c_i + u_{it} \quad (1)$$

$$y_{it-1} = X_{it-1}\beta + c_i + u_{it-1} \quad (2)$$

where, y_{it} denotes the firm innovation performance of firm i in time $t = 1, 2, 3$ and $\boldsymbol{X}$ the characteristics of firm i in time t. Differencing both equations (1, 2) gives:

$$\Delta y_{it} = y_{it} - y_{it-1} = \Delta X_{it}\beta + \Delta u_{it}, \;\; t = 2, 3, \quad (3)$$

eliminating the unobserved effect c_i.

The FD estimator $\widehat{\beta_{FD}}$ is then simply the pooled OLS estimator regressing changes on changes. Under the assumption of no serial correlation of the change in the idiosyncratic error Δu_{it}, the FD estimator is consistent and unbiased conditional on X. The dependent variables are technically restricted to the interval [-1;1], which might raise problems of censoring. In the case at hand, the extreme values, however, are highly unlikely as they represent cases in which the share of sales of new or improved products moves from 100% to 0% or vice versa in subsequent time periods. In our main model, there is only one censored observation. Given the minute improvement in consistency that a limited dependent variable estimator, like Tobit, would offer, we therefore revert to OLS for the sake of providing easily interpretable coefficient sizes. In all regressions, we use cluster-robust standard errors. Clustering is on the firm level and all our estimators show heteroscedasticity-robust standard errors.

2.3.4 Sample

The full sample contains 2,031 observations of the main explanatory variable, production outsourcing, in three waves (2005, 2008, 2011). Since small firms were not required to answer the questions about outsourcing, this sample is limited to firms with 20 or more employees. We limit the scope to manufacturing firms, excluding firms in the services and construction industries. Table 2 shows the descriptive statistics for the variables in level form. Outsourcing variables were asked as a change in the survey. Hence, they are represented in such a form.

Table 2 Descriptive statistics of the level variables (N = 2,031)

Level variables	Mean	S.D.	Min	Max	5%	95%
PRODUCT (t)	0.23	0.26	0.00	1.00	0.00	0.80
NEW (t)	0.11	0.15	0.00	0.99	0.00	0.40
IMPROVED (t)	0.12	0.17	0.00	1.00	0.00	0.45
Size (t)	4.68	1.04	3.04	9.95	3.26	6.49
HC Educ (t)	0.05	0.07	0.00	0.90	0.00	0.20
RD Input (t)	7.57	6.59	0.00	21.50	0.00	15.71
Vertical scope (t)	16.40	1.55	11.35	23.33	14.00	19.09
Change variables	Mean		Min	Max		
Production OS (t)	0.23		0.00	1.00		
Peripheral OS (t)	0.22		0.00	1.00		

The design of the study puts the following additional restrictions on the full sample. First, the transformation of the variables into a first-differenced form requires at least two consecutive observations of the same firm. This step considerably decreases the sample size, given that the panel data set is heavily unbalanced. In addition, the inclusion of lagged first-differenced control variables extends the requirement of consecutive observations to three. After accounting for these restrictions, the resulting first-differenced sample contains 363 firm-year observations. It serves as the base sample to test our hypotheses. A Cumby-Huizinga test for autocorrelation (Cumby & Huizinga, 1992) detects no presence of serial correlation ($p = 0.257$). Table 3 shows the summary statistics for the base sample with 363 observations. The Δ represents the first-differenced form.

Table 3 Summary statistics and correlation matrix (N = 363)

Variables	Mean	SD	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1 Production OS (t)	0.20		1.00														
2 Production OS (t-1)	0.26		0.28	1.00													
			0.00														
3 Peripheral OS (t)	0.21		0.34	0.23	1.00												
			0.00	0.00													
4 Peripheral OS (t-1)	0.18		0.16	0.32	0.25	1.00											
			0.00	0.00	0.00												
5 Δ Vertical scope (t)	-0.09	0.48	-0.09	-0.03	0.00	0.07	1.00										
			0.08	0.56	0.94	0.17											
6 Δ Vertical scope (t-1)	-0.14	0.50	-0.08	-0.04	-0.12	-0.14	-0.45	1.00									
			0.14	0.47	0.02	0.01	0.00										
7 Δ Vertical scope (t-1)	-0.06	0.27	-0.17	-0.18	-0.40	-0.21	-0.22	0.50	1.00								
X Production OS (t-1)			0.00	0.00	0.00	0.00	0.00	0.00									
8 Δ PRODUCT (t)	0.00	0.24	0.08	0.03	-0.11	0.02	-0.06	0.13	0.11	1.00							
			0.13	0.58	0.04	0.74	0.23	0.01	0.03								
9 Δ NEW (t)	0.00	0.15	0.01	-0.01	-0.12	0.03	-0.05	0.15	0.20	0.70	1.00						
			0.88	0.85	0.03	0.57	0.39	0.01	0.00	0.00							
10 Δ IMPROVED (t)	0.01	0.17	0.10	0.05	-0.05	0.00	-0.05	0.06	-0.02	0.79	0.11	1.00					
			0.05	0.35	0.37	0.98	0.36	0.29	0.70	0.00	0.03						
11 Δ Size (t)	0.02	0.22	0.14	0.01	0.03	0.09	-0.16	-0.06	-0.04	0.08	0.09	0.03	1.00				
			0.01	0.82	0.53	0.10	0.00	0.23	0.48	0.14	0.09	0.57					
12 Δ Size (t-1)	0.04	0.19	0.01	-0.06	0.01	0.01	0.10	-0.31	-0.08	-0.06	-0.03	-0.06	-0.05	1.00			
			0.79	0.28	0.88	0.90	0.05	0.00	0.13	0.23	0.59	0.23	0.35				
13 Δ HC Educ (t)	0.00	0.04	-0.04	-0.03	-0.03	-0.05	0.05	-0.07	-0.02	-0.05	-0.03	-0.04	-0.05	0.01	1.00		
			0.47	0.56	0.63	0.32	0.33	0.19	0.65	0.39	0.54	0.50	0.37	0.85			
14 Δ HC Educ (t-1)	0.00	0.05	-0.08	-0.05	0.03	-0.02	-0.05	0.12	0.07	0.06	0.11	-0.02	0.04	-0.06	-0.42	1.00	
			0.15	0.38	0.59	0.70	0.33	0.02	0.21	0.28	0.03	0.71	0.40	0.24	0.00		
15 Δ RD Input (t)	0.36	4.59	0.02	0.04	-0.05	-0.05	-0.15	0.08	0.05	0.29	0.24	0.20	0.06	-0.14	0.05	-0.09	1.00
			0.72	0.46	0.31	0.37	0.01	0.12	0.33	0.00	0.00	0.00	0.25	0.01	0.39	0.09	
16 Δ RD Input (t-1)	-0.25	5.28	0.03	0.02	0.04	0.06	0.06	-0.03	-0.07	-0.02	-0.06	0.02	-0.04	0.03	-0.02	0.07	-0.40
			0.63	0.72	0.46	0.23	0.27	0.53	0.17	0.72	0.27	0.64	0.45	0.56	0.73	0.20	0.00

2.4 Results

Table 4 provides the results for hypotheses 1 and 2. The relationship between lagged production outsourcing (*Production OS (t-1)*) and a change in product innovation performance is negative, as predicted by hypothesis 1 (Model 1: β = -0.070, S.E. = 0.028). The effect comes with a delay; the lag between the outsourcing variable and the innovation measure is approximately three years. The analysis of the economic effect suggests that engaging in production outsourcing decreases the expected change in the sales share of innovative products by 7.0 percentage points in comparison to peers that did not engage in production outsourcing. The results of Models 2 and 3 indicate that the adverse effect of production outsourcing loads on the development and commercialization of new products, as predicted in hypothesis 2 (Model 2: β = -0.041, S.E. = 0.020). There is, however, no delayed positive effect of production outsourcing on improved products. Instead, the coefficient of *Production OS (t-1)* is also negative in Model 3 (β = -0.029, S.E. = 0.020). These results support hypothesis 2 only inasmuch as the effects are stronger on the performance of new products. We refer to the results connected to the testing of hypothesis 3 for a reconsideration of hypothesis 2. In order to get a complete picture on the relationship between production outsourcing and product innovation performance, it is worth discussing the behavior of the contemporaneous production outsourcing variable (*Production OS (t)*). In Model 1, it seems like the positive coefficient of the contemporaneous production outsourcing variable offsets much of the lagged production outsourcing variable (Model 1: β_t = 0.062 vs. β_{t-1} = -0.070). This would draw into question our main hypothesis of a delayed negative effect between production outsourcing and innovation performance, as the negative effect would have been preceded by an increase in innovation performance during the period of the outsourcing. Models 2 and 3 reveal, however, that the positive association between contemporaneous production outsourcing and innovation performance is restricted to the performance of improved products (Model 3: β = 0.046, S.E. = 0.022). A claim of causality cannot be made between contemporaneous outsourcing variables and changes in product innovation performance. In sum, production outsourcing does not seem to have much of an effect on the performance of improved products. In contrast, the evidence supports an effect of lagged production outsourcing on the performance of new products.

Not only the lagged production outsourcing variable, but also the other firm boundary variable, the change in vertical scope (*Δ Vertical scope*) has an effect; with similar coefficients in its contemporaneous and lagged form (Model 1: β_t = 0.044, S.E. = 0.029; β_{t-1} = 0.068, S.E. = 0.027). Focusing on the effect of *Δ Vertical scope (t-1),* increasing (decreasing) the vertical scope by 1% increases (decreases) the expected change in the sales share of innovative products by 6.8 percentage points in the next time period in comparison to peers that did not increase (decrease) the vertical scope. Similarly to production outsourcing, the coefficient size depends on the type of innovation, with *Δ Vertical scope (t-1)* only having an effect on new product innovation (Model 2; β = 0.053, S.E. = 0.019 vs. Model 3: β = 0.015, S.E. = 0.018).

Table 4 First-differencing OLS regression estimates for hypotheses 1 and 2

	Model 1 Δ PRODUCT (t)			Model 2 Δ NEW (t)			Model 3 Δ IMPROVED (t)		
	Coef.	S.E.	p>|t|	Coef.	S.E.	p>|t|	Coef.	S.E.	p>|t|
Production OS (t)	0.062	0.034	0.069	0.016	0.024	0.494	0.046	0.022	0.034
Production OS (t-1)	**-0.070**	**0.028**	**0.013**	**-0.041**	**0.020**	**0.038**	**-0.029**	**0.020**	**0.161**
Peripheral OS (t)	0.009	0.036	0.812	-0.003	0.024	0.887	0.012	0.026	0.641
Peripheral OS (t-1)	0.023	0.038	0.553	0.028	0.020	0.167	-0.006	0.033	0.864
Δ Vertical scope (t)	0.044	0.029	0.132	0.032	0.022	0.148	0.012	0.022	0.582
Δ Vertical scope (t-1)	0.068	0.027	0.013	0.053	0.019	0.006	0.015	0.018	0.402
Δ Size (t)	0.064	0.077	0.410	0.057	0.047	0.227	0.007	0.053	0.900
Δ Size (t-1)	0.055	0.059	0.354	0.063	0.040	0.119	-0.008	0.037	0.837
Δ HC Educ (t)	-0.150	0.323	0.643	0.070	0.189	0.711	-0.220	0.254	0.387
Δ HC Educ (t-1)	0.221	0.300	0.461	0.362	0.159	0.023	-0.141	0.217	0.516
Δ RD Input (t)	0.017	0.003	0.000	0.009	0.002	0.000	0.009	0.002	0.000
Δ RD Input (t-1)	0.006	0.002	0.017	0.001	0.001	0.220	0.004	0.002	0.034
Ind.-øΔ PRODUCT (t)	-2.146	0.552	0.000	-0.955	0.323	0.003	-1.191	0.380	0.002
Year fixed effects	[yes]			[yes]			[yes]		
N	363			363			363		
Adjusted R-squared	0.162			0.115			0.067		

Continuing with the focus of the effects of changes in vertical scope, we introduce the models to test hypothesis 3 in Table 5. Models 4 to 6 mirror Models 1 to 3 but include the interaction term between production outsourcing and change in vertical scope (*Δ Vertical scope (t-1) X Production OS (t-1)*). The interaction term has little influence in Model 4 with the combined innovation performance as the dependent variable; the coefficient sizes of *Production OS (t-1)* and *Δ Vertical scope (t-1)* remain largely the same compared between Models 1 and 4. In contrast, when focusing on the type of innovation (Models 5 and 6), the interaction term improves the overall model fit. As the results of Model 5 show, *Δ Vertical scope (t-1)* positively moderates the relationship between *Production OS (t-1)* and the performance of new products (Model 5; $\beta = 0.083$, S.E. = 0.040). For firms that engage in production outsourcing, decreasing the vertical scope by 1% decreases the expected change in the sales share of new products by 8.3 percentage points in the next time period and in comparison to peers that did not engage in production outsourcing. These results support hypothesis 3 for the case of new product performance. As expected, the introduction of the interaction term in Model 5 reduces the coefficient sizes of the two stand-alone variables *Production OS (t-1)* and *Δ Vertical scope (t-1)*. For the performance of improved products (Model 6), interpreting the results is less straightforward. The introduction of the interaction term seems to strengthen the significance of the stand-alone variables *Production OS (t-1)* and *Δ Vertical scope (t-1)*. Both having a negative sign, the two stand-alone variables now show a similar pattern to the one on new product performance, but the interaction term has the opposite sign (Model 6; $\beta = -0.059$, S.E. = 0.055).

Table 5 First-differencing OLS regression estimates for hypothesis 3

	Model 4 Δ PRODUCT (t)			Model 5 Δ NEW (t)			Model 6 Δ IMPROVED (t)		
	Coef.	S.E.	p>|t|	Coef.	S.E.	p>|t|	Coef.	S.E.	p>|t|
Production OS (t)	0.062	0.034	0.067	0.016	0.023	0.483	0.046	0.022	0.035
Production OS (t-1)	**-0.065**	**0.033**	**0.047**	**-0.024**	**0.023**	**0.294**	**-0.041**	**0.023**	**0.084**
Peripheral OS (t)	0.010	0.036	0.783	0.001	0.024	0.980	0.009	0.025	0.716
Peripheral OS (t-1)	0.023	0.039	0.549	0.030	0.020	0.136	-0.007	0.033	0.834
Δ Vertical scope (t)	0.044	0.029	0.133	0.032	0.022	0.159	0.012	0.022	0.576
Δ Vertical scope (t-1)	0.062	0.027	0.022	0.032	0.019	0.099	0.030	0.017	0.085
Δ Vertical scope (t-1) X Production OS (t-1)	**0.024**	**0.071**	**0.732**	**0.083**	**0.040**	**0.040**	**-0.059**	**0.055**	**0.291**
Δ Size (t)	0.064	0.077	0.408	0.059	0.047	0.213	0.006	0.052	0.916
Δ Size (t-1)	0.052	0.061	0.392	0.053	0.042	0.213	-0.001	0.038	0.987
Δ HC Educ (t)	-0.150	0.323	0.642	0.069	0.191	0.720	-0.219	0.256	0.393
Δ HC Educ (t-1)	0.219	0.300	0.466	0.355	0.162	0.029	-0.136	0.217	0.532
Δ RD Input (t)	0.017	0.003	0.000	0.009	0.002	0.000	0.009	0.002	0.000
Δ RD Input (t-1)	0.006	0.002	0.015	0.002	0.001	0.172	0.004	0.002	0.037
Ind.-øΔ PRODUCT (t)	-2.147	0.552	0.000	-0.958	0.319	0.003	-1.189	0.383	0.002
Year fixed effects	[yes]			[yes]			[yes]		
N	363			363			363		
Adjusted R-squared	0.160			0.126			0.069		

In summary, the interaction between production outsourcing and a change in vertical scope depends on the innovation type, which justifies a reconsideration of hypothesis 2. We conclude that the interaction term (*Δ Vertical scope (t-1) X Production OS (t-1)*) differs significantly between new and improved product performance (P > F: 0.02). This result indicates partial support for hypothesis 2, as the combined effect of production outsourcing and change in vertical scope only matters for the performance of new products and not for the performance of improved products.

Addressing hypothesis 4, we next present the influence of the type of outsourcing on the model results. In the previous models we observe the lack of a significant direct association between outsourcing of more peripheral activities (*Peripheral OS*) and innovation performance. As the results presented in Table 6 show, neither the stand-alone variables nor the interaction terms with *Δ Vertical scope (t-1)* give any indication for a relationship between *Peripheral OS*, as well as its two components, *Services OS* and *IT OS*, and the performance of new products[5]. F-tests provide evidence that the interaction term between *Δ Vertical scope (t-1)* and *Production OS (t-1)* is different from the equivalent interactions with *Peripheral OS* (P > F: 0.036), *Services OS* (P > F: 0.007), and *IT OS* (P > F: 0.098). These results support hypothesis 4 and indicate that the effects of outsourcing on product innovation performance are limited to the outsourcing of production activities. There is no evidence for such effects after having outsourced services and IT activities. We conclude that negative effects on the performance of new products are limited to the outsourcing of activities that are closely related to the core capabilities of manufacturing firms, and are important complementary assets in the innovation process (i.e. production).

Table 6 First-differencing OLS regression estimates for hypothesis 4

	Model 7 Δ NEW (t)			Model 8 Δ NEW (t)			Model 9 Δ NEW (t)		
	Coef.	S.E.	p>|t|	Coef.	S.E.	p>|t|	Coef.	S.E.	p>|t|
Production OS (t)	0.017	0.023	0.463	0.018	0.023	0.421	0.017	0.022	0.441
Production OS (t-1)	-0.024	0.023	0.295	-0.022	0.023	0.341	-0.022	0.023	0.323
Peripheral OS (t)	0.001	0.024	0.981						
Peripheral OS (t-1)	0.022	0.022	0.312						
Services OS (t)				-0.013	0.024	0.582			
Services OS (t-1)				0.021	0.020	0.301			
IT OS (t)							0.020	0.031	0.532
IT OS (t-1)							0.016	0.029	0.578
Δ Vertical scope (t)	0.032	0.022	0.151	0.031	0.023	0.169	0.034	0.023	0.131
Δ Vertical scope (t-1)	0.037	0.021	0.072	0.037	0.019	0.060	0.033	0.020	0.098
Δ Vertical scope (t-1)									
X Production OS (t-1)	**0.087**	**0.040**	**0.029**	**0.087**	**0.039**	**0.026**	**0.088**	**0.041**	**0.031**
X Peripheral OS(t-1)	**-0.032**	**0.034**	**0.347**						
X Services OS (t-1)				**-0.061**	**0.032**	**0.060**			
X IT OS (t-1)							**-0.023**	**0.046**	**0.616**
Δ Size (t)	0.060	0.047	0.200	0.060	0.047	0.197	0.062	0.048	0.201
Δ Size (t-1)	0.054	0.041	0.190	0.061	0.041	0.138	0.052	0.041	0.213
Δ HC Educ (t)	0.081	0.191	0.670	0.073	0.194	0.705	0.084	0.193	0.665
Δ HC Educ (t-1)	0.365	0.160	0.023	0.365	0.160	0.023	0.373	0.164	0.024
Δ RD Input (t)	0.009	0.002	0.000	0.009	0.002	0.000	0.009	0.002	0.000
Δ RD Input (t-1)	0.002	0.001	0.161	0.002	0.001	0.121	0.002	0.001	0.172
Ind.-øΔ PRODUCT (t)	-0.949	0.322	0.004	-0.970	0.330	0.004	-0.983	0.325	0.003
Year fixed effects		[yes]			[yes]			[yes]	
N		363			363			363	
Adjusted R-squared		0.126			0.126			0.124	

[5] We limit the models shown here to those with the dependent variable *Δ NEW (t)*. There is no evidence for similar effects in models with the dependent variable *Δ IMPROVED (t)*.

Finally, we turn to the results of the models to test hypothesis 5. The results in Table 7[6] provide evidence that investments in the absorptive capacity (*Δ int. RD input (t-1)*) positively moderate the relationship between production outsourcing and new product performance, thus supporting hypothesis 5 (Model 12; β = 0.006, S.E. = 0.003). Illustrating the mechanisms of the moderation effect, the adverse effects of production outsourcing on new product performance are less [more] pronounced in firms that increase [decrease] investment in their absorptive capacity in comparison to firms that do not. We conclude that strengthening the absorptive capacity by investing in internal R&D helps mitigate some of the negative effects of production outsourcing on new product performance. Conversely, reducing the R&D input may have the opposite effect and exacerbate the negative effects of production outsourcing. We note that the strength of the interaction term from hypothesis 3 (*Δ Vertical scope (t-1) X Production OS (t-1)*) on new product performance becomes stronger in Model 12 in comparison to Model 5 (Model 12; β = 0.096 vs. Model 5; β = 0.083).

Across all models, *Δ RD Input* is positively associated with the dependent variables. Both a lagged change in R&D input (Model 1; β = 0.006, S.E. = 0.002) as well as a contemporaneous change in R&D input (Model 1; β = 0.017, S.E. = 0.003), are positively associated with innovation performance. This result confirms the positive relationship between investments in research and development and innovation performance in general (Hall, Mairesse, & Mohnen, 2010). In addition, the significance of the lagged R&D input variable indicates how the effects of research and development on innovation performance materialize over several years. In addition, our results provide evidence for a significant relationship between a change in the share of academic employees (*Δ HC Educ*) and a firm's performance of new products in the subsequent period (Model 2; β = 0.362, S.E. = 0.159). Greater [lessened] focus on a specialist workforce seems to affect the performance of new products positively [negatively]. Finally, the industry-level

[6] We limit the models shown here to those with the dependent variable *Δ NEW (t)*. There is no evidence for similar effects in models with the dependent variable *Δ IMPROVED (t)*.

controls for changes in innovation output are significant across all models. This indicates that the industry-level dynamics at play explain a portion of the innovative output by firms within these industries.

Table 7 First-differencing OLS regression estimates for hypothesis 5

	Model 10 Δ NEW (t)			Model 11 Δ NEW (t)			Model 12 Δ NEW (t)		
	Coef.	S.E.	p>|t|	Coef.	S.E.	p>|t|	Coef.	S.E.	p>|t|
Production OS (t)	0.017	0.023	0.468	0.016	0.023	0.500	0.016	0.022	0.486
Production OS (t-1)	-0.044	0.020	0.026	-0.043	0.020	0.028	-0.024	0.023	0.303
Peripheral OS (t)	-0.002	0.025	0.930	-0.002	0.025	0.927	0.002	0.025	0.921
Peripheral OS (t-1)	0.025	0.021	0.240	0.025	0.021	0.230	0.027	0.021	0.195
Δ Vertical scope (t)	0.030	0.022	0.182	0.031	0.022	0.173	0.030	0.023	0.186
Δ Vertical scope (t-1)	0.052	0.019	0.007	0.052	0.019	0.007	0.028	0.020	0.149
Δ Vertical scope (t-1) X Production OS (t-1)							**0.096**	**0.040**	**0.018**
Δ Size (t)	0.062	0.049	0.211	0.055	0.049	0.263	0.057	0.049	0.251
Δ Size (t-1)	0.049	0.041	0.232	0.049	0.041	0.229	0.036	0.043	0.405
Δ HC Educ (t)	0.027	0.199	0.894	0.022	0.194	0.911	0.018	0.198	0.929
Δ HC Educ (t-1)	0.314	0.157	0.046	0.340	0.154	0.028	0.332	0.158	0.037
Δ int. RD Input (t)	0.008	0.002	0.000	0.008	0.002	0.000	0.008	0.002	0.000
Δ int. RD Input (t-1)	0.000	0.001	0.749	0.000	0.002	0.774	0.000	0.002	0.762
Δ ext. RD Input (t)	-0.001	0.002	0.510	-0.001	0.002	0.432	-0.002	0.002	0.305
Δ ext. RD Input (t-1)	0.002	0.002	0.120	0.002	0.002	0.179	0.002	0.001	0.142
Δ int. RD input (t-1) X Production OS (t-1)				**0.005**	**0.003**	**0.070**	**0.006**	**0.003**	**0.033**
Ind.-øΔ PRODUCT (t)	-0.959	0.326	0.004	-0.955	0.324	0.003	-0.959	0.319	0.003
Year fixed effects	[yes]			[yes]			[yes]		
N	363			363			363		
Adjusted R-squared	0.105			0.107			0.124		

2.4.1 Propensity score matching

We substantiate the main relationship between production outsourcing and new product performance with several robustness checks. The major one, propensity score matching, is presented here. For further robustness checks we refer to Appendices B and C. The outsourcing decision may not be randomly assigned to firms. Firms that do and do not engage in production outsourcing differ significantly with regard to the levels of certain explanatory variables. Should firms with certain attributes be less likely to outsource production activities than others and the same attributes influence the expression of the dependent variable, our conclusions would be undermined. Therefore, this selection into the treatment (outsourcing) must be taken into account (e.g. Imbens & Wooldridge, 2009; Zhang & Tong, 2021). To control for such effects, we conduct a non-parametric nearest neighbor propensity score matching (Angrist, 1998; Beck et al., 2016; Gerfin & Lechner, 2002; Smith & Todd, 2005).

This econometric procedure allows us to provide information on how much the product innovation performance of an outsourcing firm would have changed in a counterfactual situation (of a quasi-identical firm), in which it would not have outsourced. This counterfactual situation is not observable; it must be approximated by estimation. We find for each outsourcing firm ('treated firm') a similar firm with the same (or very similar) characteristics than the outsourcing one, that has not engaged in outsourcing ('untreated firm'). We use information on employment, tertiary workforce, and R&D investments from the period when the outsourcing occurs (see Table 8 for the descriptive statistics before the matching). To select the control firms, we balance the subsamples of outsourcing and non-outsourcing firms according to the probability of outsourcing. Applying a probit regression, we can estimate the propensity score, which is the probability of being treated conditional on the covariates (see Table 9). Based on this score, we apply a nearest-neighbor matching procedure using the two nearest neighbors as control observations for each outsourcing firm.

As another characteristic of the matching approach, we reduce the number of potential control firms to a subsample (the selected control group) that have similar structural characteristics to those of the treated firms. Furthermore, we allow the matching to occur only for those firms that have a common support. This means that we drop all control firms whose covariates coefficients are either larger or smaller than those of the treated firms. Table 10 shows the findings of the matching estimations. The only statistically significant variable after the matching is the outcome variable radical innovation. We conclude that based on the observed characteristics, the decrease in radical product innovation performance can be attributed to the outsourcing activities of the firm. Overall, the findings from the main econometric analyses are confirmed by the matching approach.

Table 8 Descriptive statistics, before the matching

	Potential control group (N = 269)		*Treated firms (N = 94)*		*t-tests on mean differences*
	Mean	S.E.	Mean	S.E.	
Size (t-1)	4.636	0.973	4.837	0.989	0.087
HC Educ (t-1)	0.037	0.055	0.046	0.059	0.227
RD Input (t-1)	6.689	6.643	9.597	6.157	0.000
Δ NEW (t)	0.007	0.141	-0.033	0.170	0.027
Δ IMPROVED (t)	0.011	0.165	-0.007	0.198	0.369

Table 9 Probit estimation on the probability of outsourcing

	Production OS (t-1)		
	Coef.	S.E.	p>|t|
Δ Size (t-1)	0.048	0.075	0.528
Δ HC Educ (t-1)	-0.017	1.375	0.990
Δ RD Input (t-1)	0.038	0.012	0.001
Constant	-1.179	0.351	0.001
Adjusted R-squared		0.034	
Prob > chi2		0.003	

Table 10 Matching results: Average treatment effect of outsourcing

	Δ NEW (t)			Δ IMPROVED (t)		
	Mean	S.E.	p>|t|	Mean	S.E.	p>|t|
Treatment group	-0.032			-0.007		
Selected control group	0.015			-0.004		
Difference between treatment and selected control group	-0.047	0.023	0.044	-0.004	0.026	0.882

2.5 Discussion and conclusion

Our empirical investigation shows that outsourcing can have a negative effect on a firm's product innovation performance. Whether such negative effects occur depends on the type of innovation. While outsourcing may affect value creation from new products adversely, there is no indication for any effect on value creation from improved products. We suggest that outsourcing affects value creation from new products because it is a more systemic type of innovation that requires finding solutions to non-decomposable problems (Nickerson & Zenger, 2004). By distinguishing the effects of outsourcing by type of innovation, we complement recent research providing evidence that the inverse case to outsourcing, when firms vertically integrate, leads to an increase in systemic product innovation outcomes (Zhang & Tong, 2021). In combination with Zhang and Tong (2021), we can now draw a more complete picture of how boundary changes influence the innovation outcomes of firms over time. While vertical integration strengthens systemic innovation outcomes, vertical disintegration (i.e. outsourcing) hampers them.

A major distinction between this study and previous research on the link between outsourcing and financial or innovation performance is our focus on outsourcing as a change in a firm's boundaries and the subsequent effects within the firm. Most research compares firms that differ in one specific aspect of their boundaries to explain performance differences between firms. With our focus on changes and effects within firms, we can enrich our knowledge of the link between firm boundaries and performance to make a step towards a causal explanation. Specifically, we show how the type of boundary change and the magnitude of the boundary change affect its outcomes. Concerning the type of boundary change, our results show that the outsourcing of activities that are closely related to the core capabilities of the firm (i.e. production) affects innovation outcomes, while the outsourcing of more peripheral activities (i.e. services and IT) does not. Concerning the magnitude of the boundary change, which we model as a change in the vertical scope of the firm, we provide evidence that decreasing vertical scope is associated with decreased innovation performance throughout the board. The combination of the two, type of outsourcing and magnitude, most precisely predicts the negative effects of outsourcing on product innovation performance. With increasing magnitude of the outsourcing, production outsourcing increasingly hampers the performance of new products. We contribute to the literature on the link between outsourcing and innovation performance with this two-pronged description of the boundary change to more precisely identify what causes the negative effects of outsourcing on innovation performance.

As a final contribution, we substantiate the knowledge-based line of argument to explain the negative effects of outsourcing. On one hand, our results suggest that the effects on innovation performance depend on whether the knowledge associated with the outsourced activity is a complementary asset in the innovation process. In manufacturing firms, only the outsourcing of activities related to production and, hence, related to the core capabilities of the firm, leads to negative innovation outcomes. On the other hand, we provide evidence that knowledge complementarities may matter in driving the negative effects of production outsourcing on product innovation performance. A greater [smaller] investment in the firm's absorptive capacity mitigates [increases] some of the negative effects. This finding provides an important link to research at the intersection of firm boundaries and knowledge complementarities that describes positive performance benefits of extending a firm's knowledge boundaries beyond its boundaries of production (Brusoni et al., 2001; Kapoor & Adner, 2012).

This study also has methodological implications for research on the effects of outsourcing. Among studies in the field, the linking of differences in boundaries and differences in performance among firms unifies most of the empirical research. As empirical evidence shows, unobserved firm-specific factors influence both the boundary choice and the firm's performance levels leading to an inference problem that is difficult to resolve (Leiblein et al., 2002; Macher, 2006; Novak & Stern, 2008). We propose an alternative methodological approach to study the effects of outsourcing by focusing on the effects within the firm. This approach allows us to model a non-equilibrium and more dynamic representation of the relationship between firm boundaries and capabilities, which has been called for (Zenger et al., 2011).

Our findings have important managerial implications. Trading off between the benefits and costs of available boundary choices presupposes some knowledge of their expected effects (Handley, 2012). As our results show, outsourcing production activities can adversely influence capability development and future options for value creation. The effect of production outsourcing unfolds over an extended period of time and is, likely difficult to estimate in advance. In an outsourcing decision, the potential effects on innovative capabilities are weighed against efficiency and flexibility gains. A decision-maker's delicate task consists of striking the right balance between the more easily quantifiable positive effects, and the delayed and (ex-ante) difficult-to-quantify negative effects in making the boundary choice. In addition, our results indicate that strengthening knowledge accumulation within the firm through investments in internal R&D may help mitigate some of the negative effects that production outsourcing may have on product innovation performance.

We close this section on the study's contribution with a discussion of the embedment within the wider research on firm boundaries. A separate stream of empirical research on the link between firm boundaries and performance attributes some performance effects of boundary choices to governance misalignment (Leiblein et al., 2002). Studies in this stream show that the deviation from an optimal vertical scope – by either outsourcing too much or too little – is associated with a performance penalty (Kotabe et al., 2012; Lee & Kapoor, 2017; Rothaermel, Hitt, & Jobe, 2006). With this model in mind, the effects that we observe would indicate that a firm has outsourced "too much" and reduced its scope below the optimum. Explanations for such a behavior include economic irrationality, structures of decision-making within the firm, and intra-organizational politics (Bidwell, 2010; Bidwell, 2012; Mayer & Salomon, 2006). More fundamentally and applied to our study setting, the "too much" outsourcing may refer only to the strategic objective of creating value from product innovations. Seeing the boundary choice as a trade-off, there may be several optimal degrees of vertical scopes available to a firm – depending on the strategic objectives (Bidwell, 2010; Mahoney & Qian, 2013).

The linkage to the drivers of boundary choices opens a discussion about the intent of decision makers, which may be an important aspect of endogeneity considerations. We do not know whether decision makers were aware of the potentially adverse effects of outsourcing on product innovation performance. This leads to the important question whether the negative effects on product innovation performance are indeed offset by positive effects elsewhere. If they are, decision makers would have knowingly weighed the negative effects on product innovation performance against the gains of outsourcing. This is in line with research that portrays boundary decisions as trade-offs between the benefits and costs of the respective governance modes (Kapoor & Adner, 2012; Macher, 2006; Novak & Stern, 2008; Weigelt & Sarkar, 2012). In this scenario, the effects that we describe in this study are real and measurable, but endogenous still. It may, however, very well be that the effects on product innovation performance are not weighed against possible gains elsewhere. After all, the effects we describe appear with a time lag and affect the wider firm. Given the explanations for why decision makers do not follow the prescriptions of theory in making boundary choices (Bidwell, 2010; Bidwell, 2012; Mayer & Salomon, 2006), it seems conceivable that the costs of outsourcing, which we described in this study, are not weighed against the potential benefits.

The discussion of the intended effects of outsourcing leads us to the limitations of this study. As a first and most important limitation, we do not measure the expected short-term positive performance effects of outsourcing. Most managers outsource to reduce cost and increase focus (Deloitte, 2016; EY, 2013), which are expected to be short-term effects. Accounting for cost reductions would give a more complete picture of the strategic trade-off between short-term profitability and long-term capabilities development (Kogut & Zander, 1992). For future research it would be valuable to study how firms can reap short-term cost benefits from production outsourcing and whether such benefits last or eventually dissipate.

Second, we limit our analysis to two forms of governance – integration and outsourcing – and do not take into account hybrid forms. Engaging in hybrid forms may allow a firm to reap some benefits of both integration and outsourcing at the same time (Jacobides & Billinger, 2006). Research on concurrent sourcing sheds light on a closely related question (Parmigiani, 2007). Engaging in production activities internally while sourcing the same or similar production services from external providers is associated with positive effects on performance (Reitzig & Wagner, 2010; Rothaermel et al., 2006). Further research can investigate whether the effects of production outsourcing are lessened in case the firm retains some of the same production activities in-house.

Third, we do not consider any variables describing the relationship between the focal firm and the provider of outsourced production services. Previous research shows that the quality and complexity of the relationship may influence outsourcing performance (Handley & Benton, 2013; Kroes & Ghosh, 2010). A trusting relationship with a supplier increases performance in collaborative product development (Bstieler, 2006). It is therefore probable that attributes of the relationship between the focal firm and the outsourcing provider influence not only outsourcing performance but also the effects of outsourcing on innovation performance.

A final limitation addresses the restrictions inherent in the empirical setting. The analysis is limited to firms operating in Switzerland – a country with an innovative and internationally competitive manufacturing sector. In the Swiss economy, innovation activities at the technological frontier are indispensable for firms' economic wealth. In other economies that are less innovative or shielded from international competition, outsourcing might yield different effects.

Chapter 3 Digitalization as a driver of open innovation: Influence of external knowledge search strategy and appropriability concerns

Abstract: Openness in innovation is constrained by a firm's limited absorptive capacity and appropriability concerns. We clarify whether by investing in IT, firms can overcome some of these constraints and increase openness and open innovation performance. We test our hypotheses in a dynamic panel model for Swiss manufacturing firms. Our results show that the combination of IT investment and openness in terms of external knowledge search depth can increase innovation performance. This effect is contingent on a firm's ability to appropriate value from its innovations. High imitation concerns and ineffective means of innovation protection may threaten the benefits a firm can draw from IT investment in the context of open innovation.

3.1 Introduction

Increasing digitalization can play an important role in promoting open innovation (Dahlander, Gann, & Wallin, 2021; Gómez et al., 2017). IT make searching for and acquiring external knowledge more efficient, promote collaborative knowledge management, and support joint knowledge creation (Dodgson et al., 2006; Kleis et al., 2012; Trantopoulos et al., 2017; Urbinati et al., 2020). By using IT to support their open innovation activities, firms can increase the benefits they gain from open innovation (Gómez et al., 2017).

A question that remains is whether IT can also help firms to increase the level of openness in their innovation activities. At high levels of openness, the costs of open innovation outweigh the benefits, and firms may realize diminishing returns (Laursen & Salter, 2006; Wadhwa, Freitas, & Sarkar, 2017). Two major forces are responsible for the diminishing returns at higher levels of openness that constrain a firm's openness in innovation: the limited absorptive capacity for information from external knowledge sources (Grimpe & Kaiser, 2010; Laursen & Salter, 2006; Salge et al., 2013) and appropriability concerns (Cassiman & Veugelers, 2002; Teece, 1986). At high levels of openness, reaching the limits of their absorptive capacity, firms may struggle to assimilate and utilize additional information from external knowledge sources, as decision makers face cognitive overload (Hwang & Lin, 1999; O'Reilly, 1980). At the same time, high levels of openness raise the risks associated with unintended knowledge leakage, jeopardizing the appropriability of the firm's own innovations (Laursen & Salter, 2006; Teece, 1986).

As much as increasing the use of IT may promote open innovation, it seems to also promote the limitations of open innovation. Using IT to collect information from external knowledge sources can vastly increase the amount of information the firm must process, elevating the risk of cognitive overload (Dong & Netten, 2017; Gómez et al., 2017). In addition, many applications of IT in the innovation process codify knowledge to promote its exchange (Alavi & Leidner, 2001; Cowan & Foray, 1997). As a force for codification of knowledge, IT may enable unintended knowledge leakage and, as a result, elevate appropriability concerns. With this study we aim to better understand the role of IT as an enabler of both the benefits and costs associated with open innovation. Our research question is: Under which conditions can firms use IT to promote openness in innovation and increase innovation performance?

To answer this research question, we focus on product innovations in manufacturing firms and thus build on important research in the open innovation domain (e.g., Laursen & Salter, 2006). We develop hypotheses on the influence of IT on the two constraints on openness in innovation, the limited absorptive capacity and appropriability concerns. To address the first constraint, we argue that a firm's external knowledge search strategy plays a key role in how the firm can leverage its IT investment for open innovation. In line with previous research, we distinguish external knowledge search strategies focused on search depth and search breadth (Katila & Ahuja, 2002; Laursen & Salter, 2006). In conducting deep search, firms engage in intensive and trustful relationships with key external knowledge sources (Terjesen & Patel, 2017). We argue that those relationships allow firms to use technologies that enhance absorptive capacity, and promote joint knowledge creation and assimilation in the innovation process to increase innovation performance. To address the second constraint on openness in innovation associated with appropriability concerns, we argue that the increased use of IT provides no remedy. It is even possible that the use of IT compromises the appropriability of the value created by a firm's innovations, which would place an important constraint on how IT can promote open innovation.

To test the hypotheses, we use a large-scale representative firm-level panel dataset of Swiss firms, derived from six waves of the Swiss innovation survey covering 2005 to 2019. We apply dynamic panel estimation procedures, which allow us to address issues related to the autoregressive dependent variable, potential endogeneity in the explanatory variables, and unobserved time-invariant heterogeneity at the firm level (firm fixed effects). This estimation procedure affords a precise look on the phenomenon of interest and an examination of causality claims for the relationship between IT, openness, and innovation performance, while emphasizing the importance of appropriability concerns.

With this study, we make two contributions to the open innovation literature. First, we provide evidence for performance effects of a complementarity between IT investment and the external knowledge search strategy. By jointly promoting IT investment and deep search, firms manage to increase the optimal level of openness and gain advantages with regard to innovation performance. Investment in IT allows firms to both increase the benefits of open innovation at equal levels of openness (Gómez et al., 2017), as well as increase openness in terms of search depth without incurring the costs of over-search. As a second contribution, we examine the interplay between appropriability concerns and IT investment to drive open innovation. We show that threats of imitation and ineffective protection mechanisms remain an important limitation to IT's role as a driver of open innovation. Although IT investment can be beneficial for open innovation performance, these benefits critically depend on effective appropriation measures.

3.2 Theoretical background

In this section, we review the literature on the performance effects of open innovation and possible moderating factors. We start with the relationship between openness and innovation performance. We then turn to the role of IT in promoting open innovation and, finally, to the interplay between appropriability concerns and IT in an open innovation context.

3.2.1 The effect of openness on innovation performance

Open innovation comes with several benefits. It gives a firm access to a broader knowledge base to expand the set of potentially valuable ideas. This enables a firm to break out of the corset imposed by its own knowledge endowments and local processes of search, reducing the risks associated with learning traps or technological path dependency (Chesbrough, 2003; Dosi, 1988; Levitt & March, 1988; Teece, 1986).

The openness of a firm's innovation activities is limited because at higher levels of openness, the costs outweigh the benefits (Laursen & Salter, 2006; Wadhwa et al., 2017). The firm's absorptive capacity and managers' limited attention constrain the amount of external knowledge a firm can acquire, assimilate, transform, and exploit productively (Cohen & Levinthal, 1990; Koput, 1997; Ocasio, 1997; Zahra & George, 2002). When firms try to acquire knowledge beyond these limits, they reach a state of over-search in which decision-makers face cognitive overload (Hwang & Lin, 1999; Laursen & Salter, 2006; O'Reilly, 1980). As a result, firms may struggle to productively assimilate and utilize additional knowledge in the innovation process, undermining the open innovation effort (Laursen & Salter, 2006; Wadhwa et al., 2017).

Over-search is not the only reason for decreasing returns at higher levels of openness. Unintended knowledge leakage can have the same effect (Laursen &

Salter, 2006; Teece, 1986). In the exchange of knowledge with external stakeholders, a firm may reveal some of its own knowledge, potentially to its detriment (Kale, Singh, & Perlmutter, 2000). Such unintended outgoing knowledge spillovers may allow others to misappropriate value from the focal firm's innovations (Arrow, 1962; Laursen & Salter, 2006). Openness in innovation might thus dampen a firm's value appropriation from its own innovations, resulting in negative performance effects (Laursen & Salter, 2006).

The relationship between openness and innovation performance is driven by the benefits, costs and risks described above. At lower and medium levels of openness, the benefits of open innovation dominate; at higher levels of openness, the costs and risks of open innovation dominate (Laursen & Salter, 2006; Wadhwa et al., 2017). Correspondingly, most empirical research finds an inverted U-shape between openness and innovation performance (Garriga, Von Krogh, & Spaeth, 2013; Gómez, Salazar, & Vargas, 2020; Laursen & Salter, 2006; Wadhwa et al., 2017). In expectation to find a direct relationship between openness and innovation performance of an inverted U-shape, we refrain from formulating the respective hypotheses and will discuss inasmuch our estimation results align and expand existing knowledge on this relationship. In the following paragraphs, we address when and how IT investment affects the direct relationship between a firm's openness and its innovation performance.

3.2.2 The role of information technology in open innovation

IT can play a key role in promoting innovation, in particular in an open innovation context (Dodgson et al., 2006; Kleis et al., 2012; Nambisan, Wright, & Feldman, 2019; Piller & Walcher, 2006). Technologies enhance the capabilities to search for and analyze valuable information from external knowledge sources (Kleis et al., 2012; Trantopoulos et al., 2017; West & Bogers, 2014). In addition, information exchange and communication between different stakeholders in the innovation process benefit from increased IT assistance (de Zubielqui, Fryges, & Jones, 2019; Dodgson et al., 2006). Beyond information exchange, IT can also support knowledge management within the firm and across firm boundaries (Alavi & Leidner, 2001; Kleis et al., 2012; Urbinati et al., 2020). Finally, IT can directly assist the creative tasks associated with innovation. Design, simulation, modeling, and prototyping technologies support idea generation and execution, while integrating multiple sources of knowledge (Dodgson et al., 2006; Kleis et al., 2012; Urbinati et al., 2020). In summary, the use of IT can support every step of the open innovation process, reducing costs and improving quality.

Despite the advantages of IT for open innovation, without the complementary capabilities in place, firms struggle to draw the intended benefits from IT (Tambe, Hitt, & Brynjolfsson, 2012). In the context of digitalized open innovation, having the absorptive capacity to assimilate and utilize the externally acquired information and the capabilities to create and market new innovations are of particular importance (Alavi & Leidner, 2001; Roberts, Galluch, Dinger, & Grover, 2012; Tambe et al., 2012). Driven by major advances in data collection and exchange, today, firms have immense amounts of external information available that may potentially be of value for their innovation objectives. The mere availability and easy access may induce excessive information collection (Dong & Netten, 2017; Gómez et al., 2017). Such technology-enabled over-search may put decision makers in a state of cognitive overload, with adverse consequences for the firm's innovation performance (Dong & Netten, 2017; Gómez et al., 2017). Although technologies exist to help firms to increase their absorptive capacity (Tambe et al., 2012), those technologies are distinct from the technologies firms can use to search for and acquire external information. Technology-induced over-search, therefore, seems to be a result of a misalignment between the technologies a firm uses and its approach to external knowledge search. We argue that firms must seek an alignment between the technologies they use to support their open innovation activities and their external knowledge search strategy.

A firm's external knowledge search strategy refers to its activities to create and recombine knowledge for innovation, involving knowledge from sources external to the firm (Katila & Ahuja, 2002; Laursen & Salter, 2006). In open innovation research, commonly, two dimensions of external knowledge search are distinguished; search breadth and search depth (Laursen & Salter, 2006). Search breadth refers to the variety of external sources a firm seeks knowledge from. Search depth refers to how intensively a firm draws from external knowledge sources (Laursen & Salter, 2006). Firms that pursue an external knowledge search strategy focused on search depth develop intensive relationships with partners (Terjesen & Patel, 2017). Higher levels of trust and communication enable knowledge exchange and creation in such relationships (Terjesen & Patel, 2017).

We argue that firms pursuing an external knowledge search strategy focused on search depth have relationships with external partners that enable the use of technologies that promote a collaborative innovation process. Sharing knowledge management systems and tools that support idea generation and exchange in the innovation process may require specialized capabilities and, possibly, some integration into multiple data environments (Banker, Bardhan, Chang, & Lin, 2006). Using such technologies can enhance absorptive capacity and knowledge transfer, reducing risks associated with over-search and positively affecting joint innovation outcomes (Roberts et al., 2012). For this reason, we argue that IT investment helps to increase innovation performance in combination with an external knowledge search strategy focused on search depth.

Hypothesis 1. *IT investment positively moderates the relationship between external knowledge search depth and innovation performance.*

3.2.3 The interplay between appropriability concerns and IT

Adding to the firm's own constraints to open innovation from over-search discussed above, we now turn to a second, external limitation to open innovation. Engaging in open innovation requires firms to reveal some of their own knowledge to others, which may expose the firm to threats of value misappropriation and imitation (Cassiman & Veugelers, 2002; Teece, 1986). If other firms use the revealed knowledge for their own benefit and manage to excessively appropriate value or imitate the focal firm's innovative ideas, the focal firm may struggle to capture sufficient value from its open innovation activities, raising appropriability concerns (Hurmelinna-Laukkanen & Yang, 2022; Laursen & Salter, 2014). To reduce appropriability concerns, firms protect their knowledge; either through formal protection mechanisms that are anchored in law, such as patents, or through informal ones, such as secrecy or timing (Hall, Helmers, Rogers, & Sena, 2014). Knowledge protection therefore enables open innovation, as it mitigates appropriability concerns. At the same time, however, knowledge protection may also hinder open innovation, as firms try to conceal their valuable knowledge from others to pre-empt unintended spillovers and the adverse consequences thereof (Cassiman & Veugelers, 2002; Miozzo, Desyllas, Lee, & Miles, 2016; Von Hippel & Von Krogh, 2006). Firms thus need to strike a balance between openness in innovation and protecting their valuable knowledge from unintended knowledge leakage (Arora, Athreye, & Huang, 2016). At high levels of openness, protection from unintended knowledge leakage may fail, jeopardizing appropriability (Laursen & Salter, 2014).

The interplay between appropriability concerns and IT in an open innovation context is not well understood. Increasing digitalization undoubtedly supports knowledge exchange, but there is little evidence that it also supports knowledge protection. The formal and informal protection mechanisms used today function without the support of digital technologies (Hall et al., 2014). To complement formal protection mechanisms with a digital alternative, a verifiable and immutable digital proof of ownership of assets may be valuable. Applications of blockchain technology offer an important advancement in this regard (Kurpjuweit et al., 2020; Xiao, Huang, Xie, Xiao, & Li, 2020). Protection of intellectual property using blockchain, however, is still in its infancy and not widely used today. When it comes to the effectiveness of informal protection mechanisms, increasing digitalization may even have adverse effects. Codification of knowledge is an important enabler of IT-related efficiency gains (Cowan & Foray, 1997). Knowledge management systems, for instance, aim to codify knowledge to make it more widely available (Alavi & Leidner, 2001). Increasing codification enables knowledge exchange, potentially facilitating both intended and unintended knowledge leakage (Teece, 1986). Due to progressing digitalization, the effectiveness of those protection mechanisms that rely on impeding knowledge exchange, such as secrecy and employee retention, may thus erode. If appropriability concerns are present and firms struggle to draw sufficient value from their own innovations, the increasing use of IT may aggravate those concerns. The goal to support knowledge exchange with IT and, at the same time, protect the exchanged knowledge may conflict. We stipulate that the positive effects of IT investment to promote openness in terms of external knowledge search and increase innovation performance require sufficient appropriability. We expect that these benefits dissipate with higher appropriability concerns.

> **Hypothesis 2.** *Increasing appropriability concerns weaken IT investment's moderation of the relationship between external knowledge search depth and innovation performance.*

3.3 Data and methodology

3.3.1 Data

The empirical analysis uses firm-level panel data of Swiss firms, derived from six waves of the Swiss innovation survey (2005, 2008, 2011, 2015, 2017, and 2019). The Swiss innovation survey is a postal survey based on the KOF enterprise panel. The KOF enterprise panel is a representative, stratified random sample of roughly 6,500 firms randomly drawn from the Swiss business census. Stratification is on 34 industries covering the manufacturing, construction, and service sectors and within each industry on three firm size classes. The survey was conducted by the KOF Swiss Economic Institute. The Swiss innovation survey is largely aligned to the European Community Innovation Survey (CIS), which is based on OECD/Eurostat guidelines (OECD/Eurostat, 2018). The data collected with this survey has been used in many empirical papers (e.g., Beck, Lopes-Bento, & Schenker-Wicki, 2016; Garriga et al., 2013; Trantopoulos et al., 2017). The survey provides detailed information on firms' R&D and innovation activities, their structural characteristics, economic performance, as well as IT investment and usage. The response rates from the surveys are 38.7% (2005), 36.1% (2008), 35.9% (2011), 30.1% (2015), 26.9% (2017), and 23.4% (2019).

3.3.2 Measures

We examine the influence of three clusters of independent variables on product innovation performance as the dependent variable. We start by introducing the dependent variable. We proceed with the main explanatory variables, the external knowledge search variables that represent the openness of a firm's innovation effort, the IT investment variable, and the measures to capture appropriability concerns. Finally, we introduce the control variables.

Innovation performance: Our dependent variable measures a firm's product innovation performance (*Inno*). *Inno* is measured as the sales share of innovative products, including both new and improved products. This measure has been used in many empirical papers before (Arvanitis, Sydow, & Woerter, 2008; Laursen & Salter, 2006; Meuer, Rupietta, & Backes-Gellner, 2015). Measuring innovation as a share of sales allows capturing the market response to a firm's product innovation output and does not limit the focus on the generation of core technologies (Beck et al., 2016).

External knowledge search strategy: Our main interest lies on external knowledge search strategies focused on deep search, which we measure with the variable search depth (*Depth*). The operationalization of this variable is in line with the literature in the open innovation domain (e.g., Dong & Netten, 2017; Garriga et al., 2013; Laursen & Salter, 2006; Terjesen & Patel, 2017; Trantopoulos, Von Krogh, et al., 2017). To control for a second, commonly used, characteristic of external knowledge search – search breadth – we introduce the variable *Breadth* alongside the focal variable *Depth*. *Breadth* is also operationalized in line with the existing literature (e.g., Laursen & Salter, 2006). Both variables are constructed from a survey question asking about the importance of different external knowledge sources for innovation (customers, suppliers, competitors, firms from the same group, universities, other research institutions, consulting firms, technology transfer offices, patents, conventions, research outlets, information networks). *Depth* is constructed by counting the number of external knowledge sources a firm considers to be important for its innovation activities. The value 1 is attributed to all important external knowledge sources. The value 0 is attributed to all external knowledge sources a firm does not consider to be important for its innovation activities. The binary variables are then added up across the 14 external knowledge sources represented in the survey. There is a discontinuity in how the importance of external knowledge sources was measured in our data source, resulting from a migration from a 5-point to a 4-point scale between the survey waves of 2011 and 2015. In Appendix D, we lay out how we deal with this discontinuity, discuss the potential effects on our results, and conduct a robustness check. The construction of *Breadth* resembles the construction of *Depth*. If a firm uses an external knowledge source for innovation, independently of the importance, it is coded as 1. If a firm does not use an external knowledge source, it is coded as 0. The binary variables are then added up across the 14 external knowledge sources represented in the survey.

IT investment: To capture the degree with which firms invest in information technology, we measure the share of IT investment among total investment (*IT Invest*). *IT Invest* comprises investment in hard- and software. In focusing on overall IT investment, we aim for a holistic picture on the IT intensity of firms and ensure better comparability between firms (Dong & Netten, 2017). The same and closely related measures have been used in previous research (e.g., Dong & Netten, 2017; Gómez et al., 2017).

Appropriability concerns: The concept of appropriability stands for the ability of an innovator to accrue the benefits of her innovation and, as such, combines aspects of protecting and profiting from innovations (Hurmelinna-Laukkanen & Yang, 2022; Teece, 1986). The level of appropriability is determined by characteristics of the innovation, the firm, as well as the firm's context

(Hurmelinna-Laukkanen & Yang, 2022). To test hypothesis 2, we aim to capture two aspects of appropriability, the first of which addresses the firm's own ability to profit from its innovations. One major threat to a firm's ability to profit from its innovations is imitation by other firms (Harabi, 1995). To capture a firm's ability to profit from its innovations, we use a measure for the threat from imitation. This measure is based on a survey question asking about the importance of imitation as a hampering factor for a firm's innovation effort. We complement the first measure with a second one that captures aspects of the appropriability regime, designating the effectiveness of the protection mechanisms that are available to firms in a given context (Teece, 1986). This second measure is based on a survey question asking about the effectiveness of mechanisms (i.e., patents, copyrights, etc.) to protect innovation-related competitive advantages. Similar to the survey questions used to measure *Depth* introduced above, the two questions we use to measure appropriability concerns also have a discontinuity in their measurement. In the earlier survey waves (2005, 2008, 2011) they were asked using a five-point scale ('none' to 'very high') and in the later survey waves (2015, 2017, 2019) they use a four-point scale ('none' to 'high'). We integrate the data from the two measurement periods into a combined scale by representing them as a fraction of one. We use the variables on appropriability concerns only to split the sample into two, a sub-sample experiencing low appropriability concerns and a sub-sample experiencing elevated appropriability concerns.

Control variables: In our models, we additionally introduce a set of control variables, which might influence the innovation performance of firms. First, as a major predictor of innovation performance, we control for a firm's general R&D input (*RD Input*), measured as the logarithm of R&D expenditures (Crepon, Duguet, & Mairessec, 1998; Leiponen & Helfat, 2010; Roper, Vahter, & Love, 2013). Firms with intensive R&D activities are more likely to generate more advanced innovations that achieve greater market success. Due to their greater technological advancement, such innovations may be more difficult to imitate and, therefore, may improve a firm's appropriability. Controlling for R&D makes sure that the effect of appropriability on innovation performance is not driven by unobserved R&D activities. Second, we control for three important firm characteristics that often affect innovation performance. The share of employees with tertiary education among the total workforce (*HC Education*) (Grimpe & Kaiser, 2010; Leiponen & Helfat, 2010), firm size (*Size*), measured as a logarithm (Laursen & Salter, 2006; Leiponen & Helfat, 2010), as well as the share of exports among total sales (*Export Share*) (Grimpe & Kaiser, 2010; Leiponen & Helfat, 2010). Third, we introduce year and industry dummies to control for temporal and industry-specific effects.

3.3.3 Estimation strategy

We use dynamic panel estimation, as it suits well the structure of our data set. In particular, we use a system general method of moments (GMM) estimator (Arellano & Bond, 1991; Arellano & Bover, 1995; Blundell & Bond, 1998). This estimator was developed for estimating autoregressive models with many cross-sections (many firms) but few waves. Using a system GMM estimator has several advantages. It accounts for the autoregressive nature of the dependent variable (innovation performance). Including the lagged dependent variable as a regressor in the model mitigates issues associated with spuriousness and reverse causality. In addition, the system GMM estimator accounts for time-invariant, unobserved heterogeneity. Finally, time-variant unobserved heterogeneity is observed by instrumenting all potentially endogenous variables. We treat the main explanatory variables (*Depth*, *Breadth*, *IT Invest*), including the interaction term (*Depth X IT Invest*), as well as *RD Input* as endogenous. The remaining control variables (*HC Education*, *Size*, *Export Share*) enter the model as predetermined variables[7]. Only year and industry controls are treated as exogenous variables. Given these advantages, system GMM is widely used to estimate panel models with autocorrelated dependent variables and endogeneity concerns (Salge, Kohli, &

[7] The variables *HC Education*, *Size*, and *Export Share* are not strictly predetermined, as they are not determined prior to the current period. They are, however, relatively stable over time and characterize the nature of a firm. They are, at most, weakly endogenous.

Barrett, 2015; Uotila, Maula, Keil, & Zahra, 2009; Xue, Mithas, & Ray, 2021). We use two tests for the validity of the moment conditions: the Arellano-Bond test for serial correlation and the Sargan test of overidentifying conditions (Arellano & Bond, 1991).

To test hypothesis 2 and the role of appropriability concerns, we rely on split sample regressions. Using the two measures introduced above, imitation concerns and effectiveness of protection mechanisms, we form two splits. We split the samples at the median, forming roughly equally sized sub-samples and estimate each sub-sample separately.

3.3.4 Sample and descriptive statistics

The sample contains 1,258 observations of manufacturing firms. It contains only firms that have launched an innovative product at least once during the time covered by the surveys. This limitation of the sample is necessary because firms that did not innovate over such a long time (2005-2019) cannot meaningfully answer questions related to the importance of external knowledge sources for innovation. In addition, observations from at least two consecutive waves are necessary for firms to be included in the sample. Table 11 shows the descriptive statistics for the variables contained in the model[8].

Table 11 Descriptive statistics (N = 1,258)

Variable	Mean	SD	Min	Max
Inno (t)	0.19	0.24	0	1
Depth (t)	2.68	2.45	0	11
Breadth (t)	10.38	3.11	0	14
IT Invest (t)	0.13	0.15	0	0.90
RD Input (t)	6.97	6.64	0	20.23
HC Education (t)	0.07	0.09	0	0.64
Size (t)	4.31	1.27	1.10	9.95
Export Share (t)	0.40	0.38	0	1

[8] Appendix C shows the descriptive statistics of the non-transformed variables for the full sample, without the restriction of requiring observations from two consecutive waves to be included.

To capture the proposed effects with an appropriate empirical richness, we aim to introduce the main variables in different forms. First, to replicate the common finding of inverted U-shaped relationships between openness and innovation performance (Garriga et al., 2013; Gómez et al., 2020; Laursen & Salter, 2006; Wadhwa et al., 2017), we make use of linear and squared terms of search depth (*Depth* and *Depth*^{2}). Second, to test the moderation of IT investment, we introduce the interaction term of search depth (*Depth*) with IT investment (*IT Invest*). Third, to capture potential temporal delays in the effects of the explanatory variables on the dependent variable, we introduce the lagged form of the variables. We estimate our models including contemporaneous and lagged forms of the variables in order to benefit from the combined explanatory power of both (De Boef & Keele, 2008). To replicate findings from previous research and compare different external knowledge search strategies, we intend to introduce the same set of variables for search breadth also (*Breadth* and *Breadth*^{2}, *Breadth X IT Invest*, as well as contemporaneous and lagged forms). Introducing linear and squared terms, interaction terms, as well as lagged and contemporaneous variables in the same model raise multicollinearity concerns. We conduct VIF analyses to detect potential issues. While the level of collinearity among the variables based on *Depth* is moderate, the level of collinearity among the variables based on *Breadth* is clearly elevated (see Table 12). Particularly the squared term of search breadth (*Breadth*^{2}) as well as the interaction term of search breadth with IT investment (*Breadth X IT Invest*) show high levels of collinearity with the linear terms of both search breadth (*Breadth*) and IT investment (*IT Invest*). Considering the high mean value of *Breadth* at 10.38 out of 14 (see Table 11) and the correlation between *Breadth* and *Breadth*^{2} of 0.977 (not shown), the high level of collinearity between *Breadth* and *Breadth*^{2} is no surprise. Compared to the sample mean of the same variable reported by Laursen and Salter (2006) at 7.22 out of 16 for data from 2001, the stark increase may be an indication for the broad diffusion of open innovation practices that has happened since then. As transformations of variables showing such high levels of collinearity, such as mean-centering, do not alleviate multicollinearity problems (Echambadi & Hess, 2007), and to prevent possible erroneous conclusions from estimation results with validity concerns due to the inclusion of the highly collinear variables based on *Breadth*, we stick to the focal variable of our theory, *Depth*. We therefore make use of the rule of thumb to not include the variables with a VIF in excess of 10 ($Breadth^2$ and *Breadth X IT Invest*) (O'Brien, 2007)[9]. In alignment with our theory, we introduce only the linear term of *Breadth* as a control variable in our models. To show the expected presence of an inverted U-shaped relationship between search depth (*Depth*) and innovation performance, we keep *Depth* and $Depth^2$ in the models, despite a VIF of around 10. The correlations among the updated set of variables used in the main models are shown in Table 13. To control for the influence of the elevated level of collinearity among these two variables, we proceed to estimate the main models without and with the squared term ($Depth^2$) to show the results of both (Table 14 and Table 15).

Table 12 Variance inflation factors (VIF)

Variable	VIF	Variable	VIF
Depth (t)	10.3	*Depth X IT Invest (t)*	4.4
Depth (t-1)	10.4	*Depth X IT Invest (t-1)*	4.8
$Depth^2$ *(t)*	8.7	*Breadth X IT Invest (t)*	23.1
$Depth^2$ *(t-1)*	8.8	*Breadth X IT Invest (t-1)*	21.8
Breadth (t)	28.3	*RD Input (t)*	2.1
Breadth (t-1)	29.8	*RD Input (t-1)*	2.1
$Breadth^2$ *(t)*	28.1	*HC Education (t)*	1.3
$Breadth^2$ *(t-1)*	29.3	*Size (t)*	1.4
IT Invest (t)	18.4	*Export Share (t)*	1.4
IT Invest (t-1)	16.9		

[9] Appendix D shows the VIF of the updated set of variables used in the models.

Table 13 Correlation matrix (N = 1,258)

Variable	1	2	3	4	5	6	7	8	9	10
1 Inno (t)	1									
2 Depth (t)	0.184***	1								
3 Depth2 (t)	0.142***	0.932***	1							
4 Breadth (t)	0.114***	0.420***	0.340***	1						
5 IT Invest (t)	0.161***	0.119***	0.102***	0.121***	1					
6 Depth X IT Invest (t)	0.203***	0.550***	0.538***	0.240***	0.691***	1				
7 RD Input (t)	0.507***	0.215***	0.175***	0.256***	0.116***	0.147***	1			
8 HC Education (t)	0.099***	0	0	0.137***	0.074***	0	0.284***	1		
9 Size (t)	0.127***	0.170***	0.159***	0.317***	0	0	0.389***	0.088***	1	
10 Export Share (t)	0.267***	0.141***	0.113***	0.217***	0.103***	0.111***	0.437***	0.254***	0.352***	1

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

3.4 Results

Before presenting the estimation results for hypothesis 1, we examine the direct relationship between external knowledge search depth and breadth and innovation performance. The results displayed in Table 14 do not provide evidence for such a relationship. Solely the lagged form of search depth (*Depth*^{2} *(t-1)*) becomes weakly significant when the interaction term with IT investment (*Depth X IT Invest*) is introduced in Model 4. With the absence of a robust direct relationship between our openness variable and innovation performance, we cannot replicate previous findings related to external knowledge search depth (Laursen & Salter, 2006; Leiponen & Helfat, 2010). One specific caveat of our models is the absence of the squared term of search breadth (*Breadth*^{2}) (e.g., Laursen & Salter, 2006; Salge et al., 2013), limiting the scope of the replication to the relationship between search depth (*Depth*) and innovation performance. In Appendix E, we discuss the reasons for the non-appearance of the expected inverted U-shaped relationship between openness and innovation performance in our results.

3.4.1 The role of IT investment

Next, we turn to the effects related to IT investment (*IT Invest*), including the interaction term with search depth (*Depth X IT Invest*). The results shown in Table 14 provide no indication of a direct relationship between IT investment and innovation performance. With the introduction of the interaction term *Depth X IT Invest*, the picture changes. The lagged form of the interaction term (*Depth X IT Invest (t-1)*) shows a positive effect on innovation performance (Model 4: β_{t-1} = -0.104, p = 0.025). Comparing Models 3 and 4, the introduction of the squared term of search depth (*Depth*^{2}) strengthens this effect. The result of the lagged interaction term (*Depth X IT Invest (t-1)*) shows that firms' innovation performance can benefit from a complementarity of IT investment and search depth. The (weakly significant) coefficient of *Depth*^{2} *(t-1)* (Model 4: β_{t-1} = -0.399, p = 0.091), showing a negative sign, may indicate that at higher levels of openness in search depth, firms stop benefiting from increased IT investment, possibly due to over-search.

The time lag of roughly three years between the points of measurement of the interaction term and the dependent variable provides support for the idea that the combination of higher IT investment and deep search can promote innovation performance. These results indicate support for hypothesis 1. To complete the picture, we briefly address the remaining effects that are present in the main model. The strong statistical significance of the lagged dependent variable (e.g., Model 4: $\beta_{t-1} = 0.210$, $p = 0.008$) underlines its autoregressive nature. In addition, the results underline *RD Input*'s role as a strong predictor of innovation performance. This confirms the positive effect of investments in research and development on innovation performance in general (Hall et al., 2010).

Table 14 System GMM estimation

	Model 1 Inno (t)	Model 2 Inno (t)	Model 3 Inno (t)	Model 4 Inno (t)
Inno (t-1)	0.208***	0.193**	0.225***	0.210***
	(0.075)	(0.078)	(0.074)	(0.079)
Depth (t)	0.010	-0.003	0.014	-0.014
	(0.012)	(0.027)	(0.014)	(0.026)
Depth (t-1)	-0.012	0.006	-0.022	0.020
	(0.013)	(0.03)	(0.015)	(0.031)
Depth^2 (t)		0.001		0.003
		(0.003)		(0.003)
Depth^2 (t-1)		-0.003		-0.006*
		(0.003)		(0.003)
Breadth (t)	0.003	0.010	0.001	0.007
	(0.008)	(0.008)	(0.008)	(0.008)
Breadth (t-1)	-0.001	0.002	0.003	0.004
	(0.008)	(0.008)	(0.008)	(0.009)
IT Invest (t)	-0.027	0.005	0.005	0.078
	(0.156)	(0.153)	(0.176)	(0.183)
IT Invest (t-1)	-0.082	-0.023	-0.276	-0.399**
	(0.156)	(0.141)	(0.195)	(0.198)
Depth X IT Invest (t)			-0.012	-0.038
			(0.054)	(0.057)
Depth X IT Invest (t-1)			0.070*	0.104**
			(0.039)	(0.047)
RD Input (t)	0.015***	0.014***	0.015***	0.014***
	(0.005)	(0.005)	(0.005)	(0.005)
RD Input (t-1)	0.006	0.007	0.005	0.005
	(0.004)	(0.004)	(0.005)	(0.005)
HC Education (t)	-0.107	-0.101	-0.086	-0.064
	(0.174)	(0.17)	(0.158)	(0.163)
Size (t)	-0.010	-0.010	-0.004	-0.005
	(0.039)	(0.039)	(0.034)	(0.036)
Export Share (t)	0.014	0.012	0.022	0.016
	(0.091)	(0.096)	(0.084)	(0.093)
Constant	0.193	-0.350	0.156	0.100
	(0.242)	(0.22)	(0.226)	(0.232)
Year dummies	[yes]	[yes]	[yes]	[yes]
Industry dummies	[yes]	[yes]	[yes]	[yes]
N	1,258	1,258	1,258	1,258
Chi squared	104.9	114.8	137.3	135.5
AR(1) Test: Z =	-3.39***	-3.48***	-3.58***	-3.65***
AR(2) Test: Z =	0.61	0.58	0.90	1.25
Sargan Test: p =	0.98	0.97	0.99	0.99

* p < 0.1; ** p < 0.05; *** p < 0.01

3.4.2 The role of appropriability concerns

To test hypothesis 2 and the influence of appropriability concerns on IT investment as a driver of open innovation we use split samples. First, we examine the results using a split distinguishing firms with low imitation concerns (Table 15, Models A) from firms with high imitation concerns (Table 15, Models B). The comparison of Models A1/B1 and A2/B2 shows that the interaction of search depth and IT investment (*Depth X IT Invest*) is only significant in the sample with low imitation concerns (Model A2: $\beta_{t-1} = 0.093$, $p = 0.033$ vs. Model B2: $\beta_{t-1} = 0.048$, $p = 0.433$). Turning to the second split to test hypothesis 2, we compare firms with a low effectiveness of protection mechanisms (Table 15, Models C) and firms with a high effectiveness of protection mechanisms (Table 15, Models D)[10]. In the second split, the interaction between search depth and IT investment (*Depth X IT Invest*) is only significant for firms with a high effectiveness of protection mechanisms (Model C2: $\beta_{t-1} = 0.032$, $p = 0.378$ vs. Model D2: $\beta_{t-1} = 0.120$, $p = 0.045$).

In combination, the results from the two splits provide general support for hypothesis 2. They indicate that firms with elevated imitation concerns and without access to effective protection mechanisms struggle to benefit from IT investment to promote open innovation. In contrast, when appropriability concerns are low, firms seem to gain important advantages with regard to their innovation performance when combining higher IT investment with a focus on deep search.

[10] Due to missing values of the splitting variable, effectiveness of protection mechanisms, N = 1,039

Table 15 System GMM estimation – split sample

	Model A1	Model A2	Model B1	Model B2	Model C1	Model C2	Model D1	Model D2
	low imitation		high imitation		low effectiveness		high effectiveness	
	Inno (t)	Inno (t)	Inno (t)	Inno (t)	Inno (t)	Inno (t)	Inno (t)	Inno (t)
Inno (t-1)	0.108	0.080	0.175	0.177	0.144	0.147	0.109	0.103
	(0.08)	(0.081)	(0.121)	(0.121)	(0.125)	(0.116)	(0.102)	(0.094)
Depth (t)	0.018	0.007	0.016	-0.022	0.006	0.025	0.010	0.030
	(0.016)	(0.027)	(0.013)	(0.032)	(0.017)	(0.026)	(0.011)	(0.025)
Depth (t-1)	-0.032**	-0.044	0.000	0.024	-0.009	-0.005	-0.024*	-0.025
	(0.015)	(0.027)	(0.014)	(0.024)	(0.014)	(0.026)	(0.013)	(0.023)
$Depth^2$ (t)		0.002		0.004		-0.003		-0.003
		(0.004)		(0.004)		(0.004)		(0.003)
$Depth^2$ (t-1)		0.001		-0.003		-0.001		0.000
		(0.003)		(0.003)		(0.003)		(0.002)
Breadth (t)	-0.001	0.002	0.007	0.009	0.010	0.010	0.007	0.004
	(0.009)	(0.008)	(0.008)	(0.009)	(0.007)	(0.006)	(0.012)	(0.012)
Breadth (t-1)	-0.016**	-0.014*	0.007	0.008	0.016	0.017	0.004	-0.004
	(0.008)	(0.007)	(0.013)	(0.011)	(0.011)	(0.011)	(0.01)	(0.01)
IT Invest (t)	-0.262	-0.268	0.004	-0.051	-0.133	-0.160	0.187	0.099
	(0.237)	(0.238)	(0.191)	(0.207)	(0.173)	(0.17)	(0.254)	(0.21)
IT Invest (t-1)	-0.186	-0.173	0.007	-0.150	-0.072	-0.114	-0.354	-0.385*
	(0.195)	(0.197)	(0.312)	(0.315)	(0.133)	(0.167)	(0.242)	(0.215)
Depth X IT Invest (t)	0.056	0.040	-0.003	0.025	0.028	0.040	0.017	0.034
	(0.072)	(0.073)	(0.056)	(0.065)	(0.052)	(0.05)	(0.064)	(0.062)
Depth X IT Invest (t-1)	0.091**	0.093**	0.018	0.048	0.017	0.032	0.102	0.120**
	(0.038)	(0.043)	(0.061)	(0.061)	(0.029)	(0.036)	(0.069)	(0.06)
RD Input (t)	0.026***	0.025***	0.006	0.008*	0.011**	0.011***	0.011*	0.011*
	(0.005)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.006)	(0.006)
RD Input (t-1)	-0.002	-0.001	0.001	0.003	0.008*	0.008*	-0.002	-0.001
	(0.005)	(0.005)	(0.004)	(0.005)	(0.005)	(0.005)	(0.006)	(0.006)
HC Education (t)	-0.068	-0.056	0.248	0.267	-0.307	-0.289	-0.377	-0.354
	(0.204)	(0.189)	(0.312)	(0.299)	(0.318)	(0.305)	(0.342)	(0.327)
Size (t)	-0.006	0.002	-0.004	-0.026	-0.020	-0.021	-0.005	-0.001
	(0.038)	(0.036)	(0.041)	(0.04)	(0.049)	(0.045)	(0.048)	(0.041)
Export Share (t)	-0.051	-0.046	0.017	0.033	0.163	0.172*	-0.049	-0.053
	(0.098)	(0.091)	(0.128)	(0.127)	(0.117)	(0.104)	(0.131)	(0.129)
Constant	1.153	0.085	0.294	0.380	-0.586**	-0.836	1.255	0.769
	(1.037)	(0.232)	(0.769)	(0.715)	(0.298)	(0.777)	(1.31)	(0.572)
Year dummies	[yes]	[yes]	[yes]	[yes]	[yes]	[yes]	[yes]	[yes]
Industry dummies	[yes]	[yes]	[yes]	[yes]	[yes]	[yes]	[yes]	[yes]
N	733	733	525	525	544	544	495	495
Chi squared	202.7	234.6	87.7	80.5	102.8	118.7	92.2	126.6
AR(1) Test: Z =	-2.19**	-2.14**	-1.52	-1.92*	-1.76*	-1.84*	-2.65***	-2.67***
AR(2) Test: Z =	-0.96	-1.27	-1.38	-1.27	-0.06	0.04	1.08	0.71
Sargan Test: p =	1.00	0.99	0.99	1.00	0.88	0.93	0.86	0.85

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Although the results of the two split sample regressions to test hypothesis 2 both support the hypothesis, the differences in the coefficients of the key variable (*Depth X IT Invest*) between the split samples are only moderately strong. To sharpen our understanding of the influence of appropriability concerns on IT's role in open innovation, we conduct a post-hoc test and differentiate the external knowledge search variables depending on the knowledge source (similar to Köhler, Sofka, & Grimpe, 2012). We distinguish two types of external knowledge sources, 'other firms' and 'research institutions'[11]. Table 16 displays the estimation results with the variables *Depth*, *Breadth*, and *Depth X IT Invest* differentiated by type of external knowledge source. The first two models (PH1 and PH2) show the regression results for the entire sample. The next two models (PH3 and PH4) represent the split by imitation concerns with variables limited to 'other firms' as external knowledge sources (*Depth firms*, *Breadth firms*, *Depth firms X IT Invest*). Focusing first on the full-sample models, PH1 and PH2, there are no fundamental differences between using other firms or research institutions as external knowledge sources. The coefficient size of the interaction term *Depth X IT Invest (t-1)*, however, is larger and statistically significant only for research institutions as external knowledge sources (PH1: $\beta_{t-1} = 0.163$, $p = 0.118$ vs. PH2: $\beta_{t-1} = 0.363$, $p = 0.028$). The strong interaction of search depth and IT investment in using information from research institutions as external knowledge sources may indicate that advanced technologies are particularly important for the successful assimilation and utilization of scientific knowledge. When we shift the focus to the estimation results using the split sample displayed in PH3 and PH4, we see that IT investment can complement deep search from other firms as knowledge sources as well. This effect, however, is contingent on low imitation threats (PH3: $\beta_{t-1} = 0.226$, $p = 0.047$ vs. PH4: $\beta_{t-1} = 0.007$, $p = 0.956$). The result seems meaningful, as imitation threats likely originate from competitors, suppliers, and customers.

[11] 'Other firms' include competitors, customers, and suppliers. 'Research institutions' include universities, other research institutions, and technology transfer offices.

Table 16 System GMM estimation – post-hoc check

	PH1 Inno (t)	PH2 Inno (t)	PH3 – low Inno (t)	PH4 – high Inno (t)
Inno (t-1)	0.213***	0.200***	0.077	0.152
	(0.069)	(0.073)	(0.075)	(0.122)
Depth firms (t)	0.024		-0.006	0.042
	(0.027)		(0.035)	(0.03)
Depth firms (t-1)	-0.029		-0.083**	-0.005
	(0.024)		(0.036)	(0.023)
Depth research (t)		-0.005		
		(0.045)		
Depth research (t-1)		-0.074**		
		(0.033)		
Breadth firms (t)	0.033		0.074***	0.011
	(0.026)		(0.028)	(0.025)
Breadth firms (t-1)	-0.027		-0.064***	-0.035
	(0.031)		(0.024)	(0.042)
Breadth research (t)		-0.007		
		(0.025)		
Breadth research (t-1)		-0.009		
		(0.02)		
IT Invest (t)	-0.129	-0.109	-0.366	-0.060
	(0.193)	(0.135)	(0.289)	(0.225)
IT Invest (t-1)	-0.180	-0.311*	-0.295	0.040
	(0.234)	(0.17)	(0.233)	(0.272)
Depth firms X IT Invest (t)	0.019		0.021	0.006
	(0.113)		(0.178)	(0.109)
Depth firms X IT Invest (t-1)	0.163		0.226**	0.007
	(0.104)		(0.114)	(0.127)
Depth research X IT Invest (t)		0.150		
		(0.204)		
Depth research X IT Invest (t-1)		0.363**		
		(0.165)		
RD Input (t)	0.017***	0.016***	0.024***	0.007
	(0.005)	(0.005)	(0.005)	(0.004)
RD Input (t-1)	0.001	0.006	0.006	0.003
	(0.004)	(0.005)	(0.005)	(0.005)
HC Education (t)	0.021	-0.120	-0.016	0.158
	(0.162)	(0.161)	(0.175)	(0.334)
Size (t)	0.013	-0.009	-0.018	0.008
	(0.035)	(0.044)	(0.035)	(0.038)
Export Share (t)	0.011	-0.003	0.021	-0.008
	(0.084)	(0.087)	(0.089)	(0.095)
Constant	0.101	0.281	0.045	-0.507
	(0.229)	(0.242)	(0.234)	(0.808)
Year & industry dummies	[yes]	[yes]	[yes]	[yes]
N	1,258	1,258	733	525
Chi squared	153.4	137.8	173.6	152.7
AR(1) Test: Z =	-3.15***	-3.08***	-1.81*	-1.44
AR(2) Test: Z =	0.63	0.17	-1.18	-1.50
Sargan Test: p =	0.96	0.98	0.96	0.99

* p < 0.1; ** p < 0.05; *** p < 0.01

3.4.3 Robustness check

To substantiate our main findings, we replicate the main model with both random-effects (RE) and fixed-effects (FE) estimation. To test the effect of a removal of all contemporaneous variables, we additionally run a fixed-effects estimation with only lagged explanatory variables. Unlike the dynamic panel of the main model, the lagged dependent variable is not included in the model we estimate here with random- and fixed-effects estimation. As the results displayed in Table 17 show, the main effect of *Depth X IT Invest (t-1)* remains robust across estimation procedures (RE: β_{t-1} = 0.034, p = 0.032; FE: β_{t-1} = 0.043, p = 0.046; FE (lagged variables only): β_{t-1} = 0.047, p = 0.024). The exclusion of all contemporaneous variables from the model strongly reduces its explanatory power (FE: adj. R-squared = 0.143; FE (lagged variables only): adj. R-squared = 0.046). This underlines the importance of including both contemporaneous and lagged variables in the models. Unlike the results using dynamic panel estimation displayed in Table 14, in the results using random- or fixed-effects estimation, there is evidence of an inverted U-shaped relationship between openness and innovation performance. The coefficients of *Depth (t)* (RE: β_t = 0.016, p = 0.022) and *Depth*^{2} *(t)* (RE: β_t = -0.002, p = 0.025) are statistically significant showing the pattern of an inverted U-shape. We refer to Appendix E for a discussion of the discrepancy between the results of the dynamic panel estimation and the results of the random- and fixed-effects estimations regarding the appearance of the inverted U-shaped relationship.

Table 17 RE and FE estimation

	RE Inno (t)	FE Inno (t)	FE – lagged variables only Inno (t)
Depth (t)	0.016**	0.022**	
	(0.007)	(0.01)	
Depth (t-1)	-0.001	0.009	0.004
	(0.007)	(0.009)	(0.009)
Depth^2 (t)	-0.002**	-0.002*	
	(0.001)	(0.001)	
Depth^2 (t-1)	-0.001	-0.002	-0.001
	(0.001)	(0.001)	(0.001)
Breadth (t)	-0.002	0.004	
	(0.003)	(0.003)	
Breadth (t-1)	0.001	0.001	0.002
	(0.002)	(0.003)	(0.004)
IT Invest (t)	0.016	-0.061	
	(0.064)	(0.082)	
IT Invest (t-1)	-0.079	-0.158	-0.147
	(0.062)	(0.098)	(0.097)
Depth X IT Invest (t)	0.015	-0.006	
	(0.015)	(0.016)	
Depth X IT Invest (t-1)	0.034**	0.043**	0.048**
	(0.016)	(0.022)	(0.021)
RD Input (t)	0.015***	0.013***	
	(0.001)	(0.002)	
RD Input (t-1)	0.004***	0.003	0.001
	(0.001)	(0.002)	(0.002)
HC Education (t)	-0.045	-0.091	
	(0.077)	(0.178)	
Size (t)	-0.016**	0.053	[lagged control variables
	(0.006)	(0.04)	not shown]
Export Share (t)	0.018	0.119	
	(0.023)	(0.077)	
Constant	0.015	-0.267	0.025
	(0.041)	(0.194)	(0.242)
Year dummies	[yes]	[yes]	[yes]
Industry dummies	[yes]	[no]	[no]
N	1,258	1,258	1,258
Adj. R-squared		0.143	0.046

* p < 0.1; ** p < 0.05; *** p < 0.01; Note: the coefficients of the lagged control variables in the lagged variables only model are not shown here. There are no statistically significant coefficients.

3.5 Discussion and conclusion

This study examines the conditions under which IT investment helps firms to promote openness in innovation and increase innovation performance. Many technologies exist to make open innovation more efficient and more productive (Dodgson et al., 2006; Gómez et al., 2017; Kleis et al., 2012). It is unclear, however, inasmuch using technological support for open innovation allows firms to increase the openness in innovation without incurring excessive costs due to over-search or value misappropriation and imitation. We show that complementing IT investment with an external knowledge search strategy focused on deep search allows firms to increase their open innovation performance. This effect is contingent on the level of appropriability, however. When appropriability concerns are elevated, the positive effects of IT investment on the open innovation activities of firms do not appear. We contribute to the open innovation research and, in particular, to research that investigates the influence of digitalization on open innovation (Dong & Netten, 2017; Gómez et al., 2017; Tambe et al., 2012). In the following, we discuss these results and their contribution to the literature.

Our results indicate that external knowledge search depth is beneficial for innovation performance only in combination with elevated IT investment. By jointly promoting deep search and IT investment, firms manage to increase the optimal level of openness and gain advantages with regard to innovation performance. By investing in IT, firms can, therefore, not only increase the benefits of open innovation at equal levels of openness (Gómez et al., 2017), but also increase openness in terms of search depth without incurring the costs of over-search.

As a second contribution, we make a first attempt at understanding the interplay between appropriability concerns and IT to drive open innovation. Our results indicate that elevated appropriability concerns remain a limitation to a firm’s openness in innovation, despite increased investment in IT. The benefits of IT investment for open innovation are restricted to firms with low imitation concerns in environments with high effectiveness of protection mechanisms. This puts a clear limitation to the potential benefits of using IT to promote open innovation. Recent technological advances with regard to establishing verifiable and immutable proof of ownership of assets may help to overcome this limitation in the future (Kurpjuweit et al., 2020; Xiao et al., 2020). With the development and diffusion of such technological solutions to the protection of intellectual capital, IT's role in driving open innovation may become more multi-faceted.

With the specification of our models that, to the best of our knowledge, is unlike that of previous research, we make an additional contribution to the literature on open innovation more generally. Causal interpretation of the relationships found in quantitative research on open innovation topics is often difficult, particularly so when explanatory and dependent variables are measured without time lags. The structure of our models, including both contemporaneous and lagged explanatory variables, allows for a discussion of possible causal relationships between a firm's open innovation activities and its innovation performance. Controlling for the contemporaneous level of a variable, a statistically significant lagged form of the same variable is an indicator for an effect that takes some time to materialize (in our data sets, the time lag is two to four years). As is the case for the main variable of interest, the interaction of external knowledge search depth and IT investment, only the lagged form is statistically significant, despite the contemporaneous form of the same variable, which is also included in the models. This result indicates that firms combining deep search with high IT investment may see the positive performance effects materialize after several years only. Considering that the dependent variable (sales share of new or improved products) captures the effects of choices about the innovation process with a delay, it makes sense that the effects of an alignment between an external knowledge search strategy and its technological support take several years to materialize and "show up" in the dependent variable. The combination of a statistically significant lagged form and a non-significant contemporaneous form of the same variable strengthens a claim of causality. In addition, the estimation results of our main models show a statistically significant lagged dependent variable, underlining the autoregressive nature of innovation performance. To capture such effects, we make a case for using dynamic panel models with distributed lags of explanatory variables in research on open innovation.

This study contributes to research on the direct relationship between openness in innovation and innovation performance as well. Unlike previous research, we do not find conclusive evidence for a direct relationship between external knowledge search depth and innovation performance (Laursen & Salter, 2006). Only in models with a short control vector, the direct relationship between openness and innovation performance seems to have the expected inverted U-shape. In more precisely specified models, the evidence of a direct relationship dissipates. For the second measure of openness, external knowledge search breadth, we cannot replicate the evidence for an inverted U-shaped relationship with innovation performance either – albeit for different reasons. In our sample, the collinearity of external knowledge search breadth and its squared term is too high to allow an estimation including both, the linear and squared terms, to test the presence of an inverted U-shape. More generally, we observe that the mean values of both external knowledge search depth and breadth are considerably higher in our sample than in previous studies (Garriga et al., 2013; Laursen & Salter, 2006, 2014). This may indicate a growing prevalence of open innovation practices, particularly in the manufacturing sector, on which we focus.

Our findings have important practical implications. Although IT allows for better access to a vast array of available information external to the firm, the key area of application for IT to sustainably promote open innovation seems to be the intensive exchanges with the most relevant external knowledge sources. The combination of higher IT investment and a focus on intensive exchange with external knowledge sources enables firms to increase their open innovation performance. These benefits are subject to an important limitation, however. As much as technological support may promote open innovation, if knowledge protection is difficult, failing to draw sufficient value from a firm’s own innovations remains a problem.

The study has the following limitations. First, we address weaknesses regarding the measurement of IT. We use a measure that captures the share of IT investment among total investment, without differentiating by type of IT. In our derivation of hypothesis 1, we argue that the type of IT matters to either drive or alleviate the risk of over-search. To provide precise empirical support for this line of argument, it would be beneficial to capture more aspects of technology usage, such as the type of technologies firms use and whether the technologies are used collaboratively with partners or not. This would allow for more concrete evidence for an alignment between the type of technologies firms use and their external knowledge search strategy. We leave it for future research to investigate in more detail the facets of this alignment.

As a second limitation, we discuss the shortcomings of our measurement of appropriability concerns. With the use of two self-reported measures, we try to capture the abstract concept of appropriability from two angles. This gives an indication of the interplay between appropriability concerns and IT in an open innovation context but leaves much room for a more precise understanding. To provide more concrete findings, it would be valuable to connect a firm’s IT usage to its knowledge protection strategy in an open innovation context. It could be that depending on the choice of knowledge protection mechanisms, different technologies are best used to promote open innovation.

To close this section, we mention the restrictions of the study’s empirical setting. The analysis is limited to firms operating in Switzerland, a country with an innovative and export-focused manufacturing sector. In this environment, product innovation at the technological frontier is essential for firms’ economic wealth. In economies that are less innovative, the relationships between IT investment and external knowledge search strategies, as well as the influence of appropriability concerns might be different.

Chapter 4 Blockchain and network governance: Learning from applications in the supply chain sector

Abstract: Blockchain applications have the potential to greatly improve operational efficiency and effectiveness along the supply chain. Although we know what the barriers to the adoption of blockchain are, we know little about how firms overcome these barriers to reap the benefits of the technology. A particular challenge in adopting blockchain applications is the need to build and implement them among a network of users, requiring firms to collaborate. To manage and advance such collaborative efforts, blockchain projects install a centralized leadership. There is thus a tension between the need for centralized leadership and decentralized control to justify the use of blockchain technology. In this study, we investigate how blockchain projects navigate this tension. We employ a multiple case study methodology to compare five collaborative blockchain applications that are live today. Our findings indicate that the case applications all combine centralized management with decentralized oversight in a similar manner. We argue that this combination of centralized and decentralized control is a great benefit for the successful development and implementation of blockchain applications. The results underline that to benefit from blockchain technology in supply chain applications, an important collaborative organizational effort is necessary.

4.1 Introduction

Today’s supply chains suffer from a reliance on disparate, organization-specific information environments. Information sharing and coordination are often possible only if one firm is willing to link to the information environment of another, which may require a trustful relationship between the two firms (Baihaqi & Sohal, 2013; Fosso Wamba, Akter, Coltman, & Ngai, 2015; Saberi et al., 2019). The scaling of this approach to an entire supply network is difficult to imagine. If it were possible to share data across supply networks or even industries without concerns about data privacy and validity, the benefits for operational efficiency and effectiveness would be immense.

Blockchain technology may be the foundation to put into practice such industry-wide data-sharing ideas (Helo & Hao, 2019; Wang, Singgih, Wang, & Rit, 2019). As an immutable distributed ledger, blockchain offers a pathway towards trusted data in environments where network members do not inherently trust each other (Kumar et al., 2020). Several areas of application have been proposed in a supply chain context to improve operational efficiency and effectiveness (Kshetri, 2018; Schmidt & Wagner, 2019). They primarily revolve around supply chain transparency and digitization, including tracing and tracking products, automation, and supply chain finance (Durach et al., 2020; Gurtu & Johny, 2019; Hastig & Sodhi, 2020; Saberi et al., 2019).

The promised benefits of blockchains may look attractive on paper (Fosso Wamba, Kala Kamdjoug, Bawack, & G. Keogh, 2020). However, building and implementing a functioning application is an entirely different story. Over the past couple of years, many blockchain projects have failed, and few have become operational (Babich & Hilary, 2020; Disparte, 2019; van Niekerk, 2020). It is therefore important to understand how such applications are developed and implemented successfully (Cole, Stevenson, & Aitken, 2019). This constitutes an important gap in the literature, as little research has specifically investigated the steps necessary to develop and implement a blockchain application on live examples (Hennelly, Srai, Graham, & Fosso Wamba, 2020; Wamba & Queiroz, 2022).

With this study, we focus on one key aspect of implementing a blockchain application: the inherent need for a network of multiple entities. Blockchain is meaningful only when implemented as a multiparty system (Babich & Hilary, 2020; Kumar et al., 2020). In the supply chain context, many current blockchain projects are consortia, co-owned by multiple firms (Kouhizadeh, Zhu, & Sarkis, 2020). A recent example is the Global Shipping Business Network (GSBN). Nine ocean carriers and port operators are joining forces to develop and implement a platform that uses blockchain to standardize and digitize data exchange among stakeholders along the supply chain. GSBN is a non-profit organization owned by the nine participating firms (The Maritime Executive, 2020). The logistics technology specialist CargoSmart serves as a technology provider and operator of the platform (CargoSmart, 2019). As this example shows, several firms, including competitors, collaborate. Together, they create a new organization with the purpose of advancing the development of their blockchain application and establishing a network governance to specify decision-making structures, rules to enforce them, and ways to verify their enforcement (Babich & Hilary, 2020). We observe that a technology, which supposedly is a driver of decentralization and disintermediation (Catalini & Gans, 2016; Tönnissen & Teuteberg, 2020), leads firms to create new organizations – a seeming contradiction. We argue that it is important to address such a contradiction to clarify if and how firms can realize the potential of blockchain technology as a driver of decentralization and disintermediation. To make a first contribution in this regard, we ask the following research questions:

RQ1: How do firms organize to jointly develop and implement blockchain applications in a supply chain context?

RQ2: What role does network governance play in supporting the development and implementation of blockchain applications?

To answer these research questions, we study five cases of blockchain applications. The developed applications are now live – at least locally. All of them are being developed in a collaborative effort of multiple firms; they all are or resemble ‘blockchain consortia’. The five case applications aim to improve operational efficiency and effectiveness in the fields of product tracking and tracing, trade finance, and supplier management. Data on the development of blockchain applications is scarce because it is a novel phenomenon. For this reason and because our research interest revolves around a multifaceted phenomenon, we opt for a qualitative methodology (Eisenhardt, 1989). We collected data through semi-structured interviews.

Our analysis provides insights into how firms organize the adoption of blockchain in a supply chain context. A dedicated organization leads the development and implementation of the blockchain application, which is jointly controlled by several member firms. This setup combines centralized with shared control. A centralized management team coordinates member involvement, resolves conflicts, and builds consensus. The member firms share control by sending representatives to decision-making bodies, such as boards and general assemblies, and by engaging in working groups and trials. This collaborative approach to application development has several advantages over both centralized and decentralized approaches to application development. First, the management team provides target-oriented leadership and takes an important role in marketing the application. Second, the sharing of control among member firms makes an application more attractive for firms to join, as dependency concerns are mitigated. Third, the application benefits from the combined funding, expertise, and aggregated market power that comes with the involvement of many stakeholders.

With this study, we contribute to the emerging research on applications of blockchain technology in a B2B setting and, more specifically, in a supply chain context. We are among the first to investigate how firms organize to collaboratively develop and operate a blockchain application. We provide a contrasting perspective to the research on the potential benefits of the technology by describing the important organizational effort that is necessary to build applications of the technology in the first place. Member firms' engagement is intensive; trustful relationships develop. Blockchain is, therefore, not a technology that reduces the need for central administration and that functions in a trust-free environment. At least in the application development phase, it seems to be quite the opposite. New organizations are founded and intensive one-on-one engagement among a multitude of stakeholders is necessary to develop valuable applications of the technology.

The paper is structured as follows. In section 4.2, we offer an overview of the relevant research on blockchain technology, specifically, and multiparty information systems, more generally. In sections 4.3 and 4.4, we describe our case study methodology and the results of our analyses. We close the paper with section 4.5, discussing our contributions and the limitations of the study.

4.2 Background

We approach the phenomenon of interest from two sides. We begin with the relevant literature on blockchain technology. We then draw a connection to research on the governance of inter-organizational systems. We conclude the section with a discussion of blockchain governance.

4.2.1 Blockchain technology

Blockchain is a form of distributed ledger of transaction records (Pilkington, 2016). The data stored on the ledger exists across multiple nodes in multiple locations instead of being stored at one central location (Hastig & Sodhi, 2020). Control is shared among multiple independent parties without the need for a central authority (Lumineau et al., 2020). Data entry onto the blockchain is consensus-based, and the data on the blockchain are quasi-immutable (Nakamoto, 2008). Through public-private key cryptography, data can only be decrypted by the target recipient, ensuring privacy (Pilkington, 2016). These features of blockchain technology enable direct peer-to-peer exchange, even in the absence of a trustful relationship between the exchange partners. Without blockchain, such exchanges require an intermediary, which often accumulates important market power (Catalini & Gans, 2016). Blockchain also promises to drive automation by means of smart contracts (Buterin, 2014; Kshetri, 2018). For a more detailed description of the technology and how it can be used in a supply chain context, we refer to Babich and Hilary (2020) and Kumar et al. (2020).

Some scholars argue that this technology will have a profound impact on how firms interact, suggesting that established management theories may have to be reconsidered with regard to buyer-supplier relationships (Roeck, Sternberg, & Hofmann, 2020; Saberi et al., 2019; Schmidt & Wagner, 2019; Wang et al., 2019). Despite the apparent benefits and the potential to bring radical change, the impact of the technology on real-world processes has been limited (Sternberg, Hofmann, & Roeck, 2020). The successful implementation of blockchain turns out to be difficult. The research on the barriers to blockchain adoption has started to address the reasons for firms' struggles to adopt the technology (Kurpjuweit et al., 2020; Orji, Kusi-Sarpong, Huang, & Vazquez-Brust, 2020; Saberi et al., 2019; Sternberg et al., 2020; van Hoek, 2019). Multiple barriers relate to the topic of our study; relational governance (Kurpjuweit et al., 2020), problems with collaboration or lack thereof (Lohmer & Lasch, 2020; Saberi et al., 2019), a complex setup and a large number of involved stakeholders (Kurpjuweit et al., 2020; Lohmer & Lasch, 2020; van Hoek, 2019). However, none of them explicitly discuss the organization and governance necessary to enable the coordination among stakeholders.

A key influencing factor on how the technology is implemented and a major barrier to its adoption is the scope of the network of adopters. The network effects of blockchain are so strong that the development of applications rather takes place on an industry level, not on a firm level (Kumar et al., 2020). Even on the industry level, interoperability concerns would pose an obstacle to adoption, let alone on the firm level. Hence, the barriers to adoption may resemble those of other general-purpose technologies, such as the internet (Catalini & Gans, 2016), and not so much those of enterprise IT solutions, such as Electronic Data Interchange (EDI) (Lumineau et al., 2020).

4.2.2 Organization and governance of multiparty information systems

With the inherent need for a network of multiple parties, blockchain technology provides the foundation for a multiparty information system (Kumar et al., 2020). To study the organization and governance of blockchain applications, it is therefore worthwhile to consult research on the organization and governance of such multiparty systems. They involve a network of firms that 'work together to achieve not only their own goals but also a collective goal' (Provan & Kenis, 2008). The collaboration among firms allows resources to be used more efficiently; it promotes learning, product quality, competitiveness, and the capacity to address complex problems (Brass et al., 2004; Provan & Kenis, 2008). To ensure collective and mutually supportive action, multiparty information systems need a governance. It must specify the institutions involved in and the structure of the governing body as well as the distribution of the decision rights, the decision procedure, and the accountability framework (Provan & Kenis, 2008; Ross & Weill, 2004).

For multiparty networks, governance can be designed to be anywhere between entirely decentralized and fully centralized (Provan, Fish, & Sydow, 2007; Provan & Kenis, 2008). In the former case, all member firms jointly govern the network without the need for a centralized broker organization. In the latter case, a single member firm governs the network in a centralized manner. Decentralization is important to enhance member commitment. The more intensively member firms can participate and the more symmetrical the power distribution is, the more they commit to the goals of the network (Provan & Kenis, 2008). This comes at the cost of relatively inefficient decision-making and engagement of member firms. In contrast, centralizing decision-making powers at a lead organization enhances administrative efficiency (Chen, Pereira, & Patel, 2021; Provan & Kenis, 2008). A lead organization also adds stability. It is, however, in a position to misuse its position of power; a threat that deters others from collaborating (Chen et al., 2021; Markus & Bui, 2012).

In choosing a governance form, the members of a multiparty information system must strike a balance between the benefits of more centralized leadership and the benefits of more shared control (Chen et al., 2021; Provan & Kenis, 2008; Tilson, Lyytinen, & Sørensen, 2010). To reap the benefits of both, an intermediate degree of centralization can be selected. The network can be governed by a dedicated organization that is set up with the sole purpose of doing exactly that. This organization, not a member firm by itself, is called a network administrative organization (NAO) (Provan & Kenis, 2008). Oversight of NAOs is commonly ensured with a board that includes all or some of the member firms. Having laid out the role of centralization and decentralization in the governance of multiparty information systems, we now apply these concepts to blockchain applications.

4.2.3 Network governance of blockchain applications

The tension between centralized and decentralized network governance matters for blockchain applications (Chen et al., 2021). On the one hand, blockchain is a force for decentralization. It creates conditions in which the actions of independent agents cohere without any need for centralized leadership (Benkler, 2006; Lumineau et al., 2020; Pilkington, 2016). Decentralized governance would, therefore, fit well the core idea of blockchain. On the other hand, the development of a blockchain application may benefit from a target-oriented and efficient management, supporting the case for more centralized governance forms (Chen et al., 2021). The different approaches to network governance of multiparty systems, introduced in section 2.2., may serve to structure different approaches to network governance of blockchain applications, as shown in Table 18.

Although conceivable, whether a fully centralized governance is meaningful in connection with blockchains remains to be seen in the future. If a single entity controls a blockchain, other technologies may provide better alternatives, as they achieve the same at lower costs (Furlonger & Uzureau, 2019; Kumar et al., 2020). Such alternatives are readily available; for instance, data sharing through an intermediary, centralized storage, and EDI (Babich & Hilary, 2020). In line with the notion that centralized governance is maladapted for blockchain applications, Ziolkowski (2020) proposes to either use the decentralized or the brokered (NAO) approaches. For cryptocurrencies, Chen et al. (2021) find a U-shaped relationship between the degree of decentralization of platform governance and market performance, making a case for an intermediate degree of centralization. While the fully decentralized approach is well-represented in applications, such as Bitcoin

(Nakamoto, 2008), for enterprise blockchain projects, the NAO approach seems more common.

Table 18 Network governance of blockchain applications

	Centralized	**NAO-approach**	**Decentralized**
Lead organization	Yes	Broker	No
Description	A lead organization owns and controls the application. Governance is centralized (Provan & Kenis, 2008)	NAO (either for-profit or non-for-profit organization) is tasked with the governance of the network. It is distinct from members (Chen et al., 2021; Provan & Kenis, 2008)	Governance is fully decentralized. Example in blockchain-space: Decentralized Autonomous Organizations (DAO) (Lumineau et al., 2020; Ziolkowski et al., 2020)
Blockchain example	Other technologies may be better suited (Furlonger & Uzureau, 2019)	GSBN (The Maritime Executive, 2020)	Bitcoin (Nakamoto, 2008)
Strengths	Efficient decision-making, stability (Provan & Kenis, 2008)	Scalability of network size, inclusiveness (Provan & Kenis, 2008)	Inclusiveness, internal legitimacy (Provan & Kenis, 2008)
Weaknesses	Members are dependent on lead organization	Resource-intensiveness	Inefficient decision-making, inefficient member engagement

4.3 Methodology and case description

Blockchain applications are a novel phenomenon without much research and data available. We, therefore, choose a multiple case study approach (Barratt, Choi, & Li, 2011; Ketokivi & Choi, 2014). Case studies enable context-rich observations in real-life scenarios (Eisenhardt & Graebner, 2007), yielding deep insights into multifaceted phenomena, such as the organization of blockchain application development.

4.3.1 Research design

We follow the case study design outlined by Eisenhardt (1989). To be selected as one of our cases, the application must fulfil the following criteria: (1) it must make use of blockchain technology, (2) it must be live, (3) it must be owned by more than one firm and involve multiple adopters, (4) it must be aimed at increasing operational excellence along the supply chain. All our case applications are being managed by organizations founded specifically for that purpose. These organizations are or resemble a consortium and are often called that. Not all of them legally are consortia. We will therefore refrain from using that term to describe the organizational form of the study cases. We focus on the supply chain sector, which is relevant to study blockchain applications for two reasons. First, there is great potential for increased operational efficiency and effectiveness along supply chains, which blockchains may tap into. Second, processes along supply chains naturally involve multiple firms. This leads to such multiparty projects being created out of necessity.

The population of all blockchain applications that meet our three criteria is still small. To ensure that the cases are information-rich, we adopted an intensity sampling approach (Patton, 2015). Our approach to identify possible blockchain applications to study was iterative. Starting from a small set of well-known projects, we researched websites renowned in the supply chain sector and news sites that report on blockchain-related topics. Over the course of conducting the first interviews, we were able to add projects through input from informants. We aimed to include a broad variety of different blockchain applications in our study, while maintaining comparability among cases. We guaranteed confidentiality and pseudonymity to our participants.

Potential informants can be clustered into three categories: (1) employed directly by the organization that manages the application (NAO); (2) employed by one of the member firms; (3) independent experts involved in the case (e.g., journalists, industry experts, scholars). To gain a varied perspective on the applications, we included informants from more than one category per case. Table 19 provides an overview of informants by case.

To collect data through semi-structured interviews, we prepared an interview guide (Appendix H), which served as an orientation during the interviews regarding both lines of questioning and time. This ensured the coverage of all important topics, while leaving room to dive more deeply into specific topics when they arose during the conversation (Eisenhardt, 1989). The guide covered four overarching topics: (1) the informant's background and involvement with the blockchain application; (2) general information about the application, such as goals, members, and technical properties; (3) the organization, governance, and operation of the application; and (4) further questions on informants' opinions regarding the future development of the application.

4.3.2 Data collection

We conducted a first round of data collection in 2018. At that time, blockchain projects had not developed enough for their organization and governance to be studied. As a result of the prematurity of the phenomenon of interest, we used the first round of five interviews as a pre-study to inform the latter, major data collection for the main study.

We adopted a parallel approach with data collection and analysis overlapping, collecting data from spring to summer 2020. After a first phase of pure data collection, we then started analyzing interview transcripts while still conducting additional interviews. As part of the main data collection effort, we conducted 18 interviews across five distinct case applications (see Table 19). We prepared documents and conducted interviews with an English-first approach. All informants agreed to using English as interview language, as English is the spoken language among all cases. We conducted all interviews remotely. The Covid-19 pandemic precluded the possibility of in-person interviews. We used Zoom, Microsoft Teams and phone calls, depending on the informants' preferences and their companies' IT guidelines.

We recorded and transcribed the interviews and compared transcripts and audio files to correct spelling mistakes, remove duplicated words, and modified sentence structures where necessary. Handwritten notes complement the transcripts. While not subject of in-depth analysis, they were helpful during the interview process. We also collected data from openly available information about the cases to ensure consistency. This provided additional information on general aspects of the cases, not for organization-related topics which were seldom disclosed.

Table 19 Overview of informants per case

Study case	**Informant role**	**Affiliated with organization**	**Interview duration**[a]
Appl-1	Executive	NAO	0:57
	Executive	NAO	0:58
	Advisor	NAO	0:49
	Project manager	Technology provider	0:37
Appl-2	Executive	NAO	0:55
	Product manager	Member firm	0:59
	R&D manager	Member firm	0:28
	Senior reporter	Specialist publication	0:52
Appl-3	Executive	NAO	1:04
	Business development manager	Technology partner	0:53
Appl-4	Analyst	NAO	1:04
	Executive	NAO	0:33
	Executive	NAO	0:27
App -5	Product manager	NAO	1:12
	Technology specialist	NAO	0:54
	Executive	Member firm	0:56
	Engineer	University	0:51
	Senior editor	Specialist publication	0:53
Pre-study	Managing consultant	Management consultancy	0:51
Pre-study	Professor	University	0:43
Pre-study	Product Manager	Logistics company	1:01
Pre-study	Managing consultant	Blockchain consultancy	0:40
Pre-study	Executive	Blockchain start-up	0:53

[a] The interview duration is measured in hours:minutes.

4.3.3 Data analysis

We conducted two rounds of coding with two coders working independently of each other. The focus of the first round lay on descriptive codes (Saldaña, 2015). The first goal was to understand the purpose of the applications, as well as ownership, membership, and user networks. Based on the literature on governance of multiparty information systems, we aimed to understand the governance of the blockchain applications. This mirrors the first research question. The second round of coding was more inductive than the first, as we intended to inform our codes from the data (Patton, 2015). The focus shifted to understanding the relationship between organization and governance, and the adoption of blockchain, using thematic codes. Table 20 provides examples of codes from the second round of coding. To answer the second research question, we focused on understanding the role of centralization and decentralization in organizing blockchain adoption, and on how the organization and governance of blockchain applications change during the adoption process. We used MAXQDA for interview coding.

Validity and reliability of case studies are common concerns of both case study researchers and the research community at large (Gibbert, Ruigrok, & Wicki, 2008). In the following, we briefly describe the measures we took to increase both the validity and reliability of our research. To ensure a comprehensible and neutral interview guide, we iterated it multiple times among authors and obtained feedback from peer researchers. In the interview guide, the term ‘governance’ appears several times. We expected different informants to understand the term in different ways. In the interviews, we established a common understanding by first letting the informants explain their understanding of the term and then finding a common base in a brief discussion. We ensure a transparent process from data collection to the findings, through detailed case reports and extensive documentation for each of the cases. The descriptive case reports informed the second round of coding. We triangulated the statements from different informants of the same case.

Table 20 Coding strategy

Code	Case	Example quote
Decentralization	Appl-1	So the Walmart, the FoodTrust one is an easy one because you design a blockchain network and you tell your suppliers to connect and […] your work is done. But it is not a collaboration. What we are doing is through collaborations. So I need to convince everybody to work together in this infrastructure. [Executive]
Decentralization	Appl-2	No there is a difference. Those members who have a board seat have the biggest say. […] Those organizations who are shareholders but do not have a board seat, obviously, have lesser say. And then those who are licensees only, they are licensees only. [Executive]
Decentralization	Appl-4	And then, obviously, […] it is a shared solution […]. It is not a siloed solution; blockchain is never one. [Analyst]
Decentralization	Appl-5	I mean, you have got a network of different participants - blockchain does not make any sense if you make just blockchain for yourself - so it is a decentralized system. [Engineer at University]
Transformation	Appl-1	And of course, of course, I imagine - now it is a cozy club of nine or something. But when we have an audience of 100 in specific areas, we have to rearrange this stuff. [Executive]
Transformation	Appl-2	[It was] set up as a standalone entity in 2018. Now, this is something that we are seeing a lot with a lot of the other consortia, you know: they start out just being a consortium and then, because they need to have that kind of governance structure and the ability to take decisions by CEO and not by committee, they are setting up a standalone legal entity. [Senior reporter at specialist publication]
Transformation	Appl-3	So, at the beginning, when we founded the association a year ago, we were the sole master on board. And little by little, and that started with the first general assembly of the association, we started letting go some of power to the [member firms]. [Executive]
Transformation	Appl-5	[T]o my understanding […] they gave the other carriers both […] power over governance and also some sort of revenue, ability to drive revenue as well. So it wasn't just [shareholder 1] setting the rules and [shareholder 1] purely monetizing this and other companies sort of having to be involved. […] And then once [the other carriers] were involved, it naturally was seen as less of a purely [shareholder 1]-driven initiative. [Senior editor at specialist publication]

4.3.4 Case description

In this section, we introduce the five multiparty blockchain applications in the supply chain sector that we study. They are all, at least locally, live at the time of writing. We first introduce each case. Table 21 provides an overview. The more detailed case descriptions are shown in Appendix J.

Appl-1. Operated by a group of logistics providers, Appl-1 provides transparency on the location and status of finished vehicle shipments, as well as load capacity management to optimize the utilization of logistics fleets. It addresses the lack of holistic, real-time information along the supply chain of finished vehicles due to siloed, paper-based processes and a low degree of digitization of logistics service providers in the space.

Appl-2. Appl-2 offers supply chain finance solutions for SMEs and is operated by a group of banks. Trade finance as an industry remains paper-based to a large extent, meaning that information is siloed and processes are inefficient. Digital and standardized trade execution would contribute to efficiency gains. Banks integrate the application into their own trade finance products that they sell to their customers.

Appl-3. This application helps to create digital identities of products on the blockchain for the luxury fashion industry. Such digital identities offer proof of authenticity and proof of ownership. In addition, a record of item-specific events, such as sales or repairs, can be kept. Member firms can both use these functionalities for internal process improvements, as well as integrate them into their products. Appl-3 was founded and is still managed by a group of entrepreneurs.

Appl-4. Appl-4 develops a supplier information management tool that improves supplier selection, validation, onboarding, and lifecycle management. Although it is owned by a technology provider and a blockchain consultancy, a wide range of firms from industries, such as electronics, fast-moving consumer goods, pharma, and telecom, are involved in developing the application. Suppliers make the documents and information required for standard onboarding processes available on the platform offering buyers a central database to navigate the supplier space. Third-party providers offer services on the platform, such as auditing and validation.

Appl-5. Owned by a logistics company and a technology provider, this application aims to address multiple inefficiencies along the information flows of the global shipping industry that suffers from siloed information ecosystems. Appl-5 offers a platform for document sharing. This platform helps digitize work processes that are currently paper-based and lay the basis for automation of repetitive tasks. In addition, having all parties engaged in the shipping of goods coordinate on the same platform helps speed up processes and reduce errors (e.g., at customs).

Table 21 Overview of cases

Name	**Application**	**Members**	**Ownership**	**Blockchain type**
Appl-1	Track and trace in finished vehicle logistics	< 10: logistics providers and bank	< 10 logistics providers	permissioned
Appl-2	Trade finance	10-20: banks and tech. provider	> 10 banks	permissioned
Appl-3	Digital identity for luxury goods	> 20: luxury brands and tech. providers	member firms hold tokens and no financial stakes	permissionless
Appl-4	Supplier information management	> 20: firms from various industries	blockchain consultancy and tech. provider	permissioned
Appl-5	Global shipping platform	> 100: logistics companies, service providers, terminals, customs authorities	logistics company and tech. provider	permissioned

4.4 Results

In this section, we examine the evidence the five cases of blockchain applications jointly provide to address our research objectives; understand the organization and governance of collaborative blockchain projects and how they aid the adoption of the technology.

4.4.1 Organization and governance of blockchain applications

The five cases have similar organizational structures (Table 22). The centerpiece is a standalone organization that was founded for the purpose of developing and operating the blockchain application. This organization takes the role of a network administrative organization (NAO, see Table 18) (Provan & Kenis, 2008), and we will call it that throughout this section. The NAO is led by a management team, which can be made up of founding individuals, dedicated hires, or be staffed with representatives from the shareholders. An NAO may be made up of just a management team or have dozens of employees. Additionally, all NAOs have some sort of governance bodies with oversight and decision-making responsibilities – in most cases, a board and a general assembly. These bodies provide the formal ways for the involvement of member firms. As Table 22 shows, different factors determine whether firms qualify for a board seat. Working groups provide the format for representatives of member firms to jointly develop features of the strategy or the application itself.

Table 22 Organizational structure of cases

Name	Management team	Board	General assembly	Working groups
Appl-1	Team of industry experts. Responsible for operations and coordination between members	Board and general assembly are the same. Executives of member firms and Appl-1 management team. Responsible for strategic decisions and product roadmap		Established working groups with experts from member firms
Appl-2	Team of industry experts. Responsible for operations and coordination between members	Executives from large shareholders and Appl-2 management team. Responsible for strategic decisions	Representatives from all member firms. Informal extension to board	Established working groups with experts from member firms
Appl-3	Team of founding individuals. Responsible for application development and operations	Reserved seats for big industry players; additional members elected by assembly. Currently, little responsibilities	Representatives from all member firms and technology partners. Input on application development; elects board members	Established working groups with experts from member firms
Appl-4	Dedicated team from shareholding blockchain consultancy. Responsible for operations, business development, and coordination between members	Executives from 10 'industry leaders' from different industries. Responsible for strategic decisions	Representatives from all member firms. Coordinates working groups	Established working groups with experts from member firms
Appl-5	Large dedicated organization associated with the two major shareholders. Responsible for operations, business development, and coordination between members	Two bodies to be created: association encompassing major competitors in one value chain echelon, a board with representatives from a cross-section of member firms	-	Working groups not established

In all cases, the member firms not only have formal, but also informal channels available to engage with the NAO. In informal meetings, member firms interact one-on-one with representatives of the NAO and its management team. The exchanges between member firms and the NAO can be frequent and close.

> So, I got a handful of relations at [Appl-2]. I simply give [them] a call and say, 'has anyone considered this?' […] I think the way how I apply it is informal, and I think there is a formal way as well. [Product Manager at member firm, Appl-2]

> [I]t's more now a one-to-one connection between project manager and ourselves to really discuss additional features […]. [Business development manager at technology partner, Appl-3]

While the organizational structures may resemble each other among cases, the ownership structures differ (Table 21). Appl-1 and Appl-2 are owned by a rather large group of founding firms. There are no or few member firms that are not co-owners. The owners of Appl-1 and Appl-2 are mostly firms from one echelon of the entire value chain. They integrate the application into the products they sell to their customers.

> The customers are not paying anything. [Appl-2] is a platform, from their point of view. They don't have to bother whether there is a specific company or a joint venture company, or if it's owned to equal parts by the [member firms]. [R&D manager at member firm, Appl-2]

In contrast, majorities of Appl-4 and Appl-5 are owned by a pair of firms only, of which one is the technology provider. There is a large number of non-shareholding member firms. Member firms integrate the application in their own business processes and may or may not incorporate them into products they sell. The number of members far exceeds the number of owners. Among the cases, Appl-3 is the only one that was financed through an initial coin offering (ICO) and uses tokens. A traditional shareholder structure does not exist.

Tied with the ownership structure is the monetization strategy. Fundamentally, three types of beneficiaries seem to be distinguishable. Any firm that builds a functionality for the platform and offers it to be used by others can monetize that usage.

> What’s also unique about the solution is the integrated marketplace, apps that we have. [A]ll of this information that is provided by the suppliers […] will need to be verified and tested […] by third-party verifiers […]. So, [Appl-4] provides a seamless integration with all of these third-party verifiers. [Analyst, Appl-4]

In addition, member firms pay a membership fee for access to the application’s functionalities. They benefit inasmuch as the application may help improve operational efficiency and effectiveness. Alternatively, should the application be integrated into their products, member firms benefit from an improved value proposition to their customers. Finally, owners of the applications may realize a wider range of benefits. We did not gain a clear picture from the data of how owners would monetize their status in the long term. After all, these blockchain applications still require large investments without generating much revenue.

All the cases show how firms that are willing to engage with this novel technology invest in organizing and governing the collaborative effort to develop a valuable application. Developing an application collaboratively among a larger group of firms instead of independently within or among a small group of firms comes with important benefits. If different firms, competitors in particular, join forces, they aggregate market power. This makes it more likely that their application will prevail to achieve critical mass.

> [A lot of companies] put a team together to investigate different blockchain technologies, put their head around it and try to figure out, ‘Okay, how could you possibly leverage this?’ The problem is, if they go too far, they start developing some kind of solution, then they are completely isolated, then they’re like, ‘Okay, how do we actually scale up to bring other people in?’ [Technology specialist, Appl-5]

The involvement of a multitude of industry players aggregates expertise. Each member brings in perspectives from another home market, experiences with a different set of customers and regulatory environments. A technology provider may suffice to contribute the necessary technological expertise. To build an application that caters to the needs of a broad base of firms from different value chain echelons, business expertise is at least as important.

> Why I joined this consortium. It's because I think that I've seen many blockchain projects. And most of them are initiated from a tech side. And tech people don't know how to sell a platform. They […] build it from a technology point of view and not from a perspective of how to use it. [Advisor, Appl-1]

4.4.2 Impact of network governance on blockchain adoption

In this section, we examine how the cases' network governance aids technology adoption. In reference to Table 18, all our cases follow the NAO-approach, using an NAO for network governance. Below, we will introduce two benefits this approach holds over the two alternative approaches to organize blockchain adoption.

A first major feature is shared control, distinguishing the network governance of the cases from a centralized lead organization governance. Sharing control entails that no single firm can easily influence application development in its favor. Could one single or few firms do this, other firms would be reluctant to join due to a fear of competitive disadvantages and out of dependency concerns. Shared control is a major selling point to prospective new members. The opportunity to steer the development of the application as a group is a safeguard against opportunistic behavior by a few. With the credible promise to take into account different member firms' specific needs in application development, new member firms are easier to attract. The network may grow, and the application may become the front-runner in a race for network size.

> [W]e're trying to […] change processes and procedures that have been predominantly paper-based for tens or hundreds of years. And to do that, you need to have a common methodology in order to make it work. And

> hence, it requires everybody to be on the same page. So, one organization can’t do it themselves because you need to get the collective buy-in to do it in a particular way. That’s why the consortium model is being adopted. [Executive, Appl-2]

With large-scale adoption of blockchain applications, interoperability concerns are reduced. The aspiration to become the leading application within at least an industry is common among cases – and an important marketing tool. Achieving the standard as a joint effort makes an application attractive for more firms to join.

> And then regardless of if in the future it is blockchain […], a cloud database, or whatever it is, we will at least have standardized this and made this into something that can be technology agnostic. [Senior reporter at specialist publication, Appl-2]

> So we need to get to production, […]. It’s another two years of building the whole infrastructure. I think once it’s there, we have the more or less monopoly position in the market, which we aim to get, be the winner that everybody flocks to. [Executive, Appl-1]

Several informants (Appl-1, -3, -5) voiced their concerns that a platform provider from outside the industry (e.g., Amazon, Uber, Google, etc.) could build their own application and, thereby, threaten the business models of incumbents. They might not make use of blockchain technology, opting for a centralized solution instead (Chen et al., 2021). The attempt to develop a blockchain application collaboratively is intended to pre-empt such threats.

> [Selling the application] to Amazon or Alibaba […] or Google is [the member firms’] biggest fear. And they’ve already spent the last decade being subjects of those big platforms. And when you tell them, ‘Hey, we have a solution, we’re trying to build something that will free you of the shackles of Amazon and Google and Facebook’, they're extremely interested and fascinated. [Executive, Appl-3]

A second important benefit of the cases' approach to network governance, is that it allows for some centralized decision-making. Unlike the aspect of shared control, which distinguishes the cases' network governance from more centralized approaches, the aspect of centralized decision-making distinguishes it from a fully decentralized approach (see Table 18). All cases have an NAO that is led by a management team. A major task of the NAO is marketing and network growth.

> [The] CEO and marketing [of the NAO] are really focusing on developing the consortium, at which they do a great work. [Business development manager at technology partner, Appl-3]

Internally, the management team is the coordinating force among involved stakeholders, facilitating the communication with and between members, building consensus, and driving a target-oriented development of the application. Members of that team build relationships with representatives from member firms to build the trust needed to push collaborative application development forward.

> I would say the social talk within the consortium is as important as the governance structure because, basically, governance structures are just about 'okay, did you check the boxes, and is everybody behaving accordingly? […]' But this inter-human relationship […], this is the main thing. And especially when you have competitors in the room, it's trust. Well, you can only get trust in the blockchain if you have trust in your consortium. [Executive, Appl-1]

In summary, the cases provide examples of how firms collaboratively develop blockchain applications in a multiparty context that suits the collective needs of many stakeholders. They benefit from aggregated market power, shared expertise and capital. Shared control, which mirrors blockchain's technical requirement of decentralized control over the validation of entries, is an important safeguard against opportunistic behavior of those in control. It legitimizes an application's claim to an industry standard. Finally, a management team exerts some centralized control to coordinate between member firms and drive forward application development in a targeted manner.

4.4.3 Navigating the conflict between centralization and decentralization

Above, we argue that the cases' approach to network governance combines the strengths of shared and centralized control. These two features may clash. In this section, we describe how the cases handle such conflicts by adapting their network governance.

We observe that the applications' network governance, particularly the degrees of centralization, do not remain stable over time. It seems that the initial approach to network governance does not necessarily cater to the needs of the applications later in their development and implementation. There are two directions of shifts in the degree of centralization among the cases: from a decentralized beginning towards more centralization of control, and from a centralized beginning towards more decentralization of control. Table 23 provides an overview of the two directions of shifts that we observe.

Among the cases, in all but Appl-4, there is evidence of shifts towards more centralized or more decentralized control. Appl-1 and Appl-2, which both started out in a decentralized manner, are shifting more responsibilities to the NAO. Appl-3 and Appl-5, which were founded with a strong centralized team, are moving towards a more decentralized structure by ceasing some control to the larger member base. There is indication of a trend towards a more similar distribution of control among cases – despite different ownership structures and starting points. Blockchain projects that start out decentralized (Appl-1, -2) face the challenge of scaling up the organization, while keeping the benefits of decentralization. To make decision-making more efficient, central management is strengthened. In addition, with network growth, distinguishing different membership tiers becomes necessary, with some members having more power than others. In contrast, blockchain projects that start out centralized (Appl-3, -5) face the challenge of recruiting new members and securing member buy-in. Fears of dependency on the organizations in control make potential members reluctant to join. In addition, stakeholder buy-in is a concern if member firms are only marginally involved in application development.

Table 23 Observed shifts in the degrees of centralization

Direction 1: towards centralization		
Appl-1	Initially, group of firms sharing control. Since, creation of an NAO and formalized governance	[N]ow it's a cozy club of nine or something. But when we have an audience of 100 in specific areas, we have to rearrange this stuff. […] Then you have members and members; basically people just participating in the network transacting and doing nothing, but just using it. [Executive, Appl-1]
Appl-2	Initially, group of firms sharing control. Since, strengthening of the management team and decrease of the involvement of member firms	How this has evolved is that the [Appl-2] organization […] has taken a more firm grip […]. I really welcome that I don't need to have a say in all questions. […] So, the [Appl-2] organization as of today is much more effective and efficient compared to just one or two years ago. [Product manager at member firm, Appl-2]
Direction 2: towards decentralization		
Appl-3	Initially, centralized governance by a group of entrepreneur founders. In a step-by-step process, the founders relinquish their decision-making monopoly to the member firms	[A]t the beginning, when we founded the association a year ago, we were the sole master on board. And little by little – and that started with the first general assembly of the association – we started letting go some of power to the [member firms]. [Executive, Appl-3]
Appl-5	Initially, powerful NAO to push for fast network growth, which it accomplished. In order to get competitors of the main owner on board, there has been a recent move towards decentralizing control somewhat	For the [firms], we have a consortium, […]. It's kind of a bigger group of all different big [firms] within this industry. […] I think we have all top seven worldwide [firms] which will be onboarded within this group, within this association. [Product manager, Appl-5]

4.5 Discussion

4.5.1 Implications for research

With this study, we aim to shed light on how firms jointly organize the development and adoption of a technology application for the supply network and the wider industry context. It helps us go beyond the barriers and enablers to the digitization of supply chains (Gupta, Kumar, Kusi-Sarpong, Jabbour, & Agyemang, 2021; Orji et al., 2020; Saberi et al., 2019) and study real-life examples of how firms collaboratively overcome some of these barriers, which has been called for (Hennelly et al., 2020). We study five blockchain applications, all of which promise more effective and efficient operations in industries that operate in information siloes or lag behind in digitization. Although none of the applications have reached widespread adoption yet, all of them are currently at least locally live at some member firms.

The approach to network governance we described as part of the analysis resembles what Provan and Kenis (2008) call 'network administration organizations' (NAO). It combines a centralized organization, dedicated to furthering the member firms' common cause, and decentralized oversight and decision-making bodies that ensure member firm involvement. The governance form of the case applications thus combines aspects of centralization and decentralization. We argue that both, more centralized and more decentralized approaches to organizing the development and implementation of blockchain applications may not be as appropriate for such a task. More centralized approaches may put member firms in a position of dependency with regard to the lead organization. In addition, a lead organization may struggle to incorporate sufficiently broad industry knowledge to build applications that cater to the needs of a varied user base. In contrast, in fully decentralized approaches to building blockchain applications, decision-making becomes inefficient with a growing number of participants.

We motivated this study with the observation that adopting a technology which is associated with disintermediation and decentralization leads firms to create new organizations with a centralized management, trust-based relationships, and large-scale collaboration – a seeming contradiction. The case analysis shows why collaboration among large numbers of firms and the creation of new organizations for network governance may be key to adopting blockchain technology. To realize the important benefits blockchain may bring, it seems necessary to build applications for entire industries from the onset. The technical and business aspects of an application must be developed in sync. Some form of centralized control may be necessary to achieve that. This is in line with previous research on cryptocurrencies, promoting organizational forms that incorporate both broad participation among members and some centralized leadership (Chen et al., 2021). The following quote illustrates our argument:

> [W]e have this new technology, it's got some interesting features, there's plenty of applications we can imagine doing with this. And now the question is, how do you actually make it happen? And that's where the governance of those consortia comes into play. And without it, it just doesn't work. You know, you can be at the business level and see a vision on how you could leverage that technology, can have all the technology with all the goodies, all the features you can possibly imagine. But if you don't have that glue in between on how to build the network and run it successfully, you're screwed. [Technology specialist, Appl-5]

Among our cases, we observe that the network governance does not remain stable over time but evolves. At the outset, blockchain projects resemble start-ups. They organize to agilely develop proofs-of-concept among a small group of individuals or interested firms. To gain legitimacy and benefit from network effects, network growth is the major target. The growing network soon changes the nature of the blockchain projects; a formalized governance needs to be set up, coordination costs rise, member involvement becomes more difficult. In this phase, it is important to simultaneously promote application development and network growth, as well as remain attractive for new firms to join. The former is linked to a strong management, the latter to a collaborative approach and shared control. This is the phase in which the applications we studied currently are.

Departing from this standpoint, we may dare a look into the future of blockchain applications. In a mature state, which no enterprise blockchain project has reached yet, the organization of a blockchain application may become less elaborate again and mostly focus on administrative tasks. Functionality development is expected to take place on the platform by various actors simultaneously. This development is driven by competition between different ideas without the need for centralized control.

4.5.2 Implications for practice

The notion that blockchain is the wrong technology for many intra-firm projects or projects among a closely associated group of firms is well-established by now (Furlonger & Uzureau, 2019). Applications of the technology are meaningful where they involve a network of users (Kumar et al., 2020). If the application is developed internally within a firm, scaling and interoperability become obstacles that are hard to overcome. Competing applications that are developed collaboratively by groups of firms are likely stronger; they cater to the needs of a larger variety of firms, aggregate more funding, expertise, and market power. For decision-makers that are enticed by the promises of blockchain technology, it might thus be worth to watch out for the collaborative blockchain projects and be reluctant to start new blockchain projects within the limits of the firm or its immediate environment.

Being part of the effort to build an infrastructure that is based on blockchain requires firms to collaborate with other firms. They must commit to collaborating with competitors, making compromises, and, finally, integrating a jointly developed application into their own processes. This commitment is an important cost associated with adopting blockchain technology and realizing the benefits associated with it. As such, blockchain technology is only the trigger for the collaborative effort. The novel technology increases decision-makers willingness to engage in collaboration and make the commitments mentioned above. The aim may ultimately rather be standardization than using blockchain technology specifically.

On the long journey to developing an application that creates value for its users, the organizational hurdles may be greater than the technological hurdles. Making competitors collaborate to jointly develop an application for themselves and many others to use, and securing sufficient stakeholder buy-in to integrate the application in their respective internal processes, is an important organizational feat. Practitioners should be wary of blockchain projects that do not invest in a solid network governance. How seriously the owners of an application are willing to engage non-shareholding member firms in oversight and decision-making may give an indication for who the ultimate beneficiaries of the application are intended to be.

4.5.3 Future research and limitations

We observe that the organization and network governance employed in our cases are not fundamentally novel or specific to blockchain. Any collaborative projects unrelated to blockchain may be set up in a similar manner from an organizational point of view. This may change in the future if blockchains can be used for network governance also (Lumineau et al., 2020). Self-sovereign identity solutions can provide the technological basis for such applications of blockchains (Ishmaev, 2020). The Sovrin foundation is an example (www.sovrin.org). Adopting such a design can mitigate issues of trust between participants and make incentive systems more efficient. It is important to differentiate blockchain-supported governance and the governance of blockchain applications. We only addressed the latter in this study. We leave the study of the former and the combination of the two for future research.

Prior studies argue that blockchain technology will change the way firms interact. Disintermediation, for instance, may render certain business models superfluous (Catalini & Gans, 2016). The focus lies on the impact of operational blockchain applications on firms and industries. It may be interesting for future research to also investigate how the organizational features of a blockchain application impact firms and industries. Does the role that firms play in building an application impact their benefits? Does it matter whether the application was developed under a centralized management with decentralized oversight in contrast to more centralized or decentralized approaches? How does the monetization strategy of blockchain applications influence the benefits firms draw from using them? These are just a few questions that may be relevant to address in the future to understand the effects of blockchain technology more fully, as its adoption spreads.

This study has the following limitations. First, the case selection and focus of our study only give a partial view of how firms organize to adopt blockchains. We laid the focus on five blockchain applications developed collaboratively by multiple firms. Other approaches to organize the development of blockchain applications may also be employed. We do not investigate them and instead focus on the one form that seems most relevant for applications of the technology in a supply chain context. In addition, we cannot measure success due to a lack of dependent variables and the immaturity of the cases. The novelty of the phenomenon justifies such a study focus and a relatively descriptive approach to analyzing them. Second, the depth of our data is limited by our collection approach. We collected data in phone interviews with a few representatives from each of the five cases. We aimed to speak with a broad spectrum of stakeholders to strike a balance between the depth of the understanding of each case and the breadth of cases in our study. For an in-depth understanding of how each of these cases function, however, we would have had to spend more time with each of them, talking to more stakeholders and talking to them several times. To fulfil the study’s purpose – to provide an early examination of the organizational aspects necessary to adopt blockchain applications – we argue that our data set is rich and meaningful.

4.6 Conclusion

This study shows that developing and implementing blockchain applications in a supply chain context is associated with an important organizational effort. In the five case applications we investigated, it is this organizational aspect of collaboratively building blockchain applications that stands out with regard to its complexity and resource intensity. Jointly organizing the implementation of a technology among a group of firms has been difficult in the past and will be difficult in the future. Blockchain technology is no exception. Despite all the buzz around blockchain as a novel and potentially disruptive technology, the requirement to involve many stakeholders in building blockchain applications makes it a difficult technology to implement.

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Appendix

Appendix A – Principal component analysis

To substantiate the validity of the two outsourcing constructs, *Production OS* and *Peripheral OS*, we conducted a principal component analysis. *Production OS* combines the outsourcing of the production of products (*Products OS*) and components (*Components OS*). *Peripheral OS* joins IT (*IT OS*) and services outsourcing (*Services OS*). The selected sample is the largest available for an FD regression with N = 655. The factor loadings shown in Table A1 support building the two proposed constructs, *Production OS* and *Peripheral OS*.

Table A1 Rotated factor loadings (N = 655)

Types of outsourcing	Factor 1	Factor 2	Uniqueness
Products OS	0.600	0.169	0.612
Components OS	0.593	0.184	0.614
IT OS	0.283	0.338	0.806
Services OS	0.351	0.335	0.765

Appendix B – Extreme values cut regressions

Extreme values of *Δ Vertical scope* may drive regression results. To test their influence, we reproduce the model for Hypothesis 4 using a sample without the top and bottom 5% of *Δ Vertical scope (t-1)* (37 of 363 observations dropped). Shown in Table C1, Model I, the main effect on the performance of new products captured by the interaction term remains stable (Model I: $\beta = 0.141$, S.E. = 0.065). These results indicate that the main results are not driven by outliers in *Δ Vertical scope*.

Appendix C – Turnover as an additional control variable

We add turnover growth as a control variable, as the change in sales might significantly bias the results. If the sales of a firm increase, the sales’ share of new or improved products might decrease despite the firm remaining just as successful in commercializing its innovative products as it was in the past. At the same time, production outsourcing might be an answer to the commercial success of the products, for instance, a remedy for capacity constraints. Under growing sales, a decrease in the sales share of new or improved products is not necessarily a sign of hampered innovative capacity. As a result, the relationship between production outsourcing and product innovation might exist as the hypotheses above suggest, albeit not for the reasons we argue. By introducing turnover growth (*Δ Turnover*) as a control variable, we capture these effects, should they exist.

Table C1 First-differencing OLS regression estimates for robustness check

	Model I Δ NEW (t)			Model II[12] Δ NEW (t)		
	Coef.	S.E.	p>|t|	Coef.	S.E.	p>|t|
Production OS (t)	0.018	0.024	0.434	0.016	0.023	0.483
Production OS (t-1)	-0.015	0.028	0.594	-0.011	0.022	0.601
Peripheral OS (t)	-0.009	0.029	0.746	-0.001	0.025	0.972
Peripheral OS (t-1)	0.041	0.021	0.057	0.029	0.020	0.154
Δ Vertical scope (t)	0.029	0.026	0.274	0.042	0.021	0.049
Δ Vertical scope (t-1)	0.008	0.033	0.810	0.038	0.019	0.047
Δ Vertical scope (t-1) X Production OS (t-1)	**0.141**	**0.065**	**0.031**	0.096	0.039	0.015
Δ Turnover (t)				**-0.016**	**0.036**	**0.662**
Δ Size (t)	0.078	0.050	0.119	0.078	0.050	0.118
Δ Size (t-1)	0.082	0.050	0.104	0.049	0.041	0.235
Δ HC Educ (t)	0.084	0.208	0.688	0.046	0.211	0.830
Δ HC Educ (t-1)	0.508	0.191	0.008	0.250	0.178	0.163
Δ RD Input (t)	0.008	0.002	0.000	0.009	0.002	0.000
Δ RD Input (t-1)	0.001	0.001	0.378	0.002	0.001	0.126
Ind.-∅ Δ PRODUCT (t)	-1.085	0.350	0.002	-0.844	0.286	0.003
Year fixed effects		[yes]			[yes]	
N		326			342	
Adjusted R-squared		0.128			0.127	

The regression results displayed in Table C1 do not provide any evidence for such an effect (*Δ Turnover* in Model II: β = -0.016, S.E. = 0.036). The coefficient

[12] Note that the sample size decreases in comparison to the base sample (N = 363) due to the missing values of the turnover variable.

size of the interaction term (*Δ Vertical scope (t-1) X Production OS (t-1)*) even increases from 0.083 (Table 5, Model 5) to 0.096 (Model II). This result indicates that the contemporaneous growth of a firm does not influence the effect of production outsourcing on new product performance.

Appendix D – Alternative measure for knowledge search depth

In this appendix, we discuss our measurement of the variable for external knowledge search depth (*Depth*), its drawbacks, and propose an alternative measurement. We use this alternative measurement for a robustness check of the estimation results.

Although we measure *Depth* in line with existing research (e.g., Laursen & Salter, 2006), there is a discontinuity in our measurement, which might affect estimation results. In the data that we use, the survey questions about the importance of external knowledge sources, on which *Depth* is based, migrated from a 5-point scale ('none' to 'very high') to a 4-point scale ('none' to 'high') between the waves of 2011 and 2015. We set the cut-off point to distinguish deep from non-deep external knowledge search at 'high', in line with Laursen and Salter (2006). In our discontinuous measurement, this corresponds to the answers 4 and 5 on the earlier, 5-point scale, and to the answer 4 on the later, 4-point scale. Expressed in formal terms, we merge the two scales by representing both, the earlier and later versions of *Depth*, as a fraction of one and apply a cut-off point at 0.75. Answers greater or equal than 0.75 are considered as deep search, while all other answers are considered as non-deep search.

The discontinuity in measurement entails that there is also a discontinuity in the prevalence of deep external knowledge search between the earlier (2005, 2008, 2011) and later survey waves (2015, 2017, 2019). The mean value of *Depth* drops from 0.256, using the data from 2005-2011 (N = 625), to 0.127, using the data from 2015-2019 (N = 633). To test whether the discontinuity influences the estimation results, we scrutinize two aspects of our results. First, we examine the influence on the estimation results from our main models to test the hypotheses. Second, we determine whether the discontinuity in measurement influences the appearance of the inverted U-shaped relationship between openness and innovation performance. We address the first aspect in this appendix and turn to the second aspect in Appendix E, as part of the broader examination of the evidence on the inverted U-shaped relationship.

With six survey waves available, three using the earlier measurement and three using the later measurement, there are not enough lagged observations in each sample to run dynamic panel estimations separately. Instead, we introduce an alternative measure for external knowledge search depth with a continuous measurement across all six waves, using a percentile-based measure. In the traditional measure for external knowledge search depth (*Depth*), the cut-off between deep and non-deep search is fixed over time and across knowledge sources. A percentile-based approach allows a relative cut-off to take into account changes over time and differences across knowledge sources. This presents an important advantage over the traditional measurement, as the importance of external knowledge depends heavily on the source. Percentiles are calculated by external knowledge source and year. The 90th percentile serves as the cut-off for deep search[13]. The value of 1 is attributed to all external knowledge sources a firm considers to be of equal or greater importance than this cut-off for deep search. The value 0 is attributed to all other external knowledge sources. The binary variables are then added up across the 14 external knowledge sources represented in the survey. Table D1 shows the descriptive statistics of the alternative measure for external knowledge search depth (*Rel_depth*) in comparison to the traditional measure (*Depth*).

[13] As an alternative to the measure using a cut-off that is equal or greater than the 90th percentile, we constructed a similar measure using a cut-off that is strictly greater than the 75th percentile and performed the same robustness checks. The results are similar.

Table D1 Descriptive statistics (N = 1,258)

Variable	Mean	SD	Min	Max
Depth (t)	2.68	2.45	0	11
Rel_depth (t)	3.34	2.64	0	12

With the alternative measure *Rel_depth* we estimate the models to test hypotheses 1 and 2 again (Table D2). Starting with the results of Model I and Model II, which serve as a robustness check for hypothesis 1, we see great similarities to the main models, displayed in Table 14. There is no indication of a direct relationship between any of the external knowledge search variables and innovation performance. The lagged interaction of external knowledge search depth and IT investment (*Rel_depth X IT Invest (t-1)*), however, has an effect on innovation performance (Model II: $\beta_{t-1} = 0.078$, $p = 0.065$). Both the coefficient size and the statistical significance are somewhat reduced and do not quite reach the level of the main results (Table 14). Turning to the split sample regressions, APP3 through APP6, we observe a similar pattern as in the main models (Table 15) again. The effect of *Rel_depth X IT Invest (t-1)* is contingent on the level of imitation concerns and only appears for the split sample with low concerns (Model III: $\beta_{t-1} = 0.084$, $p = 0.044$ vs. Model IV: $\beta_{t-1} = 0.012$, $p = 0.755$). The same effect cannot be observed for the split on the effectiveness of protection mechanisms (Model V and Model VI). We still believe that these results indicate that the estimation results of our main models are robust, despite the discontinuity in the measurement of *Depth*. With the alternative measure *Rel_depth*, we propose a measurement of external knowledge search depth that remedies some of the caveats of the traditional measure.

Table D2 System GMM estimation

	Model I	Model II	Model III	Model IV	Model V	Model VI
			imitation		effectiveness	
			low	high	low	high
	Inno (t)	Inno (t)	Inno (t)	Inno (t)	Inno (t)	Inno (t)
Inno (t-1)	0.192**	0.201***	0.080	0.177	0.138	0.098
	(0.076)	(0.074)	(0.073)	(0.12)	(0.124)	(0.103)
Rel_depth (t)	-0.004	-0.013	-0.007	-0.030	0.020	-0.018
	(0.024)	(0.023)	(0.028)	(0.026)	(0.028)	(0.03)
Rel_depth (t-1)	0.003	0.000	-0.036	0.050*	-0.009	-0.043
	(0.029)	(0.03)	(0.024)	(0.029)	(0.021)	(0.034)
Rel_depth ^{2} (t)	0.001	0.002	0.002	0.004	-0.002	0.003
	(0.002)	(0.002)	(0.003)	(0.002)	(0.003)	(0.003)
Rel_depth ^{2} (t-1)	-0.002	-0.002	0.001	-0.005**	0.001	0.002
	(0.003)	(0.003)	(0.002)	(0.002)	(0.002)	(0.003)
Breadth (t)	0.009	0.009	0.005	0.014	0.009	0.015
	(0.008)	(0.008)	(0.009)	(0.009)	(0.007)	(0.013)
Breadth (t-1)	0.004	0.004	-0.004	0.002	0.019*	0.009
	(0.009)	(0.009)	(0.008)	(0.011)	(0.011)	(0.012)
IT Invest (t)	-0.010	-0.040	-0.226	-0.074	-0.129	0.305
	(0.148)	(0.21)	(0.221)	(0.226)	(0.157)	(0.373)
IT Invest (t-1)	-0.007	-0.388*	-0.265	0.008	0.056	-0.314
	(0.14)	(0.224)	(0.221)	(0.247)	(0.173)	(0.284)
Rel_depth X IT Invest (t)		0.004	0.030	0.019	0.022	-0.035
		(0.037)	(0.062)	(0.037)	(0.039)	(0.061)
Rel_depth X IT Invest (t-1)		0.078*	0.084**	0.012	-0.008	0.070
		(0.042)	(0.042)	(0.039)	(0.032)	(0.05)
RD Input (t)	0.015***	0.015***	0.024***	0.009**	0.008**	0.011*
	(0.005)	(0.005)	(0.005)	(0.004)	(0.004)	(0.006)
RD Input (t-1)	0.008*	0.007	0.002	0.003	0.009**	-0.001
	(0.004)	(0.004)	(0.005)	(0.005)	(0.005)	(0.006)
HC Education (t)	-0.126	-0.086	-0.133	0.332	-0.337	-0.482
	(0.168)	(0.156)	(0.164)	(0.297)	(0.332)	(0.373)
Size (t)	-0.015	-0.001	-0.028	-0.025	-0.003	-0.006
	(0.04)	(0.035)	(0.033)	(0.038)	(0.053)	(0.048)
Export Share (t)	0.018	0.009	0.024	-0.043	0.153	-0.024
	(0.094)	(0.086)	(0.087)	(0.125)	(0.114)	(0.14)
Constant	0.180	0.120	0.931	-0.018	-0.994	0.770
	(0.26)	(0.236)	(0.824)	(0.488)	(0.803)	(1.009)
Year dummies	[yes]	[yes]	[yes]	[yes]	[yes]	[yes]
Industry dummies	[yes]	[yes]	[yes]	[yes]	[yes]	[yes]
N	1,258	1,258	733	525	544	495
Chi squared	108.2	130.1	194.5	84.5	100.0	90.9
AR(1) Test: Z =	-3.40***	-3.33***	-2.25**	-2.15**	-2.01**	-2.51**
AR(2) Test: Z =	0.47	0.52	-1.43	-1.77*	-0.40	0.55
Sargan test: p =	0.95	0.97	0.84	1.00	0.93	0.95

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Appendix E – Evidence for an inverted U-shape

In this appendix, we address the direct relationship between openness in innovation and innovation performance. Our main results (Table 14), using dynamic panel estimation, do not provide any evidence for such a direct link. The results of the robustness check presented in Table 17, using random- and fixed-effects estimation, however, do. The major differences between the main model and the model used in the robustness check are, first, the inclusion of the lagged dependent variable as an explanatory variable and, second, the instrumentation of the main explanatory variables. To reconcile the discrepancy in the results, we briefly review the evidence from previous research and perform a series of robustness checks, including one using the alternative measure for external knowledge search depth (*Rel_depth*), introduced in Appendix D.

The shape of the direct relationship between openness in innovation and innovation performance has been subject of intensive research. Many studies find that this relationship has an inverted U-shape (Garriga et al., 2013; Grimpe & Kaiser, 2010; Laursen & Salter, 2006; Leiponen & Helfat, 2010; Wadhwa et al., 2017). This shape has been found for different measures of openness, with the evidence being more substantive for some measures, such as external knowledge search breadth and the share of extramural R&D (Gómez et al., 2020; Laursen & Salter, 2006; Wadhwa et al., 2017), than it is for others, such as external knowledge search depth (Laursen & Salter, 2006; Leiponen & Helfat, 2010). Focusing on the latter measure, external knowledge search depth, it is thus not entirely surprising to find inconclusive results, as we do.

To identify possible causes of the discrepancy in the results of the dynamic panel estimation (no inverted U-shape) and the random- or fixed-effects estimation (inverted U-shape), we estimate a series of alternative models. First, to understand better the factors that influence the appearance or non-appearance of the inverted U-shape, we run models with a reduced control vector using different estimation procedures; pooled OLS regression, random-effects as well as fixed-effects regressions. Second, we try to identify alternative explanations to the choice of control vector and estimation procedure. It seems possible that a driver of the appearance of an inverted U-shaped relationship between openness in innovation and innovation performance is the discontinuous measurement of *Depth* (see Appendix D). Changes in the distribution of the variable *Depth* over time might introduce patterns in the data that influence estimation results. In this case, the instrumentation of the variable *Depth* performed as part of the system GMM estimation might explain some of the discrepancy with the results from the random- or fixed-effects estimation, as the instrumentation may dampen the effects of a discontinuity in the measurement of *Depth*. To identify whether the discontinuous measurement of *Depth* influences the appearance of an inverted U-shape, we estimate the model for the time period of the earlier measurement (pre-2015) and for the time period of the later measurement (post-2015) separately. As an additional test, we replicate the models using the alternative measure for external knowledge search depth introduced in Appendix A, *Rel_depth*, which does not suffer from the discontinuity in measurement.

Table E1 shows the results of the simplified model, without lagged variables, using pooled OLS (POLS), random-effects (RE), and fixed-effects (FE) estimations. The results of the random- and fixed-effects estimations show an inverted U-shaped relationship between *Depth* and innovation performance, with statistically significant linear (*Depth*; RE: $\beta_t = 0.019$, $p = 0.006$) and squared terms ($Depth^2$; RE: $\beta_t = -0.002$, $p = 0.020$). Using the random-effects estimation as an example, both branches of the inverted U-shape are statistically significant ($p = 0.028$) and the extremum of the inverted U-shape corresponds to 5.5 external knowledge sources, slightly below the 90^{th} percentile. The results of the POLS estimation are less consistent with statistically significant effects being restricted to the model without control variables. When we turn to the results of the estimation using a split between the earlier survey waves (2005 to 2011) and the later survey waves (2015 to 2019) (‘FE – pre-2015’ and ‘FE – post-2015’), the evidence supporting the inverted U-shape fully disappears. This provides an indication that the discontinuity in the measurement of *Depth* might drive the appearance of an inverted U-shape, as we examine next.

Table E1 Inverted U-shape; *Depth*

	POLS – no controls Inno (t)	POLS – w/ controls Inno (t)	RE Inno (t)	FE Inno (t)	FE – pre-2015 Inno (t)	FE – post-2015 Inno (t)
Depth (t)	0.023***	0.015*	0.019***	0.022**	-0.020	0.016
	(0.008)	(0.008)	(0.007)	(0.009)	(0.017)	(0.019)
Depth² (t)	-0.002*	-0.001	-0.002**	-0.002**	0.000	0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)	(0.003)
Breadth (t)		-0.003	-0.001	0.003	0.007	0.007
		(0.002)	(0.002)	(0.004)	(0.007)	(0.006)
IT Invest (t)		0.104**	0.071	-0.083	-0.077	-0.074
		(0.05)	(0.048)	(0.066)	(0.155)	(0.097)
RD Input (t)		0.018***	0.016***	0.012***	0.016***	0.013***
		(0.001)	(0.001)	(0.002)	(0.005)	(0.003)
HC Education (t)		-0.023	-0.030	-0.111	-0.387	-0.160
		(0.08)	(0.079)	(0.182)	(0.537)	(0.248)
Size (t)		-0.012**	-0.013**	0.055	0.183**	0.024
		(0.006)	(0.006)	(0.04)	(0.09)	(0.055)
Export Share (t)		0.014	0.027	0.104	0.131	0.062
		(0.023)	(0.023)	(0.079)	(0.18)	(0.123)
Constant	0.217***	0.100**	0.002	-0.222	-0.715*	-0.129
	(0.058)	(0.042)	(0.039)	(0.193)	(0.413)	(0.278)
Year dummies	[yes]	[yes]	[yes]	[yes]	[yes]	[yes]
Industry dummies	[yes]	[yes]	[yes]	[yes]	[yes]	[yes]
N	1,258	1,258	1,258	1,258	625	633
Adj. R-squared	0.140	0.316		0.130	0.174	0.140

* p < 0.1; ** p < 0.05; *** p < 0.01

When we replace *Depth* (discontinuous measurement) with *Rel_depth* (continuous measurement), the evidence for an inverted U-shape becomes scanter (Table E2). Only the results of the pooled OLS estimation show statistically significant linear (*Rel_depth*; POLS – no controls: $\beta_t = 0.022$, $p = 0.004$) and squared terms (*Rel_depth²*; POLS – no controls: $\beta_t = -0.002$, $p = 0.041$)[14]. Estimations that control for more sources of heterogeneity (RE or FE) render no evidence to indicate the existence of any direct link between external knowledge search depth (*Rel_depth*) and innovation performance.

[14] In an additional robustness check to test the appearance of an inverted U-shape, we regress two dummies on the dependent variable only: one dummy for all observations below the 50th percentile of *Rel_depth* and one for all observations above the 90th percentile of *Rel_depth*. If there is an inverted U-shape, the coefficients of both dummies should have a negative sign. Both dummies do have negative signs, only the coefficient of the first dummy is statistically significant, however. This result is in line with the scant evidence for the inverted U-shape.

In summary, there is some rudimentary evidence for an inverted U-shaped relationship between external knowledge search depth and innovation performance. The more sources of heterogeneity we control for, the sparser the evidence becomes. In addition, the discontinuous measurement of external knowledge search depth in our data seems to drive the appearance of an inverted U-shape. Should there exist an optimum of external knowledge search depth beyond which the marginal returns of more openness are negative, it would be located at the upper end of the observed data range. If over-search in terms of external knowledge search depth exists, it seems to be rare.

Table E2 Inverted U-shape; *Rel_depth*

	POLS – no controls Inno (t)	POLS – w/ controls Inno (t)	RE Inno (t)	FE Inno (t)	FE – pre-2015 Inno (t)	FE – post-2015 Inno (t)
Depth (t)	0.022***	0.014*	0.012	-0.002	-0.040**	-0.006
	(0.007)	(0.008)	(0.007)	(0.01)	(0.016)	(0.018)
$Depth^2$ (t)	-0.002**	-0.001*	-0.001	0.000	0.002	0.002
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)
Breadth (t)		-0.003	-0.001	0.004	0.012*	0.008
		(0.003)	(0.003)	(0.004)	(0.007)	(0.006)
IT Invest (t)		0.104**	0.070	-0.084	-0.079	-0.085
		(0.05)	(0.048)	(0.066)	(0.151)	(0.099)
RD Input (t)		0.018***	0.016***	0.012***	0.015***	0.012***
		(0.001)	(0.001)	(0.002)	(0.005)	(0.003)
HC Education (t)		-0.023	-0.031	-0.103	-0.488	-0.158
		(0.08)	(0.08)	(0.189)	(0.532)	(0.258)
Size (t)		-0.012**	-0.013**	0.059	0.202**	0.025
		(0.006)	(0.006)	(0.041)	(0.083)	(0.056)
Export Share (t)		0.013	0.026	0.101	0.125	0.060
		(0.022)	(0.023)	(0.081)	(0.178)	(0.13)
Constant	0.202***	0.076	-0.001	-0.229	-0.796**	-0.113
	(0.058)	(0.061)	(0.04)	(0.197)	(0.384)	(0.278)
Year dummies	[yes]	[yes]	[yes]	[yes]	[yes]	[yes]
Industry dummies	[yes]	[yes]	[yes]	[yes]	[yes]	[yes]
N	1,258	1,258	1,258	1,258	625	633
Adj. R-squared	0.140	0.316		0.123	0.197	0.117

* p < 0.1; ** p < 0.05; *** p < 0.01

Appendix F – Descriptive statistics of the full sample

Table F1 shows the descriptive statistics of the non-transformed variables for the full sample, without the restriction of requiring observations from two consecutive waves to be included.

Table F1 Descriptive statistics (N = 3,413)

Variable	Mean	SD	Min	Max
Inno	0.21	0.25	0	1
# of Knowledge Sources – Deep Search	2.73	2.45	0	13
# of Knowledge Sources	10.11	3.20	0	14
IT Invest	0.14	0.16	0	1
RD Expenditures in '000	2,513.70	40,405.02	0	2,166,667
HC Education	0.07	0.10	0	1
# Employees	171.76	554.96	1	21000
Export Share	0.39	0.38	0	1

Appendix G – VIF of the variables included in the models

Table G1 shows the VIF of the set of variables included in the models.

Table G1 Variance inflation factors (VIF)

Variable	VIF	Variable	VIF
Depth (t)	10.1	*Depth X IT Invest (t)*	3.8
Depth (t-1)	10.0	*Depth X IT Invest (t-1)*	4.1
Depth^2 (t)	8.5	*RD Input (t)*	2.1
Depth^2 (t-1)	8.6	*RD Input (t-1)*	2.1
Breadth (t)	1.7	*HC Education (t)*	1.3
Breadth (t-1)	1.7	*Size (t)*	1.4
IT Invest (t)	2.7	*Export Share (t)*	1.4
IT Invest (t-1)	2.9		

Appendix H – Interview guide

1. **Introductory questions**
   a. What is your current position and how are you involved in blockchain projects?
   b. How did this involvement start?
2. **The [APPL-X][15]**
   a. Application: What obstacles does it address in current processes/workflows? What do the processes/workflows look like when the application is implemented?
   b. Membership: Could you give an overview of the different types of members of [APPL-X]?
   c. Technology: Checklist technical properties (Private/public network, consensus mechanism, kind of data, access to data/privacy)
3. **Governance structures**
   a. Governance: Please elaborate on your understanding of the term ‘governance’ in the context of blockchain applications?
   b. Governance structures: Could you describe the governance of [APPL-X]?
      a. Are there different types of participating organizations? How do they each contribute?
      b. Let’s imagine that one or a group of members wants to add or change a functionality of the application. How would the process leading from proposing the change to its actual implementation look like?
   c. Governance over time: Could you quickly describe how the governance emerged? Has it changed over time?
   d. [in case of changes] What was the reason for this change?
4. **Becoming a member and operation of [APPL-X]**

[15] [APPL-X] is a placeholder for the name of the application (e.g., Global Shipping Business Network (GSBN)

a. Rollout: How did [APPL-X] ensure the successful rollout of the blockchain application?
b. Operation: How does [APPL-X] ensure the blockchain application is operated so that it achieves its goals and objectives?
c. On the choice to join [APPL-X]: why did [EMPLOYER OF INFORMANT] decide to join the [APPL-X]?
d. Allocation of benefits: Since joining, have you experienced any negative aspects of being part of [APPL-X]? Do you think other members experience the same/different kind of disadvantages?

5. Outlook

a. What is the way forward in [APPL-X]?
b. Do you expect the joint work in [APPL-X] to change over time?
c. Are you planning to fully integrate the application into [EMPLOYER OF INFORMANT] core processes, or will it run separately?

Appendix J – Case summaries

Case Summary – Appl-1

Appl-1 was founded in 2019 and is live. It develops an application to provide end-to-end tracking and tracing of finished vehicle shipments, as well as a load capacity management to optimize the utilization of logistics fleets. Appl-1 addresses the lack of holistic, real-time information along the supply chain of finished vehicles due to siloed, paper-based processes and low degree of digitization of logistics service providers in the space. The current members include several logistics services providers and a provider of financial services. Users of the solution include both OEMs and sellers.

Appl-1 uses a permissioned blockchain. Only references to the hashed data are shared on the blockchain. Users keep ownership of the data, as the data remains stored in the users' own data centers. Only the intended recipients of the data can decrypt it. A platform on top of the blockchain network allows for development of functionalities that use the shared data.

Appl-1 is incorporated as two separate legal entities, one owning the IP and one for the exploitation of the platform. A dedicated team manages both. The founding firms jointly own both entities. Membership is possible without a financial stake, and, hence, without any claim to a share of the revenues of the platform. Appl-1 works closely with a technology partner which is a collaborator but has no ownership.

> [W]e have the IP company who owns the IP of the platform – and that's where all the shareholders are in right now – and the operational company for the exploitation of the platform. And if a new party comes in with a new functionality, which will enrich the platform, then we are willing to offer them shares in the exploitation company, but not in the IP company. [Advisor, Appl-1]

A board serves as the main decision-making body with representatives from the shareholders and Appl-1's management team. Votes are linked to ownership shares; unanimous decisions have been the norm. Working groups focus on specific topics to devise desired functionalities and prepare the decisions to be made in the board. The working groups are open for any member firm to send their experts to.

The management team aims to reduce its dependence on member firms to make certain decisions more freely. While decisions on functionalities benefit from member involvement, decisions on monetization may become the exclusive responsibility of the management team. This will enable them to better reflect market realities and react to changes in the environment with greater speed and flexibility.

> [T]he company is already independent from the shareholders in such a way that they don't have that much influence on it. The only influence that they have is they bring in the investment capital at the moment. And it's always

> like that: the one who pays wants to decide as well. But that's something what should become less and less and less. [Advisor, Appl-1]

Case Summary – Appl-2

Appl-2 was founded in 2017 by a group of banks. Current members include more than a dozen European banks and a technology provider. The application is live today with more than 500 firms using it. It develops a supply chain finance application targeted at SMEs. Trade finance as an industry remains largely paper-based, which means information is siloed and processes are inefficient. Digital and standardized trade execution would contribute to efficiency gains.

Appl-2 uses a permissioned blockchain. Banks license the application to offer it to their customers through their own platforms. The licensing is regulated by a rulebook that each member firm agrees to before joining Appl-2.

> And that rulebook is the legal and regulatory basis on which the trades occur on our platform […] and it is the same exact rulebook for every member organization. [Executive, Appl-2]

The legal entity of Appl-2 is owned by the majority of member banks. It features a dedicated management team and a board. All members with a share in Appl-2 above a certain threshold are entitled to a seat in the board. The board is the main decision-making body; the management team aims to build a consensus among board members before decisions are taken. Regular meetings among member firms and the management team allow member firms to provide input on strategic questions. Several working groups focus on specific topics on technology, development, and marketing. They are staffed by experts from member firms.

From the outset, Appl-2 chose to share control among founding members. A dedicated legal entity with a management team was only created later in the development process. Over time and with the support of member firms, the management team has taken over more responsibility to make certain decisions more freely. The reasoning is that the management team is closer to the actual application and should be able to make swift decisions.

> So, how this has evolved is that the [Appl-2] organization of the people working there has taken a more firm grip […] and only asked for input on timing issues and priorities of initiatives that are coming up, and I really welcome that I don't need to have a say in all questions. [Product manager at member firm, Appl-2]

Case Summary – Appl-3

Appl-3 was founded in 2019 by a group of entrepreneurs with several member firms currently industrializing the application. The focus lies on creating digital identities of products on the blockchain for the luxury fashion industry across a variety of uses. It now numbers more than 25 members, including luxury brands and technical partners, which use the protocol to offer their services to other member firms.

> And so, what we do is really a protocol that creates the digital passports for products, on the blockchain. And those digital passports for valuable products ensure you can fulfil three basic needs. It's a proof of authenticity, meaning that it proves that you actually have a real product. And it's a proof of ownership. It proves that you're the actual owner of that real product, that authentic product. And third, it's a way to actually record information on events. [Executive, Appl-3]

The blockchain protocol is open source and the access to the blockchain is public. Only an encrypted reference to the shared data is stored on the blockchain. The actual data is kept on decentral servers. The technical partners provide functionalities with the data on the platform. Members pay a membership fee based on their size.

In Appl-3, ownership and membership are distinct. The founders secured funding through an ICO; they remain the sole owners of the service platform used in the application. Firms join a non-profit organization as members but do not become shareholders. They instead buy tokens, which are a means to conduct transactions on the blockchain protocol. Having tokens instead of shares incentivizes the token owners to develop the network because tokens can only be spent there.

The founders make up the management team, responsible for the protocol and network growth. As governance bodies, Appl-3 has a board and a general assembly. The board consists of a pre-selected group of large industry players that have a reserved seat upon joining Appl-3 and, additionally, representatives that are elected by the general assembly. In the general assembly, all members have equal votes. Working groups, consisting of experts from the member firms, address technological and commercial aspects of application development.

Initially, the founding team had vast authority. This has since changed; in a formalized step-by-step process, the founders relinquish their decision-making monopoly to the member firms by strengthening the formal governance bodies – the board and the general assembly.

> So, at the beginning, when we founded the association a year ago, we were the sole master on board. And little by little and that started with the first general assembly of the association, we started letting go some of power to the [member firms]. [Executive, Appl-3]

With these changes, the founders of Appl-3 aim for an organization with more shared power and decentralized decision-making. Getting member firms to take on the responsibility and make them become more active in continuing to develop the application is challenging.

Case Summary – Appl-4

Appl-4 was founded in 2019 by a technology provider and a blockchain consultancy. By now, the network has over 20 members from a variety of industries, such as electronics, fast-moving consumer goods, pharma, financial, and telecom. Appl-4 develops a blockchain-based supplier information management tool that improves supplier selection, validation, onboarding, and lifecycle management. Suppliers make the documents and information required for standard onboarding processes available on the platform offering buyers a central database to navigate the supplier space. Several member firms integrated the application into their live workflows. Among the member firms are third-party providers of services, such as auditing and validation, which they offer on the platform.

The blockchain network is permissioned. The blockchain consultancy handles operations of the network while the technology provider hosts the solution on its cloud. Sensitive data is stored off-chain; only a digital passport – a summary of the information provided – is stored on the blockchain. Except for firms that joined at the outset, all members pay a fee.

As main owners, the blockchain consultancy and technology provider are most active in managing and expanding the network, providing a dedicated management team. The board of Appl-4 is made up of representatives from member firms in different industries. The selection of firms to send representatives to the board lies with the management of Appl-4. This selection is aimed to include industry 'thought leaders' that have the standing in their respective industries to attract other firms to join. The board determines the overarching project strategy.

> So, essentially the business participants or the organizations which are the members of [the board] have got a say in terms of determining the top-class features that they want as part of this product […]. And then they also decide the direction of the whole product. [Analyst, Appl-4]

Despite the decision-making power lying in the hands of the board, the blockchain consultancy can weigh in on decisions. A general assembly consisting of all member firms coordinates the engagement of member firms in the application development, which is carried out by working groups.

Case Summary – Appl-5

Appl-5 was founded as the result of a series of research projects unrelated to blockchain in 2018 by a logistics company and a technology provider. The platform is live today. Currently, the ecosystem created by Appl-5 is just short of 200 members, which include ocean carriers, cargo owners, 3PL providers, freight forwarders, customs agencies, ports and terminals, and financial institutions, among others. The application aims to address multiple inefficiencies along the information flows of the global shipping industry that suffers from siloed information ecosystems. Appl-5 offers a platform for document sharing. Sharing such documents digitally would digitize work processes that are currently paper-based and lay the groundwork for the automation of repetitive tasks. In addition, having all parties engaged in the shipping of goods coordinate on the same platform would help accelerate processes and reduce errors (e.g., at customs).

The blockchain is permissioned. On top of the blockchain layer is a marketplace for member firms or third-party developers to provide functionalities that use the shared data. If member firms first build functionalities with the shared data for internal use, they can later still share and monetize them using the marketplace. Functionality development is thus driven simultaneously by many parties.

The two founding firms own majorities of the legal entities that develop and operate the application. In the first years of Appl-5's existence, non-owner member firms were not involved in any formal governance bodies and most of their engagement was directly with representatives from the legal entities owned by the founders.

> If there is a client coming tomorrow and saying, 'Yeah, but I need this and this and this and this', then they will absolutely look into it to see whether there are amendments possible to satisfy the client, but also to improve the product. [Executive at member firm, Appl-5]

Appl-5 was scrutinized for aiming to grow its network without decentralizing control. Concerns were raised that the looming dependency would deter firms from joining an application that is owned and controlled by a big industry player and competitor. Despite this, the network of firms associated with Appl-5 has grown considerably. Recently, there have been moves towards decentralizing control somewhat with the establishment of a board with representatives from a cross-section of member firms to channel their common interests. Another governance body will comprise all major competitors in one echelon of the value chain in global container logistics.

> For the [firms], we have a consortium, […]. It’s kind of a bigger group of all different big [firms] within this industry. […] I think we have all top seven worldwide [firms] which will be onboarded within this group, within this association. [Product manager, Appl-5]

In the future, functionality development should take place freely in the marketplace, while the Appl-5 organization focuses on network development.

Curriculum Vitae

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Publications

Naef, S., Wagner, S. M., Saur C. (2022). Blockchain and network governance: learning from applications in the supply chain sector. *Production Planning and Control.* Advance online publication.