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Profiting from innovation when digital business ecosystems emerge: A control point perspective

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ABSTRACT

The digital transformation of industrial-age sectors changes product architectures and industry architectures, influencing how value is created and captured in emerging digital business ecosystems. In the industrial era, products were designed around modular architectures and complementary assets, and bottlenecks determined who profits from innovation. In the digital era, products emerge on a layered modular architecture, and profiting from innovation is shifting to those who own control points. Despite the centrality of the interplay between the product architecture and industry architecture for value creation and value capture in the digital age, the effects on competitiveness and industry dynamics remain unclear. To fill this void, we draw on the concept of control points, a novel lens to reflect bargaining positions on a layered modular architecture in digital business ecosystems. Based on a case study of 19 companies, industry associations, and consulting firms in the digital business ecosystem of smart farming, we identify strategic control points, technical control points, generic control points, and institutional boundaries as instrumental in determining value creation and value capture positions. We find that actors (i.e., incumbents, diversifying entrants, and new entrants) in emerging digital business ecosystems follow a seesaw pattern in setting control points and acquiring bargaining positions, and propose a framework that allows to analyze the dynamics within digital business ecosystems. Our study offers managerial implications for firms seeking to optimize their ecosystem strategy and policy makers to support the effective development of the institutional context.

1. Introduction

The digital transformation of industrial-age sectors, such as in the transformation from traditional agriculture to smart farming (Tilson et al., 2010), has brought about a shift of *product architectures* (Henderson and Clark, 1990) and *industry architectures* (Jacobides et al., 2006) influencing how value is created and captured (Pisano and Teece, 2007; Teece, 2018). In the industrial era, products were designed around modular architectures, offered in a single value proposition, and profiting from innovation (PFI) originated from possessing complementary assets (e.g., distribution channels or specialized manufacturing) or controlling bottlenecks (e.g., a unique solutions to a technical problem) (Baldwin, 2015; Teece, 1986, 2006, 2018). In the digital age, products are built on a stack of technologies, the so-called layered modular architecture (Yoo et al., 2010), they are part of a broader ecosystem value proposition (Talmar et al., 2020), and PFI is increasingly shifting to those who *control* relevant *points* in the digital business ecosystem, such as customer access, content ownership, or digital infrastructure (Hanelt et al., 2021; Pagani, 2013).

The transformation of product and industry architectures is driven by the nature of digital technologies. They are reprogrammable, homogeneous, and self-referential (Yoo et al., 2010) which results in modularity, convergence, and generativity, thereby gradually altering the mechanisms and dynamics of control. Modularity, the ease of interconnecting components (as evidenced by the Internet of Things or in ‘stacks’ of software solutions), reduces the effectiveness of bottlenecks since technological solutions can be replaced more swiftly. Convergence, that is the confluence of different technology systems (Wambsganns et al., 2023), decreases the value of specialized complementary assets (e.g., a sales force) as distribution channels are being incorporated

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into digital services and systems of systems (Porter and Heppelmann, 2014). Finally, generativity enables rapid and uncontrolled developments in a digital business ecosystem, even without the original players' involvement[1] (Hanelt et al., 2021; Tilson et al., 2010), eventually leading to autonomous systems (Porter and Heppelmann, 2014).

As a result, digital technologies are changing product and industry architectures, requiring new knowledge at the *product architectural* level – i.e., understanding of how digital and analog technology (or product) features function and how they interact in the digital system of systems to create value (think artificial intelligence plus a smart speaker) (Baldwin and Clark, 2000; Henderson and Clark, 1990) – and at the *industry architectural* level – i.e., how economic transactions are structured via novel digital business models and how value capture is shared among firms in digital business ecosystems (Jacobides et al., 2006; Jacobides et al., 2016).

Particularly for industries in transition, for instance from traditional farming to smart farming, firms, including incumbents, diversifying entrants and new entrants, need to find ways to balance the transition from the 'analog way' of doing business to the 'digital way' as they are coming from different 'going-in' positions (Bohnsack et al., 2021). Incumbents, who are said to have "dominance by birth right" (cf. Klepper and Simons, 2005), have traditional (physical product centered) industry knowledge and control strategic points such as the market-customer link (Tripsas, 1997). Yet, such firms lack knowledge about the functionality, application and appropriability of digital technologies, and are hampered by their path dependent behavior (Bohnsack et al., 2014; Bohnsack et al., 2021). New entrants, such as start-ups, on the other hand, have component knowledge of digital technologies, control unique solutions, and understand value capture with digital business models, yet lack an understanding of how the industry works. Finally, diversifying entrants, have knowledge of adjacent industries and semi-relevant component knowledge and seek to capitalize on them in the newly entered industry. As a result, PFI in emerging digital business ecosystems becomes a) increasingly reliant on controlling points of value creation and capture in digital business ecosystems (Hanelt et al., 2021), and b) more fluid as it is moderated by ever-changing component and industry knowledge.

To advance theorizing on how different actors can profit from innovation during the emergence of digital business ecosystems, we adopt a control points perspective. Control points, which are positioned between layers on the *layered modular architecture* (Yoo et al., 2010), bridging hierarchically arranged components of physical products with modules of digital functionality (Hylving and Schultze, 2020), are more resistant to changes in digital business ecosystems. In other words, they are less affected by the nature of digital technologies and thus provide an appropriate lens for understanding the co-evolution of both: the changing product and industry architecture (Jacobides et al., 2006) and the value creation and capture mechanisms that explain how to profit from innovation (Teece, 2018).

Past research on control in digital business ecosystems has shed light on governance aspects, such as how firms control "what is allowed and what is not" (Eaton et al., 2015, p. 220), the role of control points in the digitizing of product platforms (Sandberg et al., 2020), or the degree of required openness to ensure generativity while keeping control (Ondrus et al., 2015; Wareham et al., 2014). In addition, scholars have studied how control points influence value creation and value capture. For instance, Pagani (2013) studied how control points in value networks dynamically change over time and enable superior profits, van Dyck et al. (2021) have studied how firms use control points for positioning in industrial emerging ecosystems, and Dattée et al. (2018) explored how firms anticipate future value creation and set control points under uncertainty. However, the interplay between the product and industry perspective in light of digital transformation is less clear, despite the fact that "there is a strong connection between the architecture of the industry and architecture of physical products and technologies" (Pisano and Teece, 2007, p. 283). Thus, to understand value creation and value capture in digital business ecosystems, we need to study both perspectives simultaneously.

The transition from industrial-age industry architectures to digital business ecosystems thus changes which resources are valuable to profit from innovation. Whereas traditionally *strategic* control points were determining value capture potential (e.g., complementary assets such as a sales force), increasingly *technical* control points (e.g., owning customer data) in combination with strategic control points influence who profits from innovation. Therefore, the question arises: *How do firms in emerging digital business ecosystems set control points to create and capture value*?

To answer this question, we conduct a single-case study in an embedded design with multiple actors from the agriculture industry that are affected by an emerging digital business ecosystem of smart farming. We draw upon this case study as a rich empirical research site as this is a case where digital technologies – driven by an increasing world population and the need for a more sustainable farming system – is expected to evoke tremendous changes of incumbents' business models in the future (Dörr and Nachtmann, 2022). Furthermore, the digital business ecosystem of smart farming is currently gaining considerable interest from global technology and software companies (i.e., diversifying entrants) and an increasing number of AgTech start-ups (Moretti et al., 2023; Rennings et al., 2022).

Our study finds that control points come in two types: technical and strategic, enabled by generic control points and shaped by institutional boundary conditions. We also show that different actor groups (i.e., incumbents, diversifying entrants, and new entrants) in the digital business ecosystem follow different strategies of creating and capturing value and in setting control points. Finally, we unravel the evolution and interplay between industry knowledge as well as component knowledge in this process.

In doing so, this study contributes to the extant literature in three ways. First, we shed light on the concept of control points as a lens to understand PFI in the digital age, distinguishing them from bottlenecks and complementary assets in the industrial age. Second, we unravel the importance of gaining industry knowledge and component knowledge in setting control points and influencing bargaining power. Finally, our framework illustrates unique dynamics of actors in the transition to digital business ecosystems and allows to explain and potentially predict the actions of incumbents, diversifying entrants, and new entrants.

2. Theoretical background

2.1. Digitalization of product and industry architectures

Value creation and value capture require "an understanding of the technical [or product] architecture of the system; [and] an understanding of the industry architecture in which the technical system is embedded" (Baldwin, 2015, p. 1). The literature on product architecture is firm-centric and concerned about how innovations in products are changing competitive positions of firms (Henderson and Clark, 1990), while the stream of literature on industry architecture examines the structure and relationships between actors (Jacobides et al., 2006; Pisano and Teece, 2007). With the rise of digital technologies, both, product and industry architectures are changing (Tilson et al., 2010) and becoming more intertwined (Hanelt et al., 2021).

On the one hand, digital technologies digitize[2] modular *product architectures* of industrial-age products to digital-age layered modular

[1] An example of this would be a tractor manufacturer permitting an app store provider to handle the apps in the tractor, possibly relinquishing control over which apps are available in the tractor's app store.

[2] Digitize refers to converting so far physical artefacts into a digital form.

architectures (Yoo et al., 2010). For instance, physical light bulbs through digitization become part of a smart home system, including light sensors, Wi-Fi connectivity devices, data analytics, and digital applications that allow services, such as remote control (see example A and Fig. A1 in the Appendix). This process renders product architectures more fluid (e.g., due to the inherent modularity), lowers entry barriers (e.g., due to the provision of APIs), and decreases the heterogeneity of value propositions, converging to an ecosystem value proposition (in the light bulb example from separate value propositions to a smart home solution) (Talmar et al., 2020). This transition requires organizations to acquire *component knowledge*, that is to learn about component functions as well as learn about component interactions in a system (Sanchez and Mahoney, 1996; Wambsganns et al., 2023). As "the digitization of products presents new opportunities for innovation" (Henfridsson et al., 2014, p. 2), the integration of digital technologies also allows to leave existing pathways of path dependent behavior and gradually creates new capabilities (Bohnsack et al., 2021).

On the other hand, digital technologies digitalize[3] *industry architectures* from (linear) value networks and business ecosystems (Adner and Kapoor, 2010) into digital business ecosystems (Hanelt et al., 2021). In industrial-age settings, companies were – in accordance with the underlying modular product architecture – organized in market-based and hierarchy-based value systems (Jacobides et al., 2018a), or in business ecosystems with coordinated interdependencies (Adner and Kapoor, 2010).[4] The digitalization of the product architecture – i.e., towards the emerging layered modular architecture – is also changing business ecosystems, turning them into *digital business ecosystems*. Digital business ecosystems are characterized by vast and heterogenous number of participants, a turbulent nature, increasing number of competitors from separate industries with different business models, leading to a convergence of industries (Bröring et al., 2006) and constantly changing customer preferences (Hanelt et al., 2021). What is more, digital business ecosystems, a concept originating from Information Systems literature, describe "a sociotechnical network of individuals, organisations and technologies that collectively co-create value" (Senyo et al., 2019, p. 52). Thus, the digital business ecosystem goes beyond the established business ecosystem lens in management as it incorporates technologies being part of value creation in an ecosystem. The change from business ecosystems to digital business ecosystems requires constant technology-enabled learning not only about the (evolving) product architecture (i.e., *component knowledge*),[5] but also about the (evolving) industry architecture (i.e., *industry knowledge*)[6] (Andersson et al., 2008). This includes awareness of capabilities of technologies, sensitivity to use contexts, understanding of suitable business models, and competencies for boundary-spanning activities, such as the "activity of generating a value path by connecting digital resources as a value offer to users" (Henfridsson et al., 2018, p.92). As a result, organizations become also more malleable (Hanelt et al., 2021). Fig. 1 illustrates the transition from the industrial age to the digital age from a product architecture and industry architecture perspective.

2.2. Profiting from innovation and new mechanisms of control

The transition from the industrial-age product and industry architecture to the digital-age architecture not only requires organizations to acquire new component and industry knowledge (Jacobides et al., 2006), but it also concomitantly alters the ways companies can profit from innovation. As the landscape for innovation from a product and industry architecture perspective becomes, as Henfridsson et al. (2018) put it, "open-ended" in the digital age, established mechanisms for PFI are shifting. Teece, who coined the term profiting from innovation, confirms: "Spurred by digitization, this dramatic shift to a rich plethora of complementors-partners – some necessary, many optional – has changed the economic and business landscape, also requiring specific embellishment to the PFI framework." (Teece, 2018, p. 1382).

Whereas in the industrial age, the ownership of complementary assets, the appropriability regime, and the management of bottlenecks determined who profits from innovation (Baldwin, 2015; Teece, 1986),[7] the inherent nature of digital technologies allows firms and users alike to recombine digital technologies and to create value in myriad novel ways, breaking industrial-age value appropriation mechanisms and renders appropriability mechanisms less relevant in many industry. Products in the digital age emerge on a layered-modular architecture (Bohnsack et al., 2021; Yoo et al., 2010), hence PFI becomes a multi-level value capture issue and requires novel types of complementarities (Teece, 2018) and control of critical points, such as customer access, unique content, or platform ownership, in the digital business ecosystem (Pagani, 2013). See Fig. 2 for an illustration of value appropriation in a digital context, based on modular connections between components, control points and control mechanisms, as well as between incumbents, diversifying entrants, and new entrants.

Thus, to profit from innovation in the digital age, appropriating mechanisms shift in unison with the product and industry architecture. As business ecosystems around modular products turn gradually into a layered modular architecture in digital business ecosystems, control over value creation and capture becomes key to appropriate value from innovation (Teece, 2018).

The literature on ecosystems and platforms provides insights into the mechanisms of control. Central elements to consider for control in digital business ecosystems are the location of a firm in the ecosystem (Adner and Kapoor, 2010), the governance of the ecosystem (Wareham et al., 2014), and the evolution over time. First, appropriation is dependent on the *location* in the digital business ecosystem. Firms can either be a focal firm or a complementor. While focal firms benefit in contexts where upstream challenges are dominant (i.e., suppliers face innovation challenges), complementors are better off in a context with greater downstream challenges (i.e., buyers and complementors face innovation challenges) (Adner and Kapoor, 2010).[8]

Second, and related to that, a focal firm needs to manage the *governance of the ecosystem*, particularly the openness of the created (digital business) ecosystem (Karhu et al., 2018; Ondrus et al., 2015). According

[3] Digitalize refers to applying digitized processes to a wider socio-technical system.

[4] Historically, the ecosystem concept was introduced to the management domain by Moore (1993) and is now widely used and discussed in management literature Aarikka-Stenroos and Ritala (2017); Jacobides et al. (2018b); Thomas and Ritala (2022). An ecosystem is often considered "a community of hierarchically independent yet interdependent heterogeneous participants" Thomas and Ritala (2022), p. 517 who collectively create value in ways that no single participant could have done on his own Adner (2017); Talmar et al. (2020); Thomas and Ritala (2022). In contrast to business networks, markets, or industries, the concept of ecosystems is broader: it encompasses a more heterogeneous set of participants (or actors) affecting the ecosystem, spans multiple industries, and includes public and private sectors Aarikka-Stenroos and Ritala (2017); Thomas and Ritala (2022).

[5] We understand component knowledge as knowledge about features as such and knowledge about the system of products and their interfaces (i.e., product architectural knowledge).

[6] We understand industry knowledge to be similar to what Andersson et al. (2008) called architectural knowledge. However, for conceptual clarity, we refer to this type of knowledge as industry knowledge.

[7] Fig. A2 in the Appendix illustrates the appropriation of value in an industrial-age setting based on a bottleneck solution (cf. Baldwin, 2015).

[8] The reason are asymmetries between the focal firm, suppliers and complementors. The focal firm can be dependent on suppliers to innovate in order to deliver a complete product (e.g., Dell being dependent on Intel), or dependent on complementors to innovate so that customers can experience the full potential of the otherwise complete product (e.g., Airbus being dependent on flight simulators to integrate new models for training purposes).

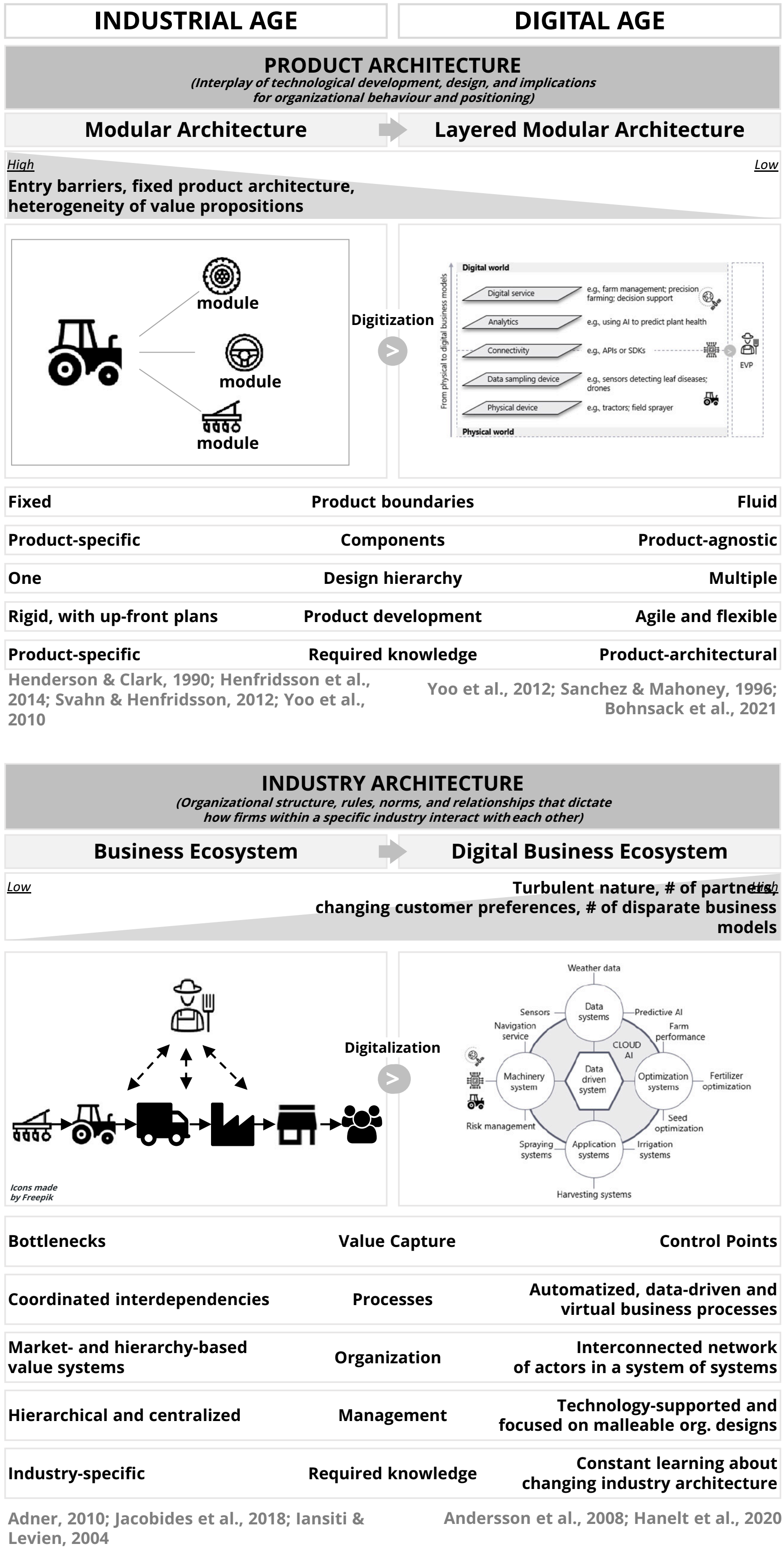

Fig. 1. Transition from the industrial age to the digital age from a product architecture and industry architecture perspective.

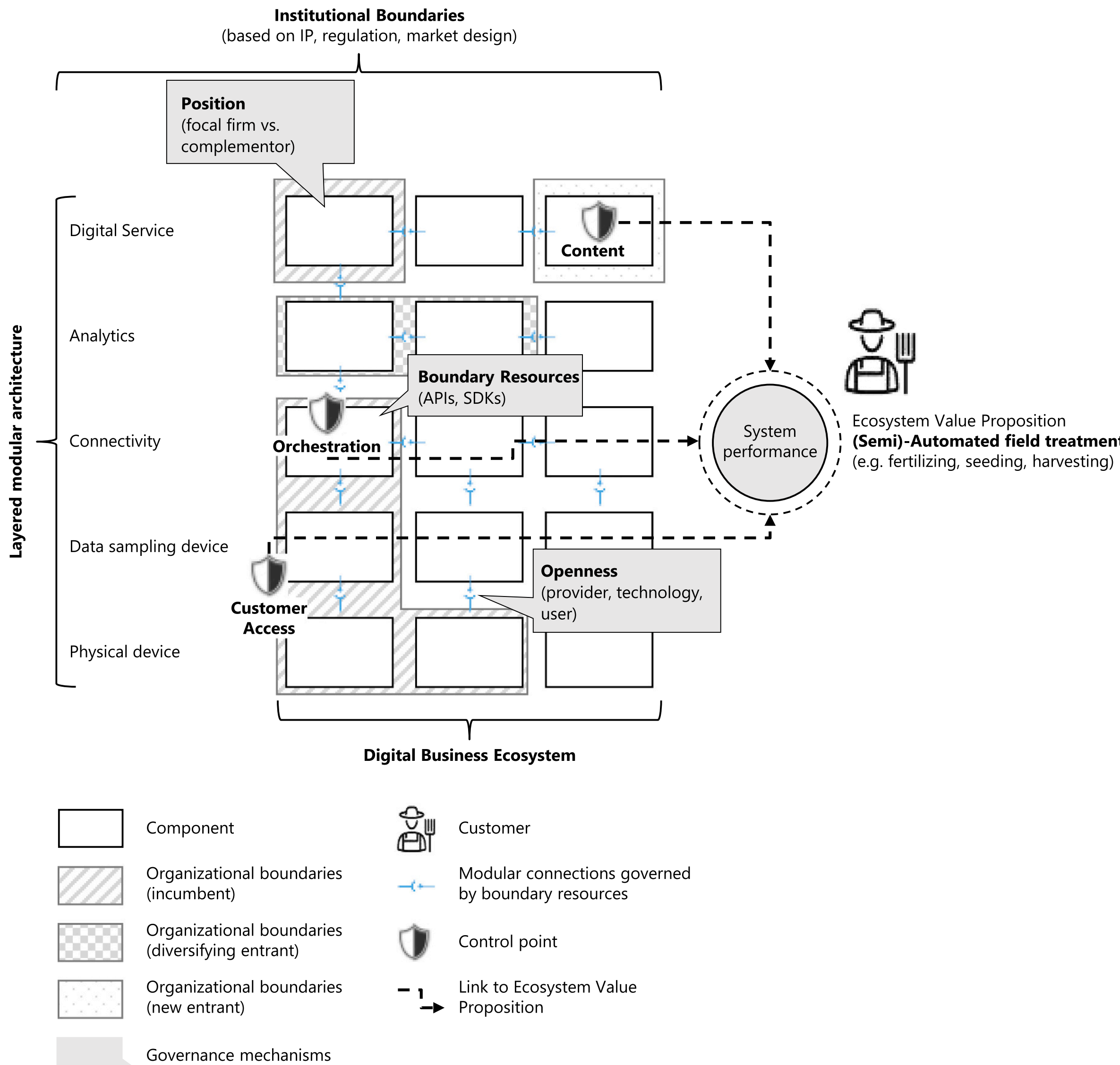

Fig. 2. Firm positioning and control in digital business ecosystems on the layered modular architecture.

to Ondrus et al. (2015), openness has to be governed on three levels: the provider level (i.e., to compete, collaborate or co-petition), the technology level (i.e., the provided interoperability), and the user level (i.e., whether to allow multi-homing). Ondrus et al. (2015) find that openness to same industry firms creates greater potential for adoption, but different industry firms lower such potential. While opening digital business ecosystems at the technology level increases market potential as does openness at the user level. Wareham et al. (2014), however, provide a more nuanced perspective and posit that the degree of openness matters. The question they ask is how to balance 'too many vs. too little flowers' (i.e., complementors) in an ecosystem. That points to the task of focal firms to balance control and autonomy of their ecosystem. For instance, Atari's demise is at least in part due to full openness and a subsequent overflow of low-quality games which shows that more is not always better (Wareham et al., 2014). This control vs. autonomy paradox, as Eaton et al. (2015) named it, is managed in practice by so-called boundary resources (i.e., Application Programming Interfaces (APIs) or Software Development Kits (SDKs)), defined as "software tools and regulation that serve as the interface for the arm's length relationship between the platform owner and the application developer" (Ghazawneh and Henfridsson, 2013, p. 174). These artefacts "provide access to the core resources of the service system, stimulating generativity, while at the same time affording the firms that created the infrastructure control over the service system" (Eaton et al., 2015, p. 220). This then governs the possible recombination options by firms and users, referred to as 'design recombination' by firms and 'use recombination' by users (Henfridsson et al., 2018).

Next, governance[9] and openness also need to be managed as an *evolution over time*. What Eaton et al. (2015) refer to as 'tuning of boundary resources' is a process which involves a dialectic between the focal firm and the participants in the digital business ecosystem in which

[9] A special case of governance are multi-sided platforms. According to Gawer (2022), p. 111 *"platform firms and their ecosystems are the emblematic organizational form of the digital age"*. Digital platforms, in contrast to physical (or product or industry) platforms cf. Constantinides et al. (2018); Gawer and Cusumano (2014), come in different forms, most notably innovation platforms (e.g. Apple iOS), transaction platforms (e.g. Uber), and hybrids thereof (e.g. Facebook). While value creation and capture in innovation platforms is depending on the above-mentioned mechanisms, transaction platforms are a more special case. They match heterogenous user groups and value increases for each user with each additional user through what is called network effects. Here the key challenge for value creation and capture is to manage network effects while attracting and balancing user groups from multiple sides.

power is shifting through digitalization over time. For instance, Apple's strict control of apps that are allowed or not allowed on the app store led end-users to jailbreak iPhones in order to run apps that were not granted access, which in turn led Apple to become more open for independently developed apps over time. That is to say that through cascading events of resistance and accommodation of focal firms, complementors, users and artefacts in the digital business ecosystems, the appropriation of digital resources changes. Clearly, this process is related to power and control (e.g., market position, public visibility, financial resources), and different actors have different degree of influence, either needing to accommodate boundary resources or being able to push.

2.3. Control points in digital business ecosystems

As the previous section illustrated, control is central to PFI in digital business ecosystems. The Value Chain Dynamics Working Group at Massachusetts Institute of Technology (MIT) coined these positions *control points* when they studied how commercial benefit could be gained in and around the telecommunications industry (Trossen, 2005). Subsequently, the concept has been further developed in the Information Systems literature. While some scholars refer to it as bottlenecks (Dattée et al., 2018), others see it more abstract as positions of greatest value and/or control of participants within a given digital business ecosystem (Pagani, 2013).

There is an agreement that control points are located between artefacts and layers on the layered modular architecture and are (intentionally) set by companies. For instance, Dattée et al. (2018) show that setting control points within an emerging digital business ecosystem involves the envisioning of the right partner selection or the identification and occupation of strategic bottlenecks to gain control of the ecosystem (cf. Hannah and Eisenhardt, 2018; Helfat and Raubitschek, 2018) and its overall value proposition with the goal to capture value in the future. Their study of the IT and telecommunication industries revealed different ecosystem strategies, (i.e., either choosing between configurations of interdependencies with component suppliers and complementors and control points based on strong intellectual property, or unique customer access, depending on corporate strategy). In this sense, control points are dynamic and include competitive dynamics that require firms to anticipate the future when setting control points. For instance, Apple can control the architectural definition or vetting rights to allow membership in the ecosystem and thus protecting (or orchestrating) value capture in the future (Dattée et al., 2018). Vice versa, the developer of a technology is offering content to other ecosystem participants which might lead to revenues (i.e., value capture) in the future (e.g. Spotify via its freemium business model). As Teece (2018, p. 1377) puts it: "The astute identification of a future bottleneck is a potential opportunity". Thus, the identification of control points is an iterative and dynamic process accompanied by high uncertainty.

Control points exist in diverse contexts within digital business ecosystems. As such, van Dyck et al. (2021) were the first to distinguish between strategic control points, which encompass sociological and institutional aspects (e.g., a brand), and technical control points. The latter refer to technical solutions including property rights that either enable or restrict access to a company's product(s) or ecosystem. Importantly, the influence and power of these control points are also shaped by regulations (Elaluf-Calderwood et al., 2011). For instance, EU Data protection policies, such as the General Data Protection Regulation (GDPR) or the EU Data Act, define how companies may use a technical control point such as customers' personal data.

Based on these considerations, we define a *control point as a technical or strategic feature in a digital business ecosystem – such as customer access, a unique solution, or an orchestration position – that competitors must navigate, thereby significantly decreasing their bargaining power.*

Given the transition to digital business ecosystems and to a layered modular architecture of industries, such as the agriculture, automotive or energy industry, and the importance of control points within a digital business ecosystem, the question then is how firms set control points, what combination of control points leads to a superior position to profit from innovation, and what is the role of (component and industry) knowledge in this process. Additionally, how do the actors' positions evolve over time as industries transition to digital business ecosystems?

3. Methodology

To shed light on how actors set control points on the layered modular architecture in an emerging digital business ecosystem, we apply exploratory qualitative research based on a single case study in an embedded design (Yin, 2016). We analyzed the case study data by means of an abductive research approach. This approach is appropriate because our understanding of how firms set the control points that allow them to profit from innovation is still fuzzy.

3.1. Empirical context: The digital business ecosystem of smart farming

The phenomenon of an emerging digital business ecosystems is observable in the development and implementation of smart farming technologies and practices (Klerkx et al., 2019). Smart farming is a highly ambiguous setting where the race for market power (or control) between *incumbents*, i.e. agricultural machinery producers, agricultural and chemical input suppliers, *diversifying entrants*, i.e. IT companies or technology providers and *new entrants*, i.e. emerging AgTech start-ups is currently on, and value creation and value capture are not well defined yet. The digital business ecosystem of smart farming, thus, provides an appropriate case allowing to empirically investigate the influence of technical and industry architecture over time on bargaining power.

Fig. 3 presents an overview of the evolution of smart farming. By building on Porter and Heppelmann's (2014, p. 4) notion of the "*evolution of products into intelligent connected devices – which are increasingly embedded in broader systems*" we conceptualize the evolution of smart farming along three phases: *(1) Smart products* (e.g., physical products that are digitally enriched via smart components such as sensors or digital user interfaces), *(2) optimized smart product systems* (e.g., smart products, that enable connectivity and remote access, and networks that enable communication between the product and the product cloud running on remote servers that contain the product's external operating system), and *(3) autonomous system of systems* (e.g., smart product systems that are enabled to (partially) operate on their own by means of artificial intelligence (AI) and big data that allows to learn and adapt to the environment).

In the past (phase 1), smart farming was characterized by the value proposition of selling smart physical products using digital technologies in niche applications (e.g., GPS). Nowadays (phase 2), precision agriculture technologies, predominantly using digital tools and information technologies (i.e., optimized smart product systems) to determine and manage variability in all aspects of agricultural production, play an essential role in smart farming. The aim is usually to implement so-called "sustainable intensification" strategies, i.e. to realize higher economic returns by less input factors and with the positive side-effects of adding social and environmental value, e.g. by reducing the necessary amount of fertilizers and plant protection products (Klerkx et al., 2019; Pedersen and Lind, 2017). Thus, the value proposition is currently emerging towards an ecosystem value proposition consisting of a more holistic solution, which leads to challenges for incumbents positioning themselves in the emerging digital business ecosystem eventually leading to the dissolution of standalone physical products such as agricultural machineries. In phase 3 (i.e., in the future), with the increasing use of big data, machine learning and pattern recognition based on AI and cloud computing, smart farming could gradually evolve into an autonomous system of systems in which technical and industry architecture are changing again and the machinery system (e.g., tractors) is less central and only one component of the overall system. This illustrates

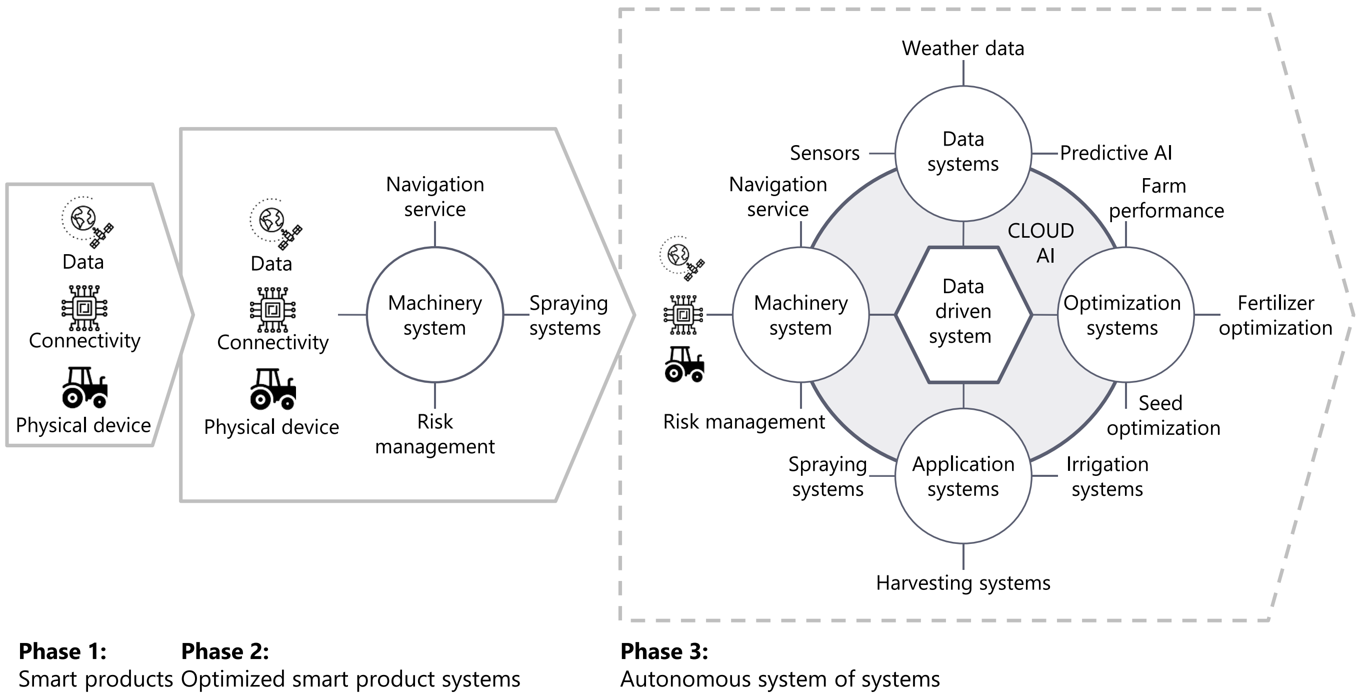

Fig. 3. Evolution of the digital business ecosystem of smart farming. Based on Porter and Heppelmann (2014).

that the competitive position of "solely physical" becomes diluted over time. Accordingly, on the higher-level digital technologies and services have impact on the evolution of the value proposition towards an ecosystem value proposition. At the same time, they have an influence on the technology architecture itself.

The current market situation in the digital business ecosystem of smart farming is the transition from phase 2 to phase 3, which is the focus of our case study. In this phase, value still mainly relies on selling physical products. But, with the advent of digital technologies, value is increasingly created through data collection and associated services. As a result, a layered modular architecture emerges in the digital business ecosystem (see Fig. 4): On the lowest layer, *physical products* such as tractors or spraying systems create value for farming. On the next layer, *data sampling devices*, such as sensors, add value by collecting data. Only through the layer *connectivity* is this data able to flow from physical devices to digital layers, enabled by standards and interfaces. Then, the *analytics* layer, which could for instance consist of the use of AI on satellite data to predict the plant health, could be used by farmers as decision-support system, e.g. in the form of precise fertilization or pesticide recommendation (as currently witnessed in so-called "smart spraying systems"). Finally, in the *digital service* layer, there are farm management information systems, which are often web-based software systems or applications that manage agricultural data and enable an easy handling of recording and documenting agricultural processes from

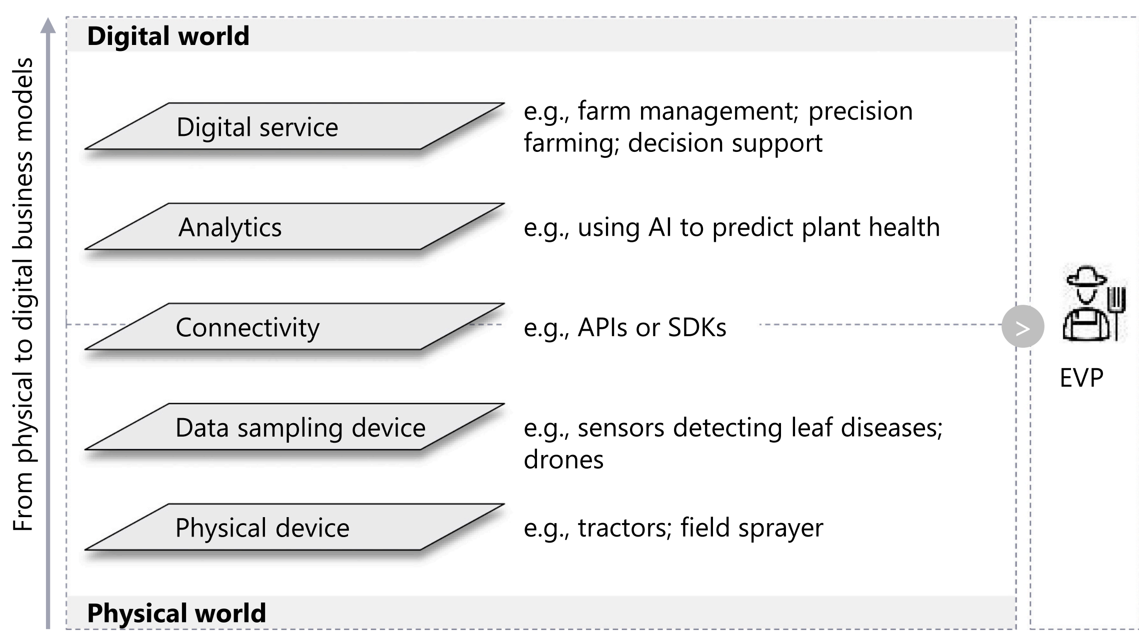

Fig. 4. Product architecture within the digital business ecosystem of smart farming.
Based on Yoo et al. (2010), Fleisch et al. (2014) and Bohnsack et al. (2021).

soil cultivation to harvest.

3.2. Sample and data collection

To explore the digital business ecosystem of smart farming, for our case study we selected experts from the most relevant sectors being engaged in forming and impacting the digital business ecosystem. Most of the interviewees were drawn from the pool of contacts which has been built up by the authors over the past few years being engaged in the field of smart farming, as well as in the agriculture and chemical industry, and joining different innovation networks and industry associations. To develop a unit of analysis for our single-case study in the embedded design, we aggregated interviewees in strategic groups (Porter, 1980), that ultimately represent different going-in positions for the digital business ecosystem of smart farming. We identified six strategic groups (or actor types), namely (1) Large equipment manufacturer (i.e., incumbent company), (2) Chemical company (i.e., incumbent company), (3) Dealers (i.e., incumbent company), (4) Software provider (i.e., diversifying entrant), (5) Technology provider (i.e., diversifying entrant), and (6) Specialists / AgTech start-up[10] (i.e., new entrant). Most of our interview partners were directly involved in commercializing digital tools within their organization. In addition to these managers stemming from corporates or start-ups, we included two other groups of experts, namely (7) the user group of farmers, and (8) industry associations, institutions, and consultants, reflecting a meta-perspective on different actors' strategies in the emerging digital ecosystem of smart farming. In line with Talmar et al. (2020), we included the farmer in our study because the customer group is key not only to generate an ecosystem value proposition but also to gain more insights into the relationships between the different strategic groups within the digital business ecosystem. All interview partners were German. Hence, the main point of view was the European market, although our experts were mainly working for multinational companies (see Table 1).

Interviews were conducted online via Zoom between September and December 2021. The interviews lasted between 30 min and 1.5 h. A basic questionnaire was used to conduct semi-structured interviews. In the end, we conducted interviews with 19 companies (including one consultancy, one industry association and one farmer). Additionally, we triangulated our interview data by including secondary data (e.g., company websites, company, and news reports) to provide additional and background information on the firms and interview partners.

Furthermore, to extend our data and validate our initial findings (c.f. Antons et al., 2016; Owen et al., 2021), in June 2023 we conducted a two-hour workshop with seven experts including four actors from the first interview round (Large equipment manufacturer A and B, and Chemical company C, Dealer C) as well as three new players who have not been interviewed in the first round (Specialists / AgTech start-up C, Industry association B and C) (see Table 1). As a preparation for the workshop, we sent around a short video introducing our main initial results. We additionally conducted three more interviews following a similar procedure as in the workshop. One was with a farmer we had not previously interviewed to get additional insight from a customer perspective, and the other two were with companies we had already interviewed in the first round (one with the Technology provider and one with Chemical company B).

[10] It should be mentioned that specialists were not directly part of our multiple-case study. However, since our interview partners often referred to established niche players, i.e. specialists, producing for instance highly customized equipment while reacting fast to customer requirements in comparison to large equipment manufacturers who need to serve global needs, we subsequently included them as an actor type in the digital business ecosystem of smart farming.

3.3. Data analysis

The data analysis was performed using a qualitative, abductive research approach, which is suitable for studying complex, real-world phenomena and allows to generate and refine theories based on observed data (Behfar and Okhuysen, 2018; Dushnitsky and Yu, 2022). The concept of control points, although already elaborated in the literature, still presents room for exploration and contextualization within specific domains, industries and especially in digital business ecosystems. Adopting an abductive approach allows to delve deeper into understanding the nuances, variations, and emergent constellations of control points in a digital business ecosystem. This exploratory nature also allows to uncover new insights and expand the existing knowledge base. Consistent with other studies (see e.g., Weber et al., 2019), the abductive analytical approach of this work included inductive and deductive reasoning procedures, as the work consults existing literature and aims to compare emerging codes and themes with previous literature to refine theory development (in line with Gioia et al., 2013; Weber et al., 2019). The interview data revealed how companies strategically respond to the changing business environment and position themselves in the digital business ecosystem. As stated in Section 2.3, we assume that positions revealing a certain bargaining power manifest themselves in digital business ecosystems through control points. Accordingly, we restricted our data analysis to control points that emerged from the interview data. Therefore, as a first step, we followed suggestions by Gioia et al. (2013) for inductive reasoning. Thus, we inductively derived first-order codes that closely represented our raw data (Gioia et al., 2010). In total, our raw data consisted of approximately 290 pages of transcripts from interviews and the workshop, which were analyzed by means of the qualitative data analysis software MAXQDA. In this step, we read through the interview transcripts and coded statements relevant for a subsequent identification and description of (potential) control points. This iterative process also involved several discussions among the authors and finally led to 40 first-order codes.

In a second step, for deductive reasoning we assigned some inductively derived first-order codes purposefully to pre-defined second-order themes (following suggestions by Weber et al., 2019) that represent control points previously discussed in literature, as laid out by Pagani (2013) and van Dyck et al. (2021). These seven second-order themes are *content, modularity, digital infrastructure, orchestration, networking, customer access* and *brand.* However, as not all first-order codes could have been assigned to the predefined second-order themes, we analyzed the remaining first-order codes according to similarities and differences (Gehman et al., 2018) and grouped them into eight new emerging second-order themes. Thus, after deriving first-order codes, we identified relationships between them and compared the emerging codes with previous literature.

Following a similar logic, in a third step the 15 second-order themes were aggregated into three overarching dimensions: *technical and strategic control points* (as already observed by van Dyck et al., 2021), as well as a new dimension that emerged from our interview and workshop data, namely *institutional boundaries*, which reflect factors such as government regulation. Moreover, our analysis led to the definition of *generic control points*, that are control points which all actors must navigate to enter the digital business ecosystem. In line with Gioia et al.'s (2013) methodology, Fig. 5 represents the data structure that emerged from the analysis of control points within digital business ecosystems. We used the data structure to assess the relationship between different control points and to evaluate the bargaining power of the strategic groups in our case study through different control point constellations.

In a fourth step, within the workshop we asked the participants to indicate themselves on which layers of the layered modular architecture (see Fig. 4) in the digital business ecosystem they are active. Additionally, participants were asked to evaluate the relevancy of the different strategic and technical control points as well as their respective interplay

Table 1
Overview of interviewees and workshop participants and their company background.

Company pseudonym	Initial type and scope of activities	HQ	Founding year	Size (# employees)	Interviewees
Large equipment manufacturer A (i.e., incumbent)	Agricultural equipment manufacturer	DE	< 1900	≥1000 ≤ 10,000	Product manager; Head of Crop Innovation
Large equipment manufacturer B (i.e., incumbent)	Agricultural equipment manufacturer	US	< 1900	≥10,000 ≤ 100,000	Engineer; Manager Solution Controls Strategy
Chemical company A (i.e., incumbent)	Chemical (plant protection) manufacturer	DE	< 1900	≥10,000 ≤ 100,000	Head of Venture for digital agriculture
Chemical company B (i.e., incumbent)	Chemical (plant protection) manufacturer	DE	< 1900	≥100,000	Commercial Manager in the area of digital farming
Chemical company C (i.e., incumbent)	Chemical (fertilizer) manufacturer	NOR	> 1900	≥10,000 ≤ 100,000	Digital Agronomist, AgTech Ecosystem & Partnerships
Dealer A (i.e., incumbent)	Dealer	DE	> 1900	≥10,000 ≥ 100,000	Chief Business Development Officer Agriculture and Digital Farming
Dealer B (i.e., incumbent)	Dealer	DE	< 1900	≥1000 ≤ 10,000	Sales consultant / machine specialist
Dealer C (i.e., incumbent)	Authorized Dealer	DE	< 1900	≤500	Sales consultant / service technician
Software provider (i.e., diversifying entrant)	Software provider	US	> 1950	≤100,000	Sales manager Federal Government
Technology provider (i.e., diversifying entrant)	Technology provider	DE	< 1900	≤100,000	Engineer; System development for software-driven systems in the field of agriculture
Specialists / AgTech start-up A (i.e., new entrant)	AgTech Start-up	DE	> 2015	≤10	Founder and CEO
Specialists / AgTech start-up B (i.e., new entrant)	AgTech Start-up	DE	> 2015	≤10	Co-founder; farmer; Managing Director & Head of Partner Management and Agriculture
Specialists / AgTech start-up C (i.e., new entrant)	AgTech Start-up	DE	>2015	≤10	Co-founder and business developer
User (farmer) A	Farmer	DE	n.a.	≤10	Employee on farm
User (farmer) B	Farmer	DE	n.a.	≤10	Employee on farm
Industry association A	Industry association	DE	< 2000	≤1000 and ≥ 10,000 (incl. members)	Division Manager Agriculture
Industry association B	Industry association	DE	< 1950	≤100	Project leader & business model developer; farmer
Industry association C	Institution	DE	< 1950	≤1000	Project manager smart farming
Industry association D	Consultancy	DE	> 2015	≤10	Founder; Expert for digitalization in agriculture / satellite data applications

to gain bargaining power within the digital business ecosystem, in general and from their individual company perspective.

In a fifth step, based on interview, workshop and secondary data, we compared the control point constellations of different strategic groups within the digital business ecosystem. The comparison helped to identify individual control points and control point constellations that strategic groups followed to gain control or enter the digital business ecosystem. Moreover, such comparison led to the definition of the *institutional boundaries* and the *generic control points* as well as a better understanding of the linkages between institutional boundaries and the different control point types.

4. Results

4.1. Strategic, technical and generic control points

To understand how companies seek to capture value within an emerging digital business ecosystem, as a first step we systematically analyzed the interview data and derived different control points that we allocated to the different control point types. In total, the analysis led to the identification of six *technical control points* within digital business ecosystems (content, modularity, digital infrastructure, data, scalability, (unique) solution) and seven *strategic control points* (orchestration, networking, customer access, brand, know-how, agility, financial resources). During the workshop, participants agreed that *modularity* and *scalability* have a more generic nature in smart farming as all actors must have these control points to enter the digital business ecosystem (i.e., solutions need to be scalable and modular in their deployment to enable fit and interoperability within the digital business ecosystem). Moreover, we identified an additional dimension which relates to institutional boundaries, encompassing *market design* and *state intervention*, which are external conditions that moderate the value creation and capture potential as well as the product and industry architecture. *Market design* refers to the institutional control to design the playing field of a specific market (competition law related). It includes data frameworks and digital infrastructure, standards, or (prevailing) regulations and policies, such as data protection or data traffic regulations in the case of digital agriculture. *State intervention* refers to the active institutional intervention, such as subsidies or providing central access to open data and free software, in the digital business ecosystem promoting the use of digital technologies and facilitating data accessibility. In Table A1 (see Appendix) we provide an overview of the technical, strategic, and generic control points as well as the institutional boundaries including descriptions, examples, and interview quotes.

4.2. Control point evolution in the transition from a physical industry architecture to an emerging digital business ecosystem

As a next step, we seek to understand the evolution of control points considering the digital transitions from phase 1 (smart products) to phase 3 (autonomous system of systems) (cf. Fig. 3). In these three phases, digital transformation changes the industry and product architecture leading the strategic groups to set different control points and occupy different layers while contributing to the emergence of a digital business ecosystem throughout the three phases (see Fig. 6).

In phase 1, before optimized smart product systems entered the agricultural industry, a rather linear value chain dominated in which actors mainly individually create value propositions for their customers in the physical world.[11] *Customer access* is the major control point of the dealer, whereas specialists or start-ups might join the value chain based on a *unique solution*. The chemical company and the integrated large

[11] Although some physical products are digitally enriched via smart components such as sensors or digital user interfaces, a layered modular architecture has not been in place.

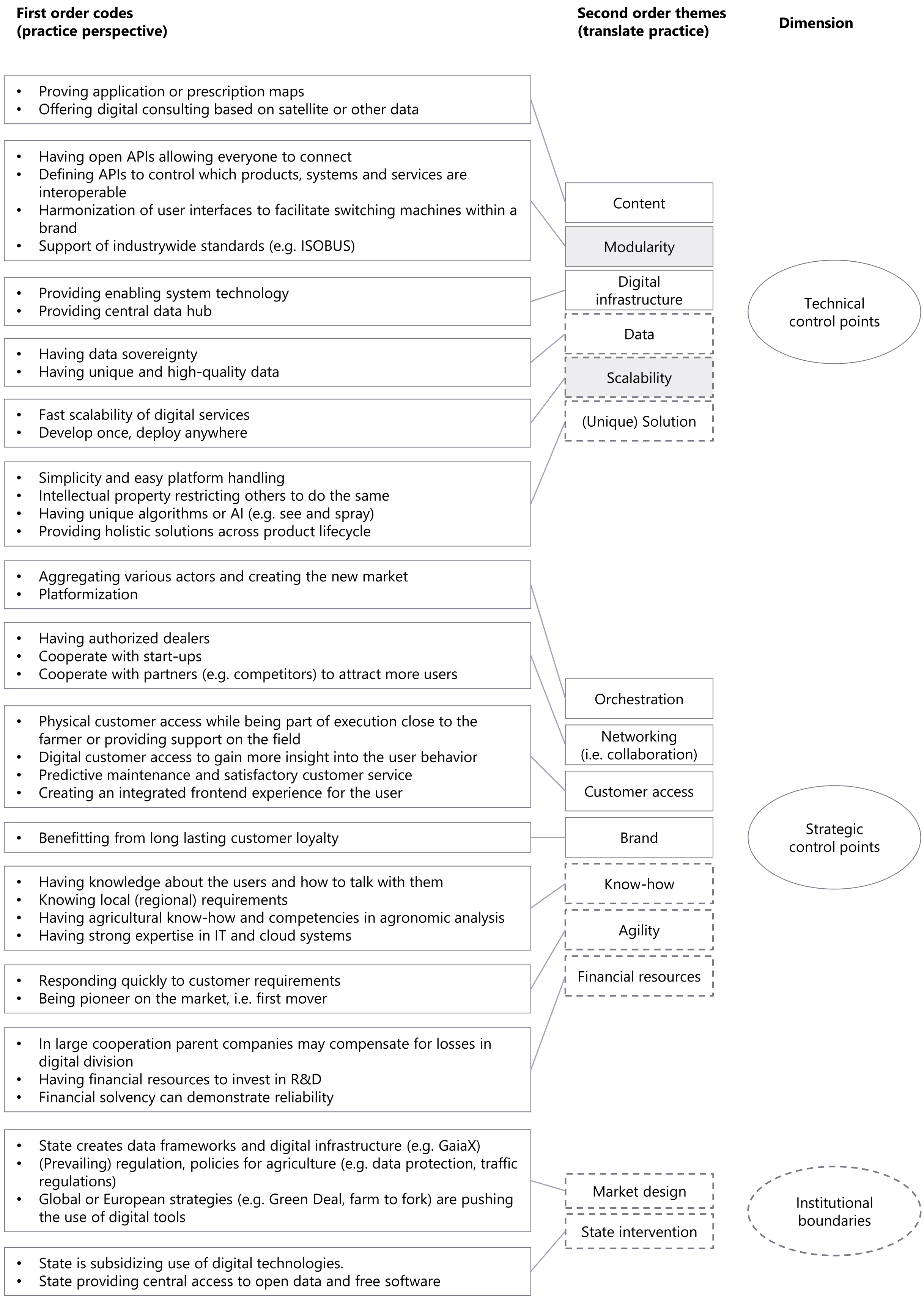

Fig. 5. Data structure.
Remark: The second-order themes and dimensions framed by solid lines have been explicitly discussed in the literature as control points (the others framed by dashed lines have not and emerged from our data). Generic control points for the emerging digital business ecosystem of smart farming are highlighted in light grey.

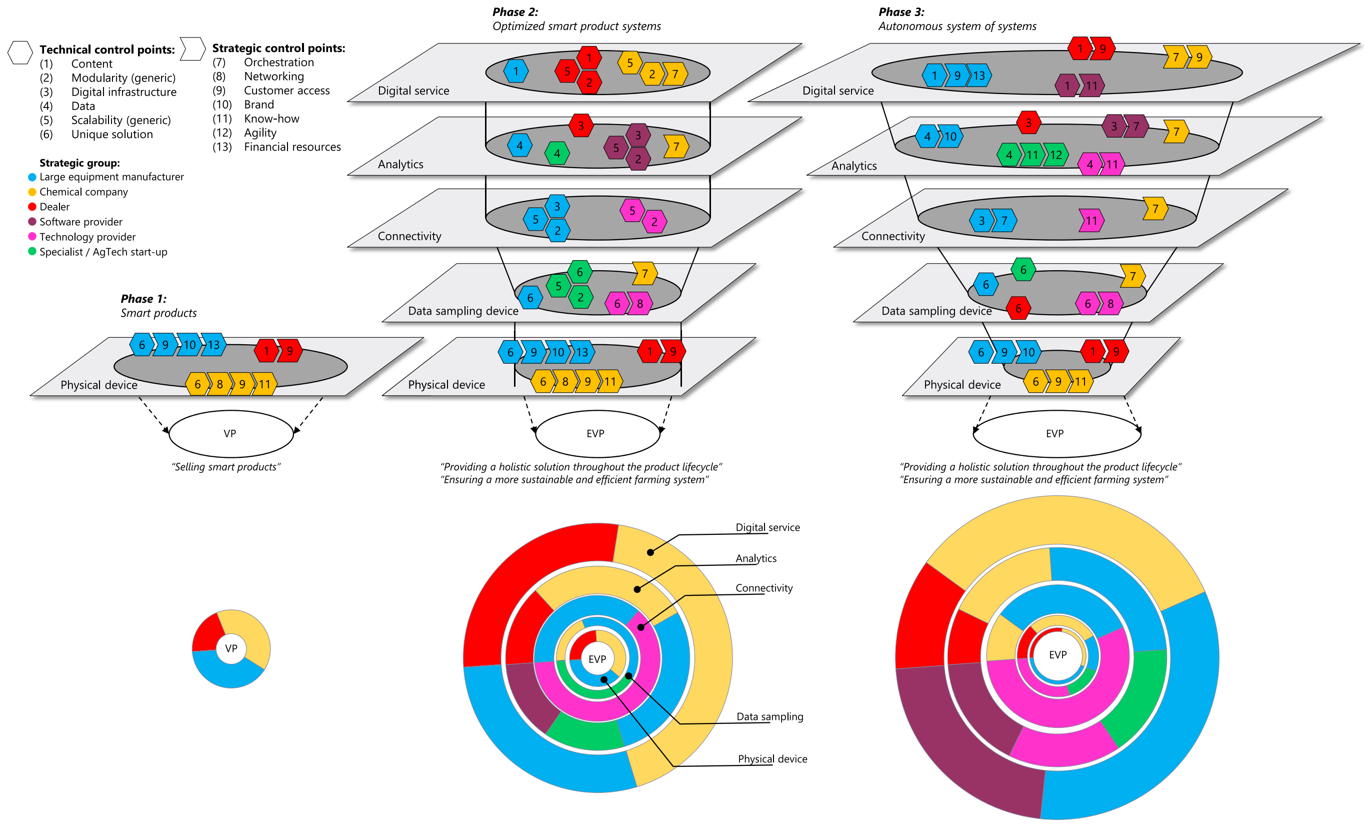

Fig. 6. The control point lens on the digital business ecosystem of smart farming and value capture evolution over time (simplified version shows only selected but relevant control point constellations for different strategic groups). Remark: VP stands for "Value Proposition", whereas EVP stands for "Ecosystem Value Proposition". In phase 1, value propositions for the user are created mainly by individual actors. Phase 2 and 3 reveal a digital business ecosystem perspective, where multiple actors on different layers contribute to the overall EVP. The varying thickness of the circles in the bottom half of the figure illustrate the growing value share towards the upper layers (i.e., digital service) of the layered modular architecture.

equipment manufacturer share the strategic control point *brand* and *know-how*, as they have built-up industry knowledge and strong customer loyalty already based on former *unique solutions*. Next to the control points shown in Fig. 6, a technology provider or a specialist / AgTech start-up may hold another *unique solution* adding value for the (end) customer and a small share in the strategic control point *networking* to build up the fundament for its future positioning in the digital business ecosystem. In contrast, the software provider does not have control points in phase 1.

In phase 2, with introduction of optimized smart product systems, the former value proposition changes to an ecosystem value proposition (i.e., *'providing a holistic solution throughout the product lifecycle'*), which was mentioned by Manufacturer B in our interviews, or, differently framed, *'ensuring a more sustainable and efficient farming system'*, which is the overarching goal of smart farming (Miranda et al., 2019). However, this can only be achieved if companies collaborate in digital business ecosystems, where actors hold different control points on different layers. Phase 2 depicts that with the emergence of optimized smart product systems (e.g., precision farming technologies, such as smart sensors detecting emerging plant diseases connected to a smart sprayer enabling the targeted application of plant protection agents), new control points emerge on multiple layers and are occupied by different actors. Most notably, the control points *digital infrastructure*, *data* as well as *modularity* and *scalability* become relevant with the advent of optimized smart product systems. Thus, this phase can be summarized as the emergence of the digital business ecosystem of smart farming. In this phase, competition for dominant designs and standards directing to interoperability across different physical products and digital services are still a challenge, which certain actors seek to address leading to the emergence of several *unique solutions* on different layers and multiple efforts towards *modularity* and *scalability*.

In phase 3, with the increasing amount of data and the growing importance of, among other things, cloud computing, IoT, AI (i.e., the emergence of an autonomous system of systems), and changes in the industry and product architectures, the existing control points in the digital world as well as the control points on the connectivity layer become even more relevant. In addition to the current ecosystem value proposition, the demand for 'better interoperability' will become more important to address the shortcomings of the current system, increasing the relevance of generic control points (i.e., *modularity* and *scalability*) for the ecosystem value proposition and to enter the digital business ecosystem. Likewise, in phase 3, the relevancy of certain other control points (i.e., *content*, *digital infrastructure*, *orchestration*, *agility*, and, most importantly, *customer access* and *data*) to realize the common ecosystem value proposition and gain a bargaining position is increasing.

In general, our analysis reveals that control points are unevenly distributed among the different strategic groups in the layered modular architecture, and it appears that some groups focus on both strategic and technical control points, while others focus mainly on strategic control points or on technical control points throughout the phases (see Fig. 6). The upper part of Fig. 6 shows a side view of the layered modular architecture as well as selected but relevant control point constellations of the different strategic groups among the three phases. The lower part of Fig. 6, demonstrating a top view on the different layers, represents the value which each strategic group is contributing to the ecosystem value proposition and is able to capture; again based on the selected but relevant control point constellations. The varying thickness reflects how added value and value capture migrate from the physical layer to the digital layers from phase 1 to phase 3.

In summary, with the rise of digital technologies, the industry and product architectures are changing, new control points are emerging, different control point constellations among multiple levels are being pursued, and the importance of individual control points is changing. Moreover, with the advent of optimized smart product systems (phase 2) not only more actors (e.g., from adjacent industries as well as start-ups) are joining the game but also the "value pie" is growing over time, which is also reflected by the number of different control points to be found on the different layers. The interviewees assume that additional value to the ecosystem is added layer by layer, which was confirmed by the workshop participants. Referring to this assumption, one interviewee reported:

> "Against the backdrop of digitization and data processing and the gold of today, namely data, the actual machines are just accessories and become - to put it drastically - just a means to an end."
>
> (Large equipment manufacturer B)

Accordingly, in the future upper layers contain a larger potential to create and capture value. Hence, actors seek to acquire control points on these layers. This suggest that decisions to set control points in a transition phase are critical as they define the value creation and value capture potential a company has in the emerging digital business ecosystem in the future. At the same time, it offers opportunities for new entrants to enter the business ecosystem.

4.3. Going-in positions into the digital business ecosystem and control point constellations

To understand how different strategic groups set and occupy different control points to create and capture value, increase their bargaining position, or how new actors enter the emerging digital business ecosystem, we subsequently compared control point constellations of the different strategic groups over time. Importantly, we observe that the actors pursued different strategic pathways in this transition depending on their 'going-in positions', i.e. *(1) incumbent, (2) new entrant* and *(3) diversifying entrant*.

Incumbents entering the digital business ecosystem of smart farming with an 'analog to digital' going-in position include the strategic groups of the large equipment manufacturers, the chemical companies, and the dealers (cf. Table 1). These incumbents in the agricultural industry are strong on the physical layer in phase 1 (i.e., they had already a significant stake in the agricultural industry, cf. Fig. 6). To address the growing importance of digital technologies, these actors first sought to complement their strategic control points on the physical layer with technical control points on the digital layers in phase 2. Naturally, some struggle to capture value as they miss the necessary component knowledge for the digital layers and how to capture value on digital layers with new business models.

> "So we are definitely not yet at the stage where we can offer integrated business models. [...]. The digital solutions, we have different ones there. We have hardware sensors that are also sold through dealers. We have software solutions that are currently provided free of charge to farmers, which are actually mainly for customer loyalty at the moment [...] and for building and testing digital solutions. Because at the end of the day, if we want to go into any kind of integrated service business models, the products have to work. They have to work, both technically and professionally. [...]. With us it's also about upgrading the product. So we have apps that accompany the product, but we're still not making money from those apps."
>
> (Chemical company B)

However, our interviews and workshop revealed that incumbents actively sought to improve their position and knowledge to capture more value from the newly occupied digital layer. Not least, in a subsequent step when the initial digital layer is mastered, a next layer would be targeted in phase 3.

> "Behind our products, which go in different directions, is the vision of optimizing crop production through digital solutions. The basis for this is, of course, the data that is generated in agriculture. We can ultimately incorporate this data into intelligent agronomic models that lead to very intelligent recommendations and enable the farmer to optimize crop production, because the farmer naturally does not always have all the data available in order to always make a data-based decision, which is sometimes also more of a gut decision. With our tools, we want to give farmers the opportunity to receive support and decision-making assistance, where we ultimately combine all the available data and make intelligent recommendations."
>
> (Chemical company C)

Nonetheless, not all incumbents followed the same path. While the large equipment manufacturer and dealer try to occupy technical control points themselves (including a need to increasing their component knowledge), others intended to leverage their existing strategic control points *know-how*, *networking,* and *orchestration* (thus their industry knowledge) in order to integrate *unique solutions* of other (new) actors via the generic control point *modularity*.

> "A key point is also networking with partners, so we don't see that we can build the ultimate platform on our own, but we are also focusing very specifically on cooperation with other companies in the value chain, to of course also bring their offers onto the platform, but also vice versa, that we integrate forecast models into other arable land indices, in order to of course also be present there."
>
> (Chemical company C)

Interestingly, incumbents project for phase 3 also vied for a more integrated position in which they would offer one-stop solutions, integrating different systems.

> "We are product system driven. [...]. And now we take it a step further and look at the whole process. What does [the farmer] actually do? That we can provide a one-stop solution. That we can help them solve their day-to-day problems. In the past, the customer was the integrator, he bought the different machines, connected them together and then used them to solve his problems. We are going one step further and offering complete solutions. We want to be faster and more customer-focused."
>
> (Large equipment manufacturer B)

Overall, our data revealed that incumbents in the emergence of smart farming initially learned about new digital components and subsequently sought to leverage their incumbent strategic control points to capture value. What is more, they sought to provide more holistic solution by either orchestrating different players or integrating different systems in their platform, as illustrated in Fig. 7.

Actors that follow a *diversifying entrant* path (i.e., technology providers and software providers), entered the industry in phase 2 providing digital infrastructure to connect different machines in the emerging digital business ecosystem based on generic control points *modularity* and *scalability*. These actors have strong positions in their incumbent industries (i.e., own valuable control points, such as *unique solution*, *brand*, and *financial resources*), which they try to exploit now in unrelated industries (i.e., in the emerging digital business ecosystem of smart farming).

> "For us, the business model has always remained the same. In terms of our business model, we serve the automotive industry or the manufacturing sector no different than we serve the agricultural sector. What has changed is that we explicitly provide an adapted platform for this sector. We have realized that for this sector you can't work with a standard platform that is the same for everyone, but you need a specific one. So we call it the so-called industry approach."

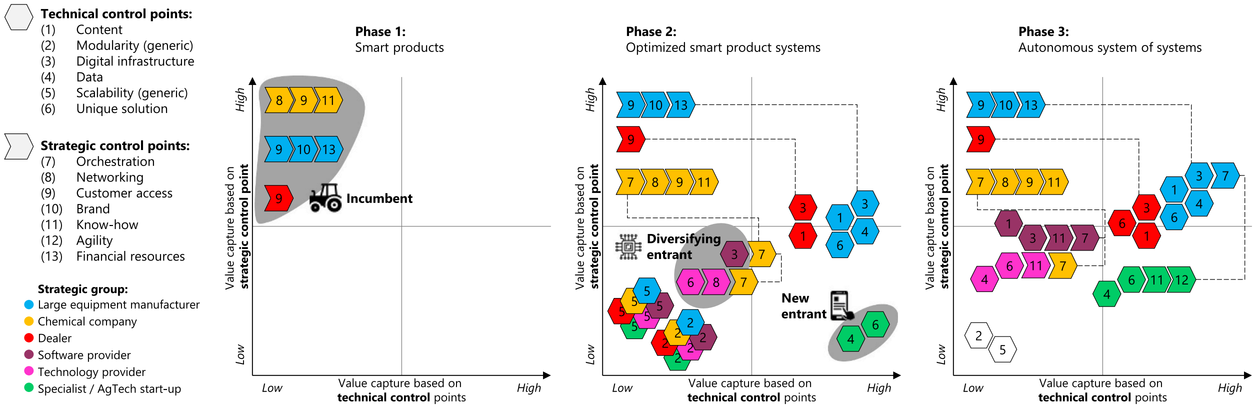

Fig. 7. Value capture for different strategic groups based on technical and strategic control points.

(Software provider)

However, in unrelated industries the existing technical control points become initially generic as the firms try to gather the necessary industry and component knowledge. Thus, in our sample diversifying entrants enter the digital business ecosystem in phase 2 by collaborating with incumbents, learn about the industry and occupy control points on the data collection, connectivity, and analytics layer to create interoperability between actors and ultimately capture value.

> “So whether it’s fertilizer or other chemical products that are manufactured, they [chemical company] have to concentrate on that and the whole issue of IT technology, platform, coordination of information, artificial intelligence, they [chemical company] have to outsource that to someone who naturally brings a much higher level of expertise to the table.”
>
> (Software provider)

> “We also use the representation of the layered [modular] architecture. We usually try to enrich this layered architecture with use cases and the required technology components, especially when it comes to management and market communication. Technology components can be inserted at each level, and the technology components can then be connected in the stitch for a use case. That helps quite a bit.”
>
> (Technology provider)

> “Ultimately, it’s also about making the data available in such a way that it generates added value. […] the data as such do not necessarily have a lot of value, but you have to process or analyze them in some form so that they generate a meaningful value. And of course, we are also looking at how we can cross-link different data, how we can store them in a more meaningful way and provide them with metadata and things like that.”
>
> (Technology provider)

With the intention to gain a leading position in phase 3, the diversifying entrants in our sample are seeking to gain more *know-how* in the emerging digital business ecosystem to subsequently leverage their technical control points. Eventually, they may own control points in *content* and *data* enabling them to offer *unique solutions* also on digital service layer, in which they become the *orchestrator* of *digital infrastructure* or *data*. Thus, we observe that diversifying entrants are twin-dependent on technical and strategic control points to capture value compared to other going-in positions.

Last, the *new entrant* going-in position, especially referring here to AgTech start-ups, enter the emerging digital business ecosystem in phase 2. They do so mainly by setting technical control points directly on the digital layers (e.g., digital services such as yield prediction) and by developing unique, technical solutions with smart sensors and digital features for technical niches (e.g., field robots for harvesting). Their going-in position is often characterized by comparatively little own (financial) resources; thus, their path is characterized by occupying technical control points, such as *content, data,* and *unique solution* and subsequently learn about the industry.

> "We are a very young startup and have only been established out of university two years ago. That means, of course, that we’re still looking for our product’s market fit. But what are we doing? We actually started with a pure service, I want to say that we basically offer parameters, let’s say in breeding or in agricultural practice about the plant stock, automatically and then on a large scale. [...] Instead of having 4 or 5 people out in the field all day collecting these values manually, one person just goes out in the field. He flies over it with a drone for half an hour and then that data is processed overnight and the next day you have a spreadsheet that is much cheaper to produce."
>
> (Start-up A)

To compensate for their lack of strategic control points, such as *financial resources*, and their lack of industry knowledge, new entrants stress the control point *agility*. Thus, their going-in position is characterized by addressing specific jobs-to-be-done in niches that add complementary value and providing superior user experience.

> “As a startup, the question is where is the money going to come from to pay the people who are going to implement what we are planning. That is the biggest hurdle. It always is. You’re always running three months ahead, chasing the next order. [...] But things change so fast that what you thought you had to do two years ago may be obsolete today. So you have to be agile. [...]. Finances, financial strength, or financial back-up is always important. But trained people that fit to the companies’ expertise, so for us artificial intelligence, image evaluation, software engineers and those people, they make the difference in the end. And the strategic partnerships that you develop. That means you sit at the table with the right people and then you get the chance to establish your product or your service.”
>
> (Start-up A)

By contributing components, such as farm robots or unique sensors for the assessments of crops and soils, to the overall ecosystem value proposition and closely collaborating with selected partners, new entrants build-up their *know-how* in the transition to phase 3. In this way, the dependence of value capture for the new entrant is moving from technical control points to strategic control points, even aiming at altering standards of the ecosystem, as mentioned by one interviewee:

> "And if you specialize in that [key technology] and then hopefully manage to be the one where others say, yes, I’ll take [key technology]. It’s a little bit like the MP3 format. [...]most important is that

you have a strategy that fits the market. Whatever that looks like, and that you have an agile team to execute it."

(Start-up A)

Finally, and confirming prior studies pointing to the importance of regulation (Elaluf-Calderwood et al., 2011), we find that institutional boundaries (i.e., *state intervention* and *market design*) influence a firms' value creation and capture potential with control points since they set the external boundaries in an industry and across. We found that institutional boundaries can both, hamper and drive innovation, as the quotes below illustrate. As such, institutional boundaries can lead to opportunities towards setting new control points (Trossen, 2005).

"In the EU, using aircraft to apply pesticides is prohibited due to environmental concerns. When pesticides are applied from the air, there's a high risk that they won't solely land on the intended fields but will also spread into the surrounding environment. This practice has been banned for two decades, with a few exceptions. However, with the precision of drones, it's possible that this legislation might be reconsidered in the next 5–10 years."

(Large equipment manufacturer A)

"Innovation is often driven by rules and regulations. As Europe faces stricter guidelines and limits on pesticide use, there will be a growing demand for advanced technology to meet these challenges. This means we'll be pushing for more technological solutions and advancements."

(Large equipment manufacturer A)

4.4. *Control points dynamics: learning and leveraging to create and capture value in digital business ecosystems*

While prior research on control points has not been clear on what control points are and often referred to them as bottlenecks (e.g., Dattée et al., 2018), our results show that control points refer not only to technical solutions, but to technical features (e.g., *data*) or strategic features (e.g., *brand*) in a digital business ecosystem, which gives companies bargaining power and provide superior value creation and capture opportunities. As such the concept of control points is wider than bottlenecks and control points can be defined as *a technical or strategic feature in a digital business ecosystem that competitors must navigate through, thereby significantly decreasing their bargaining power. Control points are a force multiplier if a competitor cannot advance without passing through this control point and help to profit from innovation.*

Thus, our results confirm the distinction between technical and strategic control points and in addition uncover the respective roles for value creation and value capture. Building on what Henfridsson et al. (2018, p.94) call "digital resources as entities that serve as the building blocks in the creation and capture of value" we find that *technical control points* determine mainly the value creation potential on the different layers in the layered modular architecture of digital business ecosystems and *strategic control points* determine predominantly the value capture potential. In addition, we find that the two hitherto regarded technical control points *modularity* and *scalability* need to be considered *generic control points*. We confirmed in our study that they are the necessary condition to participate in a layered modular architecture and afford the connection with other actors to co-create value across different layers and to contribute to the emerging ecosystem value proposition.

Finally, we find that in order to profit from innovation in emerging digital business ecosystems, a combination of technical control points and strategic control points is necessary. While technical control points are needed to create value in digital business ecosystem, strategic control points are needed to capture value. In that sense, strategic control points are necessary to leverage technical control points to profit from innovation and vice versa (see Table 2).

Depending on the initial going-in position – i.e., incumbent vs.

Table 2
Potential constellations of technical and strategic control points to profit from innovation in digital business ecosystems.

Control points		
Technical	**Strategic**	**Examples of leveraging**
Content (e.g., parameters about plant health using drone imaging systems)	- Brand - Customer access - Networking	*Leverage technical control points:* New entrant collaborates with incumbent to get customer access to leverage content *Leverage strategic control points:* Content's value is amplified when integrated into broader agricultural networks, allowing for collaborative research and data sharing.
Digital Infrastructure (e.g., infrastructure to connect machines)	- Financial resources - Networking - Orchestration	*Leverage technical control points:* Significant investments ensure the development of a robust and scalable digital infrastructure of a diversifying entrant. *Leverage strategic control points:* New entrant's unique content, such as specialized crop growth algorithms, gains trust and recognition through networking.
Data (e.g., data is used in agronomic models for intelligent recommendations)	- Customer access - Networking - Agility	*Leverage technical control points:* With unique data, actors (incumbents, diversifying entrants and new entrants) can offer exclusive insights to their customers, thereby enhancing loyalty. *Leverage strategic control points:* Rapid data processing and adaptability offer timely insights to farmers, adjusting to real-time conditions.
Unique Solution (e.g., unique solutions such as field robots)	- Brand - Customer Access - Know-how	*Leverage technical control points:* A unique solution (e.g., by new entrants) opens doors to exclusive partnerships or customer segments (with incumbents or diversifying entrants). *Leverage strategic control points:* A solution's uniqueness is enhanced by the company's (e.g., incumbents) deep expertise in a specific agricultural challenge.
Scalability (generic) (e.g., precision plant protection systems adapt to both small plots and large expanses)	- Orchestration - Financial resources	*Leverage technical control points:* Significant investments ensure the development of a robust and scalable digital infrastructure. *Leverage strategic control points:* A scalable digital infrastructure can enable the orchestration among different systems and services.

(*continued on next page*)

Table 2 (*continued*)

Control points		
Technical	Strategic	Examples of leveraging
Modularity (generic) (e.g., solutions need to be modular for interoperability)	- Orchestration - Know-how - Agility	*Leverage technical control points:* The modularity of a product is enhanced when the company has access to deep knowledge about farming practices and needs. *Leverage strategic control points:* Modular farming solutions can be orchestrated to work seamlessly with various other systems, enhancing their utility.

(diversifying or new) entrant – a company requires either to *learn* and acquire component knowledge to set a technical control point (e.g., in-house or via buying a startup) in the case of incumbents, or to *learn* and acquire industry knowledge to set a strategic control point (e.g., via partnering with an incumbent) in the case of an entrant (see the cycle in Fig. 8, the numbers indicate the cycle of an incumbent, entrants start the cycle at number 3). A technical and strategic control point in unison then allows to fully *leverage* technical or strategic control points and to profit from innovation. Importantly, considering that technological innovation continues on the layered modular architecture towards autonomous systems of systems (Hanelt et al., 2021; Porter and Heppelmann, 2014), the cycle in Fig. 8 is ongoing, creating a continuous pattern of learning and leveraging.

5. Discussion

This study set out to explore the ways in which incumbents, diversifying entrants, and new entrants vie for advantageous value creation and capture positions to profit from innovation within emerging digital business ecosystems by strategically positioning control points on the layered modular architecture. Interest in control in ecosystems in general and control points specifically has gained momentum in the past years (Dattée et al., 2018; Eaton et al., 2015; Pagani, 2013; Sandberg et al., 2020; Tilson et al., 2010; Wareham et al., 2014). Prior research has been invaluable in understanding how firms in digital business ecosystems influence value capture potential – e.g., via the role of openness, positioning, tuning, or network effects – and as a result seek control. The notion of control points, which is gaining increasing interest in the literature, explains these points of bargaining power in digital business ecosystems (Dattée et al., 2018; Pagani, 2013; van Dyck et al., 2021). In this study, we show that the concept of control points is wider than bottlenecks and can be defined as *a technical or strategic feature in a digital business ecosystem that competitors must navigate through, thereby significantly decreasing their bargaining power. Control points are a force multiplier if a competitor cannot advance without passing through this control point.*

Taking the emergence of the digital business ecosystem of smart farming as our empirical setting, we investigated how different actors in the ecosystem set both, strategic and technical control points, for value creation and value capture in the layered modular architecture. We further uncovered pathways of setting control points that different actors have adopted to enter a position of control in industries impacted by digital transitions. This is valuable as it illustrates how different actors in transitioning industries are competing and achieving a controlling position. Finally, our analyses revealed the importance of both, component and industry knowledge in setting control points and influencing who profits from innovation.

5.1. Control points as a lens for profiting from innovation

Although prior research has studied the evolution of control in ecosystems (Dattée et al., 2018; Eaton et al., 2015; Sandberg et al., 2020), these studies have mostly remained firm-centric and do not consider the shift in industry and product architectures. As a notable exception, Pagani (2013) considered the value network over all, yet she did not consider the different types of control points.

Our study unravels the interplay between strategic and technical

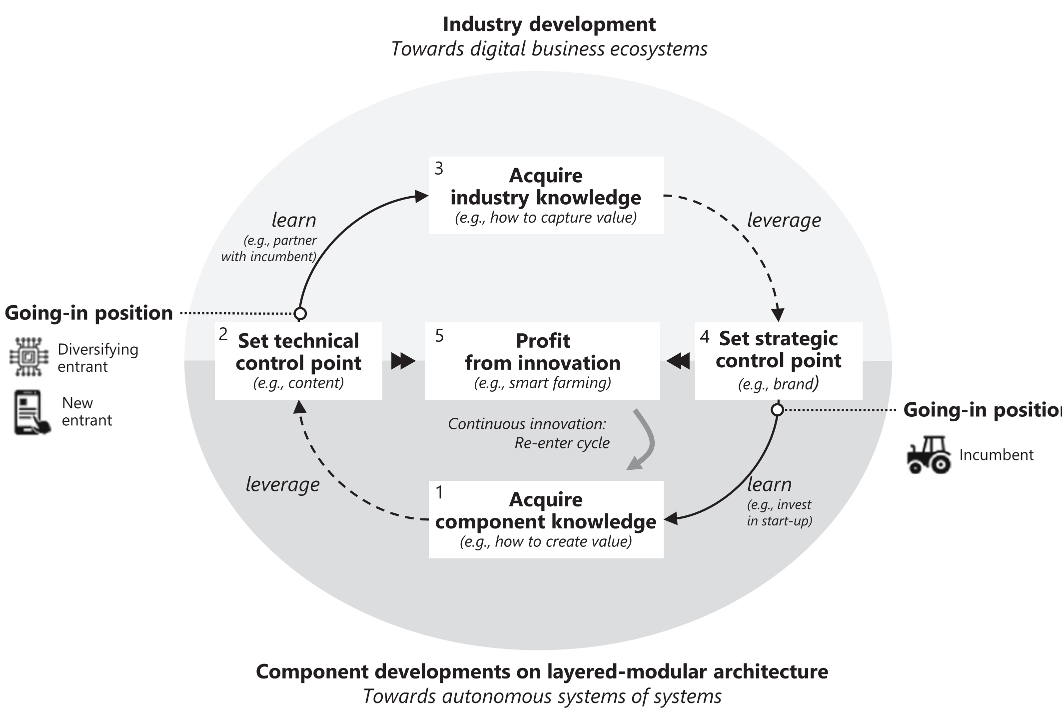

Fig. 8. The cycle of profiting from innovation via knowledge creation and control point setting.

control points, depending on the going-in position into the layered modular architecture. More precisely, by deciphering the control point constellations of different actors we identify general going-in positions that enable these actors to achieve a sustained position in the emerging digital business ecosystem. On a general note, and in line with prior research on the fundamental question *who survives (or profits from innovation) during radical change* (Tripsas, 1997), we find that both incumbents as well as (new and diversifying) entrants can achieve a sustained position (Sköld et al., 2020). By taking a control point lens on this fundamental question, the present study, thus, adds a more fine-grained viewpoint to enrich the ongoing discussion on who profits from innovation. In essence, we find that *incumbents* would enter an emerging digital business ecosystem with strategic control points (e.g. *brand*), while the *diversifying entrant* would enter with a generic technical control point and the *new entrant* with a focused technical control point (e.g., *unique solution*). The control point perspective, thus, complements the seminal discussion on complementary assets as a lens to explain "who profits from innovation" in digital business ecosystems (Teece, 1986, 2006). We also add an element of value creation to the PFI framework, which has traditionally focused on value capture. However, we observe that in the digital age and with technical control points, value creation is becoming part of, and perhaps a necessity for, the PFI framework.

In a digital business ecosystem context, which is emerging and has still a fluid, yet, unclear industry architecture, the mere discussion of complementary assets at given time point no longer suffices to explain value appropriation (Teece, 2018). Accordingly, a more dynamic approach is needed. Reflecting on this, we argue that actors (incumbents, diversifying entrants and new entrants) in addition to their going-in positions need to co-evolve with the gradually emerging novel industry architecture. Hence, to adapt their set of control points to achieve a sustained position in the digital business ecosystem, all actors need to first develop a minimum understanding of the shifting industry and product architectures. Initially, incumbents are benefiting from their longstanding experience and thus, deep "traditional" industry knowledge which enables them to profit by deploying their complementary assets, referred to as *industry architectural advantage* (Jacobides et al., 2006). However, as the industry architecture shifts, appropriation mechanisms also shift and initially valuable complementary assets are no longer relevant (Sköld et al., 2020; Tripsas, 1997). Hence, by jointly considering the set of control points and the underlying knowledge perspective, we add to Teece's PFI framework (Teece, 1986, 2006, 2018) and provide a more fine-grained approach to elucidate how different actors can profit from innovation depending on their going-in position. Contrary to industrial-age value appropriation, appropriation of value in digital business ecosystems depends on the combination of technical and strategic control points. Thus, we find that firms in addition to their going-in position acquire the necessary industry knowledge to develop more strategic control points, or component knowledge to set more technical control points. As a result, companies build momentum to move up towards the top right corner of Fig. 9. In that process, with each move companies are first putting themselves in a more vulnerable position.

As such, an *incumbent* setting a technical control point on the layered modular architecture reduces the value of its strategic control point on that layer initially. However, after gathering more component knowledge, the firm can leverage its strategic control points and the value capture potential increases over time. Moreover, the incumbent is in a position to co-evolve and potentially influence the evolving industry architecture. This resonates with prior research that explores the emergence of an industry architecture (Jaspers et al., 2012;

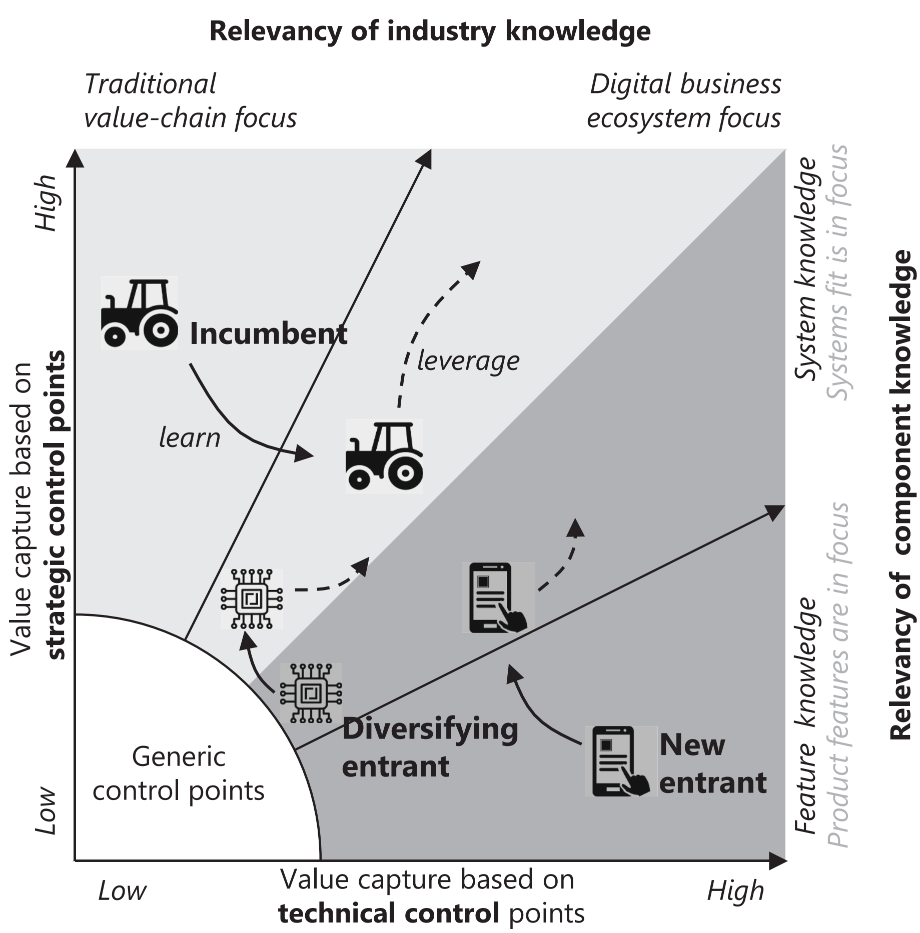

Fig. 9. Seesaw patterns of control point development.

Staudenmayer et al., 2005). Subsequently, the incumbent can set a new technical control point and again leverage its strategic control point after gathering more component knowledge. As such, over time, the incumbent is slowly moving up its value creation and value capture potential based on its strategic and technical points. An example of that process are physically focused companies – in the agricultural industry but also in other industries such as the car industry – that build digital twins, but often lack initially knowledge to capture value from them.

Vice versa, *diversifying entrants* (e.g., large software or technology providers) often enter new industries with technical control points that are more generic in the former unrelated industry due to insufficient industry knowledge. Not least diversifying entrants lack the necessary strategic control points. The logic they seem to follow is to collaborate with incumbents in the industry to learn about the industry architecture and, in doing so, over time set strategic control points to leverage it with component knowledge. This is a slow process (Dattée et al., 2018) and has also the goal to move to the top right corner of Fig. 9. However, not in every case this process is successful. This then leads such entrants to leave the industry again. In this regard, the notion of interindustry architectural designs (Jaspers et al., 2012), which can be witnessed in emerging digital ecosystems, might be an interesting perspective to pursue. Hence, future research could focus on the interplay between incumbents and diversifying entrants in setting control points to jointly define a novel architectural industry design: do they jointly set (technical or strategic) control points in a collaborative manner and to what extent can diversifying entrants transfer their technical control points (from their industry origin) into the emerging digital business ecosystem without losing value?

Finally, *new entrants* (e.g., AgTech start-ups) in most cases focus and remain in their entry position. The few that seek to expand their position on the layered modular architecture follow the same process as diversifying entrants, that is first they seek more industry knowledge and subsequently exploit their technical control points on new layers with newly set strategic control points.

Overall, we find that players follow a 'seesaw' pattern of moving their position in the digital business ecosystem (see arrows in Fig. 9). We observe a dynamic between exploiting established control points ('*leverage*') and developing new control points ('*learn*') on different levels of the layered modular architecture. Newly set control points require to learn about necessary industry or component knowledge to capture value, which reduces value capture potential initially as illustrated by a shift towards the origin in Fig. 9. This pattern offers a new perspective on the growing interest in ecosystem evolution (cf. Stonig et al., 2022) and suggests that companies require ambidextrous capabilities of managing digital business ecosystems (Tushman and O'Reilly, 1996). Moreover, our findings seem to confirm the relevance and value of dynamic capabilities for PFI, as actors need to sense and seize value creation and capture options to set a control point (Teece, 2018). Future research should study the rhythm, frequency, and scope of setting control points (i.e., leverage and learn pattern) in digital business ecosystems and, depending on the type of player, their implications on PFI.

5.2. Pathways and the importance of industry and component knowledge

Our findings confirm that firms in an emerging digital business ecosystem have different pathways of appropriating value depending on their going-in position (Bohnsack et al., 2021). We further find that their potential to appropriate value and therewith sustained position in a digital business ecosystem depends on setting new technical control points (for incumbents), strategic control points (for diversifying entrants and new entrants), and also both, strategic and technical control points (for an integrated position) (see Fig. 10).

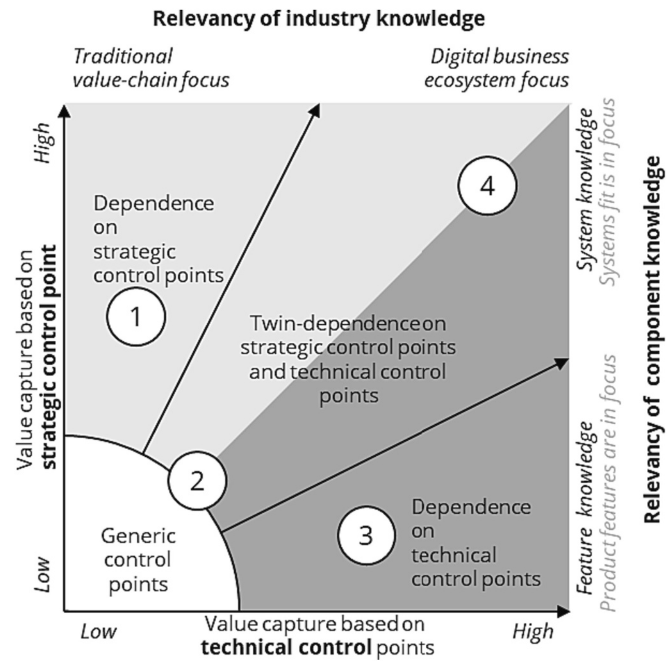

Fig. 10. Control point dependence of value capture in digital business ecosystems.

Depending on the going-in positions, we find different potential for value capture. The first going-in position, the incumbent (see circle 1) seems to hold high value capture potential due to extensive industry knowledge.[12] The second position (circle 2) is a diversifying entrant player, which at least initially may have low value capture potential as control points are generic and the contribution to the ecosystem value proposition is low. These players are then at risk to leave the industry again if they cannot find ways to create and capture value. Hence, they initially (prior digital business ecosystem emergence) need to compensate missing industry knowledge by partnering with incumbents. However, as soon as the "old" physical product-centered value creation logic is phasing out and the digital industry age becomes dominant, these players may leverage their knowledge stocks (i.e., orchestrating digital business ecosystems) gained in other industries. Thus, the "architectural advantage" may shift from the incumbent to the diversifying entrant. Moreover, a coalition of different ecosystem players with complementary control points and industry and product knowledge seems feasible. These findings advance theorizing in ecosystem orchestration (Autio, 2022) and suggest that co-orchestration may be a viable option to jointly leverage value creation potential. The third position (circle 3) is a new entrant, suggesting a relatively high value capture potential, often based on unique solutions that contribute to the ecosystem value proposition. However, it remains unclear if and how this actor can achieve a sustained position in the digital business ecosystem in the long run without collaborating or being bought by an incumbent or diversifying entrant. Finally, the fourth position (circle 4) represents an integrated system of a systems player, showcasing the highest value capture potential among the four positions, in a way a "super-app" that spans all layers of the layered-modular architecture in a digital business ecosystem. This position has not been occupied in our sample; however, an example would be Amazon in eCommerce, which is fully integrated on all layers of the layered modular architecture (starting from the Echo to the content to

[12] Following Shipilov et al. (2023), it should be noted that this may only hold in Adaptive or Decentralized ecosystems (which have several or no dominant player) and less so in Centralized Ecosystems (with one dominant player).

the digital app) with extensive industry and component knowledge, being able to dominate the ecosystem and capture beyond superior profits. Thus, the integrated position is a North Star in any industry.

In accordance with the going-in position, the emergence of digital business ecosystems requires firms to learn constantly, either about the industry (new entrants and diversifying entrants) or about digital components and their potential (incumbents). Thus, the requisite capabilities for a successful value creation and value capture requires an up-to-date understanding of the fabric of an industry (i.e., industry knowledge) and knowledge of the technical aspects of creating products or solutions (i.e., component knowledge).

Future research should study the interplay of pathways, how actors pre-empt, defend, and attack control points in ecosystems, similar to competition between platforms (cf. Eisenmann et al., 2011; Karhu et al., 2018). Also, studying the morphing of digital business ecosystems from decentralized to adaptive to centralized, depending on control point evolutions, is a fruitful area of future investigation (Shipilov et al., 2023). Moreover, understanding the phenomenon of orchestration in digital business ecosystems (Autio, 2022) seems a viable avenue for future research: when will the incumbent and diversifying entrant team up in a coalition? Or what control point constellations can break existing ecosystem leadership.

5.3. Navigating digital disruption: competitive advantages in emerging digital ecosystems

In the dynamic landscape of technological change, a prevailing assumption has been that incumbents often falter in the face of disruptive change (Eggers and Park, 2018; Tripsas, 1997). This is largely attributed to their tendency to develop incrementally, adhering to a familiar technological trajectory within a well-understood paradigm, and their path dependent behavior (Bohnsack et al., 2021). However, incumbents have also survived in the dynamic landscape of technological change when the market-customer link was not threatened (Sköld et al., 2020). In these cases, complementary assets may be co-specialized to a specific technology (Jacobides et al., 2006) and incumbents have value in conjunction with a certain trajectory but much less value in conjunction with another. Thus, when an invention depends on specialized complementary assets for its successful commercialization, an incumbent with proprietary access to these assets will outperform competitors without such access, even with an inferior technology. On the contrary, if the market-customer link is threated and the technology is inferior, the incumbent is at risk (Tripsas, 1997).

In the context of control points this begs the question: Which player is in a better position in an emerging digital business ecosystem? Based on our study and extant literature, several scenarios unfold: First, when the relevance of industry knowledge is high (e.g., because it is important to understand sector nuances, regulations, or customer behavior), and strategic control points are necessary to leverage the digital technology (e.g., a strong brand or established relationships are necessary), incumbents with deep industry expertise have an advantage (cell 1 in Table 3). This is seen, for example, in the way that traditional banks have embraced online banking, or in the way established car companies continue to dominate the automotive industry (with the exception of Tesla) (Bohnsack et al., 2021). However, when industry knowledge is relevant but technical control points are more important (e.g. technical infrastructure or a unique solution), diversifying entrants have an advantage if they come from related industries (cell 3). Even though the incumbent has more industry knowledge, the technical control point holds greater value in this case (Tripsas, 1997; Chandler, 1990). For example, Sony, a diversifying entrant, used its unique solution to improve smartphone photography.

On the contrary, in a situation where component knowledge is highly relevant to leverage a digital technology (e.g., feature knowledge and how to combine technological systems) the scenarios are likely to change: If the value of strategic control points is high (e.g., when a

Table 3
Advantages in relation to control points and industry vs. component knowledge.

	Relevancy of industry knowledge (Important when understanding sector nuances, regulations, and behaviors is paramount)	Relevancy of component knowledge (Important when technical intricacies determine product quality as well as combining systems capabilities)
High value of strategic control points (Dominant when brand, relationships, or financial resources are key)	(1) Incumbent has an advantage (*Leveraging deep industry expertise*) Example: A traditional bank introducing online banking.	(2) Diversifying entrant has an advantage (*Bridging industry knowledge with digital technologies*) Example: Microsoft using cloud expertise for farming analytics.
High value of technical control points (Dominant when driven by tech advancements such as AI or cloud solutions, emphasizing technical infrastructure and expertise)	(3) Related industry diversifying entrant has an advantage (*Applying component knowledge to traditional offerings in related markets*) Example: Sony enhancing phone photography with camera expertise.	(4) New entrant (start-up) has an advantage (*Innovating with deep component knowledge*) Example: A start-up offering blockchain-based secure transactions.

strong brand or financial resources are important), diversifying entrants have an advantage (cell 2). For example, we observed software providers offering their superior cloud-based farming analytics having an advantage compared to incumbent or start-up solutions. However, when technical control points are required in combination with component knowledge to profit from digital technologies, new entrants (i.e., start-ups and scale-ups) with deep technical expertise are likely to lead in this scenario (cell 4) (cf. Hopp et al., 2018). One example is the introduction of blockchain-based secure transactions by new entrants in the banking industry (Wustmans et al., 2021).

It is important to note that any advantage may be temporary, due to the ongoing cycle of innovation as described in Fig. 8 (cf. Hanelt et al., 2021). Not least, the continuous see-saw pattern to learn and leverage implies that in each iteration a different player can have an advantage. Future research should therefore investigate why, how, and when which actor is more likely to dominate, and explore the suggested scenarios across industries, ecosystem types, and regulatory landscapes.

6. Conclusion

In this study, we aim to understand how companies can profit from innovation in emerging digital business ecosystems from a control point perspective. We thereby contribute to the literature on PFI (Teece, 1986, 2006, 2018), ecosystem emergence (Stonig et al., 2022), and value appropriation in digital business ecosystems through control points (Pagani, 2013). By studying control point constellations in the emerging business ecosystem of smart farming, we combined a technology and actor lens. This builds on recent suggestions that understanding value appropriation in ecosystems requires an industry and product architectural perspective (Baldwin, 2015; Pisano and Teece, 2007). Our results reveal that control points have a different nature than bottlenecks, and for firms to capture value and profit from innovation in digital business ecosystems, they need to set technical and strategic control points on the layered modular architecture. This process requires the acquisition of industry and component knowledge (Wambsganns et al., 2023) in order to achieve a control point constellation that co-evolves with the emerging digital business ecosystem and, in particular, the layered modular architecture (Yoo et al., 2010). Our study thus contributes to the literature by providing a novel view on control points and how they dynamically evolve over time within a digital business ecosystem, thereby heeding the call of Bharadwaj et al. (2013, p. 478) for "richer models that delineate interdependent ecosystems that evolve more rapidly than what we have seen in traditional settings".

Our findings hold important implications for managers and policy makers. In the early phase of an emerging digital business ecosystem, companies need to radar the layered modular architecture and determine the players and their potential moves to identify relevant control points that should be occupied to profit from innovation. Companies can first analyze their own going-in position regarding available knowledge and control points, and subsequently develop a strategy to acquire missing knowledge (i.e., learn about component and/or industry knowledge) and then leverage available resources. Later, an analysis of the changing landscape of institutional boundaries and upcoming novel technologies can open up new opportunities in the future. Companies should plot their own and competitors' positions in our suggested framework. This allows to determine subsequent moves and an advantageous position in a digital business ecosystem, and to anticipate entrances and moves of diversifying and new entrants.

Policy makers, on the other hand, benefit from this study by understanding the implications that policy interventions have on the emerging digital business ecosystem. As such, the framework allows to simulate the development of a digital business ecosystem based on an intervention in combination with expected 'seesaw' moves. This could aid the effective development of institutional boundaries.

Finally, while this study provides an understanding of how one mega trend of our time – digital transformation – influences the pathways and value capture potential of companies, it is ambiguous on the effect of the two other mega trends – artificial intelligence and sustainability. The impact of generative AI on the layered modular architecture and on value capture will be exciting to observe. Equally, and perhaps even more importantly, the emerging digital business ecosystem challenges our assumptions about sustainability (cf. Bohnsack et al., 2022), particularly with regard to using digital technologies for sustainable development, but also developing digital technologies responsibly. Thus, a responsible control point perspective that considers generative AI and sustainability concerns in the digital age is needed in the future.

CRediT authorship contribution statement

René Bohnsack: Conceptualization, Investigation, Methodology, Project administration, Resources, Validation, Visualization, Writing – original draft, Writing – review & editing. **Michael Rennings:** Conceptualization, Supervision, Validation, Visualization, Writing – review & editing. **Carolin Block:** Conceptualization, Data curation, Investigation, Methodology, Visualization, Writing – original draft. **Stefanie Bröring:** Conceptualization, Project administration, Resources, Validation, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.respol.2024.104961.

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