Exploring the dynamic capabilities of technology provider ecosystems: A study of smart manufacturing projects

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Abstract
This study examines the capabilities of technology provider ecosystems within smart manufacturing implementation projects. Whilst the study of capabilities for technology implementation is well acknowledged, the existing literature lacks a focused analysis on the dynamic capabilities required from ecosystems of technology providers engaging with adopter firms for the development of smart manufacturing solutions. More specifically, research has overlooked how such provider capabilities address the adopter’s requirements and facilitate the related innovation outcomes for the adopter firm. Thus, our findings provide several contributions to the literature. Firstly, by examining two smart manufacturing projects within Pharmaceutical and Semi-conductor manufacturing contexts, we provide an in-depth analysis of the complexity of adopter requirements. Secondly, we uncover the nature of three main technology provider dynamic ecosystem capabilities. These reflect comprehensive skills in technology search and learning, project implementation, and knowledge transfer capabilities supporting the development of solutions for decision-making and predictive maintenance. Thirdly, we reveal how provider ecosystems build on these capabilities to address the complex requirements of the adopter firm and facilitate different types of process innovation outcomes. Respectively linked to performance, sustainability and evolving process sustainability.

1. Introduction

The concept of smart manufacturing refers to seamless monitoring of production based on manufacturing assets that leverage sensors, computing platforms and data intensive modelling (Rusnak, 2018). The structure and complexity of smart manufacturing systems fundamentally reflects the response to macroeconomic challenges demanding a higher degree of product customisation, efficient supply chain management and sustainability goals. This is also reflected in the policy initiatives that nations have developed to facilitate technological innovation and sustainability in manufacturing industries (Bonvillian and Singer, 2017; European Commission, 2014; Li, 2018; OECD, 2017). The need to respond to these challenges in fact, has driven manufacturers to seek for greater business and manufacturing process integration to improve both decision-making and production management (Chobakhloo, 2019; Müller et al., 2018; Szalavetz, 2019). Machine connectivity, for example, can help workers use production data more efficiently and creatively, which forms an important aspect of smart manufacturing systems (NIST, 2022).

However, the implementation of smart manufacturing systems also poses the challenge of integrating multiple technologies and significant organisational adaptations (Caglano et al., 2019). These aspects fundamentally reflect the complexity of the manufacturer’s requirements and challenges related to interoperability, cybersecurity, and data management for decision-making (Sjödin et al., 2018). In their study, Parkarachian and Kazemi (2018) highlight a number of challenges that manufacturers are facing, among which the critical one is the need to address the limited integration of manufacturing environments. For example, Sjödin et al. (2018) highlight that a full smart factory implementation is where manufacturers have a complete overview of operational, production, and supply chain analytics.

In order to address the above-mentioned challenges, from the

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technology provision side there is the need of a high level of technological specialisation, frequently resulting in the solution being designed from an ecosystem of provider firms (Benitez et al., 2020; Teece, 2018). The growing technological complexity shaping both manufacturing and other industries has in fact directed research along the study of innovation ecosystems (Nambisan and Baron, 2013; Thomas and Autio, 2020). Ultimately, outlining the increasing importance of such ecosystems for technological developments (Benitez et al., 2020; Kiel et al., 2017a; Reynolds and Uygur, 2018), the strategies of complementors (Miehé et al., 2023; Tavalaei and Cennamo, 2021) or the need to rely on partners for product or service co-creation (Reim et al., 2018; Sjödin et al., 2021). From a capability viewpoint, the importance of benefiting from the provider’s knowledge and the joint R&D effort between providers and adopters has been recognised in both prior and recent studies on advanced manufacturing technologies (AMTs) (Rahman et al., 2009; Szalavetz, 2019). Recent studies also identified the need to better understand the orchestration of provider ecosystems and the nature of the challenges to adopt complex systems (Benitez et al., 2020; Battaglia et al., 2023).

Whilst there has been a growth of research on the dynamic capabilities required by an ecosystem in different contexts (Linde et al., 2021; Helfat and Raubitschek, 2018), and from the emergence to the development of an ecosystem (Adner and Kapoor, 2010; Daftre et al., 2018; Dedehayir et al., 2018; Kahle et al., 2020), there is a need to understand the dynamic capabilities required from established technology provider ecosystems and how orchestration occurs within projects (Benitez et al., 2020). More importantly, examining how such capabilities address the adopter’s challenges and drive several innovation opportunities for the adopter. To address this overall gap, our study uses dynamic capabilities theory (Teece et al., 1997; Eisenhardt and Martin, 2000) to examine innovation ecosystems orchestration and how such capabilities enable different types of innovation outcomes (Elloen et al., 2009; Sheehan et al., 2023). More specifically, we study this within the context of external capability acquisition for adopter firms (Lorenzoni and Lipparini, 1999; Mahmood et al., 2011; Weigelt, 2013). In doing so, we uncover how technology adopters benefit from dynamic capabilities of technology providers ecosystems to achieve different innovation opportunities within smart manufacturing projects.

Informed by the preceding discussion, the purpose of our paper is to uncover the dynamic capabilities required by a technology provider ecosystem to address specific adopter requirements. Hence, we also examine how adopter firms benefit from such capabilities to achieve different innovation outcomes from the use of different smart manufacturing systems.

The contributions of the present study are two-fold. Firstly, we contribute to the study of Benitez et al. (2020) uncovering the structure of established technology provider ecosystems able to deliver smart manufacturing solutions to multinational firms within diverse projects (see Section 3.3). Within this context, we uncover how the ecosystem leader developed this ecosystem and that each ecosystem complementor may in turn be a project orchestrator (Autio, 2022). In uncovering these structural details, our study addresses the need to understand the attributes of different ecosystems configurations (Gomes et al., 2021), and the orchestration of ecosystems based on a hub firm (Nambisan and Baron, 2013; Nambisan and Sawhney, 2011).

The second contribution of our study is to the work of Linde et al. (2021) who use dynamic capabilities and ecosystems theory to analyse smart manufacturing projects and the related innovation outcomes. In doing so, we also contribute to studies identifying the need to further assess dynamic capabilities theory in different contexts and types of firms, as well as the related innovation outcomes (Barreto, 2010; Eisenhardt and Martin, 2000; Elloen et al., 2009; Sheehan et al., 2023). Our analysis uncovers three types of dynamic ecosystem capabilities required to manage smart manufacturing projects, providing insights on how these capabilities address the requirements of the adopter firm and enable different innovation outcomes over time. The latter evidence also demonstrates how adopter firms may leverage different innovation opportunities (Szalavetz, 2019), including performance and process sustainability outcomes (Sjödin et al., 2018). Further, this adoption-innovation outcome view, extends our analysis into the theoretical relationship between technology adoption and innovation (Bourke and Roper, 2016; Koellinger, 2008; Stornelli et al., 2021).

Our paper is structured as follows. In section two of this paper, we present the theoretical background relatively to the literature on smart manufacturing, innovation ecosystems, and dynamic capabilities. Section three provides an overview of our research method including the description of the ecosystem attributes. We then present our findings in the fourth section of the paper where we outline the characteristics of the three identified dynamic capabilities. Lastly, we conclude the paper with theoretical and managerial implications, and a final section highlighting our study’s limitation. In the latter section, we also advance suggestions for future research into both ecosystem and capabilities research opportunities.

2. Theoretical background

2.1. Smart manufacturing challenges and innovation opportunities

The concept of smart manufacturing refers to different layers of information-based technologies building on data analytics and sustaining automation of manufacturing operations (Lu and Weng, 2018). The literature often links the smart manufacturing concept to the fourth industrial revolution or to the evolution of advanced manufacturing technologies (AMTs). Thus, linked to the application of information technologies to automate and integrate the phases of manufacturing processes (Srai et al., 2022; Stornelli et al., 2021; Szalavetz, 2019). In support of these linkages in a study on smart manufacturing implementation, Cagliano et al. (2019) build on the AMT and IT-based technology implementation literature to understand smart manufacturing implementation. Following the latter approach, we refer to smart manufacturing as related to data analytics and computing, human-machine interaction, real-time responsive operational technologies (Cagliano et al., 2019; Gobakbloor, 2019; Mittal et al., 2020).

Our view of smart manufacturing reflects a technology architecture composed of layers (Lu and Weng, 2018; Osterrieder et al., 2020). Specifically, we build on Osterrieder et al. (2020) who highlight four key layers of a smart factory: (i) the physical layer (machines and related shop-floor artefacts); (ii) data layer (e.g. network infrastructure); (iii) cloud and intelligence layer (e.g. data processing through analytics); (iv) Control layer (e.g. technologies enabling control). The integration of these layers supports the structure of technologies such as Manufacturing Execution Systems (MES) or decision-making platforms which integrate machine sensors and data from planning systems required for the more efficient monitoring of manufacturing processes (Stornelli et al., 2021).

Fatorachian and Kazemi (2018) explain that manufacturers adopt smart manufacturing technologies to address the key requirement of “integration”. This relates to the common lack of integration between different IT systems causing a lack of interoperability (Fatorachian and Kazemi, 2018; Mittal et al., 2020). The capabilities of smart manufacturing technologies incorporate the solution to this integration issue. More specifically, through solutions linked to data coming from physical and digital devices shaping the development of operational platforms of different kinds (Battaglia et al., 2023; Nakagawa et al., 2021). For example, through vertical-horizontal integration platforms (Benitez et al., 2023) or interorganisational collaboration platforms (Liu et al., 2022). Overall, providing enhanced data visualisation, process automation, and prediction capabilities to several manufacturing and business processes (Hassellbait et al., 2018; Osterrieder et al., 2020).

In order to benefit from smart manufacturing technologies, firms also need to develop capabilities in data management (Sjödin et al., 2018), and address both interoperability and cybersecurity issues which may
also be linked to digital maturity limitations (Ghobakhloo, 2019). To address such technological complexity there is a need for diverse capabilities which cannot be provided from a single technology provider, and often requires the involvement of multiple firms (Benitez et al., 2020; Kiel et al., 2017a).

Lastly, smart manufacturing systems enable several innovation opportunities among which also sustainability opportunities. From a process innovation viewpoint, the key benefits of Internet of Things (IoT) platforms is the improved collaboration and decision-making. This fact is linked to the greater social interaction on the shop-floor, autonomy of work processes and process automation (Cagliano et al., 2019; Mittal et al., 2020; Osterrieder et al., 2020). Due to this type of process innovations, smart manufacturing provides an embedded link to sustainability outcomes (Kusiak, 2018). Thus, for this study, we consider sustainability as embedded in the process innovation effects driven by smart manufacturing implementation (Sjödin et al., 2018). The literature has shown that smart manufacturing generates sustainable outcomes through by-product effects of a manufacturing environment that produces less waste (Kiel et al., 2017b; Ren et al., 2019). In this view, big data analytics (BDA) arguably constitute the most important technology enabling control over the lifecycle of products (Ren et al., 2019). For example, through the opportunity of retrofitting older manufacturing equipment with smart capabilities reducing costs and controlling the lifecycle and maintenance of equipment (Jaspert et al., 2021).

### 2.2. Technology provider innovation ecosystems

The concept of ‘ecosystem’ has been widely examined in the strategic management field to analyse both competitiveness and innovation (Adner, 2006; Adner, 2017; Dhanaraj and Parkhe, 2006; Gaver and Cusumano, 2014; Iansiti and Levien, 2004; Wareham et al., 2014). Early works can be traced back to the seminal work of Moore (1993) who outlines ecosystems as a metaphor for the interdependency of organisations. Whereas recent streams have addressed the need to shed light on the ability outcomes (Kusiak, 2018). Thus, for this study, we consider sustainability as embedded in the process innovation effects driven by smart manufacturing implementation (Sjödin et al., 2018). The literature has shown that smart manufacturing generates sustainable outcomes through by-product effects of a manufacturing environment that produces less waste (Kiel et al., 2017b; Ren et al., 2019). In this view, big data analytics (BDA) arguably constitute the most important technology enabling control over the lifecycle of products (Ren et al., 2019). For example, through the opportunity of retrofitting older manufacturing equipment with smart capabilities reducing costs and controlling the lifecycle and maintenance of equipment (Jaspert et al., 2021).

For the purpose of this study, we build on the innovation ecosystem literature and the perspective of innovation ecosystems as a set of heterogenous partners collaborating to shape a market-driven value proposition (Ritala and Almanpoupolou, 2017; Thomas and Autio, 2020). Moreover, acknowledging innovation ecosystems within an evolutionary view: from the ecosystem birth to its maturity when it is able to address diverse market requirements (Autio, 2022; Nambisan and Sawhney, 2011; Nambisan and Baron, 2013; Thomas and Autio, 2020). The concept of ecosystems therefore differs from the typical supply chain structure and governance (Jacobides et al., 2018). Within this construct, we recognise the role of hub-firms (ecosystem leaders) that initiate, design and orchestrate an ecosystem establishing rules of collaboration and governance among complementors (Nambisan and Baron, 2013; Thomas and Autio, 2020). Specifically, recognising that it is strategically beneficial for complementors to be part of an ecosystem, whilst the ecosystem itself benefits from diverse complementors which facilitate its growth (e.g. Miehe et al., 2023; Tavlaeei and Cennamo, 2021; Thomas et al., 2022). Hence, although it is the leader who typically orchestrates the ecosystem, complementor firms may also engage in orchestration activities to shape the ‘functioning of an ecosystem’ (e.g. Autio, 2022).

Secondly, within the aim to examine the innovation outcomes of ecosystem orchestration we also refer to the work of Nambisan and Sawhney (2011) who called for future research on orchestration capabilities. This study posits that there are three main orchestration processes to consider: a) managing innovation leverage (e.g. leveraging different technologies), b) managing innovation coherence (e.g. rallying partners to meet market requirements), c) managing innovation appropriability (e.g. contractual agreements for partners to gain value from their products). These processes guide our analysis on the identification of the capabilities that the ecosystem needs and examining these through the management of different projects.

Linking the above theoretical views to smart manufacturing projects, offers a valuable context to empirically assess innovation ecosystem theory. Although several studies have examined the capabilities of ecosystems in manufacturing contexts, empirical evidence is mainly focused on the early stages of ecosystem development (Kahle et al., 2020; Benitez et al., 2020). Thus, there is a need to further examine the orchestration of established ecosystems, and how orchestration occurs within projects. Building on the latter point, Benitez et al. (2020) called for further research in this direction to examine the specific setting of technology provider ecosystem actors and how they engage in agile co-creation, bundling up different solutions for market opportunities. Thus, our study is based on the need to focus on established technology provider ecosystems and their ability to “generate a broad variety of offerings to meet customer requirements” (Thomas and Autio, 2020), within smart manufacturing projects.

#### 2.3. Dynamic capabilities and innovation ecosystems

Based on the preceding discussion, we incorporate the dynamic capability perspective (Teece et al., 1997) as the ability of firms to “integrate, build and reconfigure internal and external competencies to address rapidly changing environments”. In doing so, we address the need to further examine the contextual relevance and nature of such capabilities (e.g. Barreto, 2010) and how they form a stimulus for different innovation outcomes (Elloen et al., 2009; Sheehan et al., 2023). The evolutionary nature of innovation ecosystems (Thomas and Autio, 2020) provides a valuable context to assess the innovation-enabling role of dynamic capabilities which promote change and distinguishes them from ordinary capabilities (e.g. Helfat and Winter 2011). This theoretical view, also links to studies emphasising the need to explore the idiosyncrasies of dynamic capabilities according to market dynamics (Eisenhardt and Martin, 2000). More specifically, examining the collection of routines enabling changes to the resource base, learning and innovation in products and processes (Eisenhardt and Martin, 2000; Winter, 2003; Zollo and Winter 2002). Hence, the relationship between the nature and contextual relevance of dynamic capabilities against the enabled innovation outcomes, forms the theoretical perspective of our study. In doing so, we aim to empirically assess how the dynamic capabilities of a technology provider ecosystem stimulate innovation opportunities for adopter firms implementing different smart manufacturing systems.

Whilst several studies have examined technology capabilities in manufacturing ecosystems (Kahle et al., 2020; Reynolds and Uygur, 2018), relatively few studies have explicitly focused on how dynamic capabilities enable innovation for the ecosystem (Linde et al., 2021; Helfat and Raubitschek, 2018), such as through the capability of the hub firm to sense novel technologies, and integrate ecosystem partners (Linde et al., 2021). Thus, further research is needed to understand how technology provider ecosystems rely on both ecosystem orchestration capabilities and the capabilities of complementors to self-organise for novel market offers (Autio et al., 2018) and specifically within smart manufacturing contexts (Benitez et al., 2020). Based on the preceding gaps described, our study aims to address two main objectives. Firstly, we aim to identify categories of dynamic ecosystem capabilities (Linde et al., 2021), alongside the relationship between hub-firms and complementors within different projects (Miehe et al., 2022). Secondly, we aim to understand how such dynamic capabilities facilitate innovation (e.g. Elloen et al., 2009). Specifically, the innovation effects for adopter firms implementing diverse smart manufacturing technologies.

Within the latter theme of adopter firms benefiting from external provider capabilities, prior studies in the strategic management literature have provided empirical evidence on how firms benefit from intricate networks (Lorenzoni and Lipparini, 1999; Mahmood et al., 2011). The
employed different validity criteria (e.g. Gibbert et al., 2008). The analysis of findings and strengthen the construct validity.

In doing so, we selected projects related to Semi-conductor and Pharmaceutical manufacturing firms, which have been identified as the two most R&D intensive industries respectively (e.g. OECD, 2019), and hence within the high-tech standard industry classification (e.g. Hatzichronoglou, 1997; Heidenreich, 2009; OECD 2019). More specifically, where each selected adopter firm normally invests more than 10% of annual revenue in R&D activities, and had experience with complementary adoption of smart manufacturing technologies. For example, Project A (Pharmaceutical Manufacturer) has been defined from informants as a radical digital transformation project for the manufacturing network; whilst Project B (Semiconductor Manufacturer) relates to a more recent predictive maintenance application which is now being scaled up to several plants of the manufacturing network. Thus, in selecting these similar technological cases, we were also able to address our aim of understanding the details of the type of adopter requirements and the capability of the provider ecosystem to address these requirements.

3.3. The ecosystem attributes

The sampled ecosystem has been developed by the firm Futuryng, a company formed by technology and management consultant experts and the ecosystem leader that identified technology start-up opportunities addressing digital transformation challenges. They also facilitated the growth process of these start-ups by exposing them to venture capital involvement of government funding, business associations, or orchestrated by Universities as neutral orchestrators (Benitez et al., 2020; Kahle et al., 2020).

In addition to the attributes described, the ecosystem is based on a heterogeneous set of firms which all have a technological specialisation (see Fig. 1) and protected intellectual property. Each firm accepting to be part of the ecosystem is required to adapt their technology to specific technological standards but may freely deploy solutions for market

These criteria determined the selection of an innovation ecosystem able to deploy smart manufacturing solutions to multinational manufacturing corporations which conduct high levels of R&D for both product and process innovation. In doing so, we selected projects related to Semi-conductor and Pharmaceutical manufacturing firms, which have been identified as the two most R&D intensive industries respectively (e.g. OECD, 2019), and hence within the high-tech standard industry classification (e.g. Hatzichronoglou, 1997; Heidenreich, 2009; OECD 2019). More specifically, where each selected adopter firm normally invests more than 10% of annual revenue in R&D activities, and had experience with complementary adoption of smart manufacturing technologies. For example, Project A (Pharmaceutical Manufacturer) has been defined from informants as a radical digital transformation project for the manufacturing network; whilst Project B (Semiconductor Manufacturer) relates to a more recent predictive maintenance application which is now being scaled up to several plants of the manufacturing network. Thus, in selecting these similar technological cases, we were also able to address our aim of understanding the details of the type of adopter requirements and the capability of the provider ecosystem to address these requirements.

3. Methodology

3.1. Research approach

In order to uncover the nature of the capabilities of a technology provider ecosystem and their relationship with adopter requirements, we adopted case study and qualitative methodology (Yin, 2018). This approach was supported by semi-structured interviews and the perspective of two informant categories (provider - adopter firms) to substantiate the analysis of findings and strengthen the construct validity.

To ensure methodological rigour to our case study approach, we employed different validity criteria (e.g. Gibbert et al., 2008). The following points detail the actions taken in our study: (i) Internal validity - we outlined our research framework through theory triangulation (Section 2); adopted a three-level abstraction coding to identify patterns (Section 2.5). (ii) External validity - we sought for case studies that would provide contextual and theoretical relevance (Sections 3.2–3.3) (iii) To ensure construct validity we triangulated different data sources with interview transcripts for the analysis (Section 3.4–3.5). (iv) Reliability - We followed a case study protocol which is summarised in Appendix A.

In addition to the above methodological framework, our research was also shaped by recent studies in manufacturing contexts, based on case studies, triangulation of secondary data (e.g. Sjödin et al., 2020; Paiola et al., 2022) and literal replication (e.g. Chirumalla, 2021).

3.2. Project selection and sampling strategy

Building on a purposive sampling strategy (Bryman and Bell, 2011) and following Linde et al. (2021), we selected an innovation ecosystem that would illuminate how smart manufacturing projects are managed. In doing so, our sample focuses on an innovation ecosystem of technology provider firms led by an ecosystem leader (See section 3.3). To further justify the purpose of our research, we focused on an established ecosystem able to address complex adopter requirements. In order to control for extraneous variation and define the limits of generalisability (e.g. Eisenhardt, 1989) we adopted a literal replication approach, selecting technological projects with similar characteristics to substantiate analysis of findings (Yin, 2018). Thus, our purposive sampling approach deployed the following criteria for both the innovation ecosystem and related cases of smart manufacturing projects: i) Select an established ecosystem with relevant experience in managing cases of projects for high-tech multinational manufacturing firms defined by such firms as complex smart manufacturing solutions ii) Select projects where more than one ecosystem firm was involved to deploy a smart manufacturing solution iii) Select projects where the adopter firm had experience with smart manufacturing implementation and a long-term technology investment strategy.
opportunities and build on other ecosystem firms. This attribute makes the innovation nature of this ecosystem different from a typical industrial platform designed from large firms (Gawer and Cusumano, 2014) and opens up to a co-creation opportunity among actors that can design multiple market driven solutions (Benitez et al., 2020; Ritala and Almpanoulou, 2017; Thomas and Autio, 2020). Within this setting, the ecosystem leader (hub firm) endorses the role of ecosystem connector by providing the ecosystem firms freedom to collaborate as well as covering the role of project supervisor. This attribute provides a greater degree of openness to the ecosystem (Nambisan and Sawhney, 2011) allowing the advantage to address various market requirements and accelerating product development when needed.

Lastly, as explained in our selection criteria, the ecosystem is now established and open to further growth, with relevant experience in designing and implementing technological solutions for leading multinational manufacturers in different sectors: Pharmaceuticals, Semiconductors, Electronics, Automotive, Cable manufacturing, Aerospace, and Fast-moving consumer goods market.

Another important effect of this degree of openness is that firms also have an interchangeable project orchestrator role (Autio, 2022). Hence, when a firm uncovers the market opportunity and needs to involve other ecosystem firms, they can become the orchestrators of the project along with being the main point of contact with the customer. Whereas Futuryng retains the leader role ensuring project supervision. As described in section 3.4 the two projects we examined are respectively a collaborative decision-making platform (Project A) and a predictive maintenance system (Project B). For Project A, there were two specific firms from the ecosystem: the app composer firm which allows the integration of different applications into a single dashboard; and the messaging technology firm that provides the final system with a chat communication window which facilitates group and shop-floor problem discussion.

In Project B, the ecosystem firms involved were the IoT platform firm which created the digital twins of production machines; the previously described app composer and the artificial intelligence firm which designed the application for the predictive maintenance management.

In order to illustrate this further, Fig. 2 shows the technology firms involved in both projects (shaded in grey), and where the orchestrating both projects (e.g. also the main point of contact with customer) is the app composer firm. Whereas the ecosystem leader covered a supervisory role.

3.4. Data collection

In this study we adopt a longitudinal approach through in-depth interviews. This type of longitudinal access is desirable in qualitative studies to observe the evolving outcomes of technology implementation projects (e.g. Tyre and Orlikowski, 1994). Thus, we collected interviews in different waves over the course of four years (e.g. Hannah and Eisenhardt, 2018) and primarily through individual, semi-structured in-depth interviews, and secondary data related to each project analysed (See Table 1).

In total, the results are based on thirty interviews. Moreover, we included additional material from the ecosystem leader’s documentation on both projects to increase the reliability of the research and trustworthiness of results through data triangulation (Flick, 2018). The secondary data was in the form of presentations of each project which was then analysed and coded as explained in section 3.5.

To further sustain the construct validity of this study (Kumar et al., 1993), we ensured that informants from both adopter firms and provider ecosystem side had extensive experience in technology implementation projects from working together with different industry partners. Moreover, we ensured the data collection from the provider ecosystem firms addressed the understanding of the adopter challenges as well as the same perspective from adopters.

During the interviews, respondents were asked questions to reflect on the capabilities required and main outcomes of such projects. For example, for the provider firms we guided them to respond to questions relating to broad themes such as: Which type of ecosystem relationship were involved in the project? What were the key challenges that adopters were trying to address? What are the key contractual agreements among the ecosystem firms? (e.g. Nambisan and Sawhney, 2011; Warham et al., 2014).

3.5. Data analysis

In order to advance theoretical understanding of complex and emerging technological project analysis, we followed a three-level abstraction following an inductive approach (Gioia et al., 2013; Van Maanen, 1979). In doing so, we aimed at effectively and accurately identifying links within analytical themes emerging from our interview transcripts. Through a series of iterations and comparisons, it was possible to identify first order themes and overarching dimensions so that a framework could be developed. In order to retain a repository of data and identify different patterns we also utilised qualitative data analysis software N-Vivo 12.

We first conducted an in-depth analysis of raw data (e.g. interview transcripts). During transcription we identified key phrases and passages related to the research questions. In the coding process we also integrated the secondary data sources (see Table 1) within specific nodes of our coding tree (e.g. Fig. 3). For example, in the Need to implement an integrated solution for decision-making we coded verbal fragments which would illustrate the type of challenges identified from the adopter as well as secondary data (e.g. figures included in documents collected) that illustrated the operational aspects related to this need (e.g. Fig. 5).

We first started with an open coding phase by coding common words,
phrases, terms mentioned by respondents. In doing so, it was possible to identify first-order categories. For example, one of the informant statements (Project B, informant 6): “For one of the projects three teams were involved: The App composer firm, IoT Platform and artificial intelligence firm” enabled us to code this under the code configuring ecosystem project team. The second step of the analysis aimed at uncovering patterns within the first-order categories. This iterative approach led us to identify 11 second-order themes, which were on a higher level of abstraction compared to the first-order categories. These themes related to various aspects of the project such as Leveraging ecosystem technology specialization and modularity or Managing communication for technology co-development.

The third step involved the generation of overarching dimensions that represented a still-higher level of abstraction in the coding. Based on the data, we identified five overarching dimensions corresponding to the adopter’s requirements, providers’ capabilities and innovation outcomes. As a final step, we engaged in theorizing how the capabilities identified facilitated different types of outcomes for the adopter firm, including sustainability outcomes. For example, the ecosystem project implementation capability, enabled the successful design of the smart manufacturing system as well as the continuous improvement of the system alongside the adopter’s process improvements. This critical view of findings was also supported by active discussions of the research team based on the theoretical background of the present study.

Fig. 3 summarises the first and second order codes and the overarching dimensions which form the constructs of the identified adopter requirements, dynamic ecosystem capabilities, and innovation outcomes related to the data analysis.

4. Overview of findings

Fig. 4 illustrates the mapping of our results linking to our conceptual framework. On one side it outlines the ecosystem actors, where a main project orchestrator drives the project through a more intense relationship with the adopter firm. The ecosystem leader instead monitored both projects contributing to business development. In addition, Fig. 4 illustrates that there is a complementarity of three main types of dynamic capabilities needed for the ecosystem to successfully address the requirements of the adopter firm and facilitate the related process innovation outcomes. In exploring this relationship, we find that the moderating role of capabilities is proved by data describing that they not only address the adopter’s requirements but also sustain the internal adaptations of the adopter firm to eventually achieve several innovation outcomes overtime.

Lastly, we explain the results of our data through a narrative synthesis throughout sections 4.1 to 4.5, building on the most representative quotes of our informants. In order to further explain both the definition and content of our coding scheme, Appendix B includes additional quotes to support the evidence reported for each of our coding categories respectively to each of the related first order codes.

4.1. Complexity of adopter requirements

The relationship between adopters and technology providers begins upon the identification of a challenge or problem in the manufacturing operations from the adopter firm. The adopter generally performs a technology scouting process followed by the selection of the provider and a proof of concept stage that defines the requirements. Our findings show that the complexity of adopter requirements reflects two key aspects. Firstly, the need of a technology system that enables the improvement of decision-making. Ultimately, based on the need to standardise production indicators encompassing different process events such as the root causes of problems or information sharing during shift-hand overs. Secondly, the need to design a technology that is scalable and fulfilling the requirements of different manufacturing plants. We grouped the requirements into the (i) Need to implement an integrated solution for decision-making and the (ii) Need to design a scalable technology solution.

Starting with the first theme (i), our adopter informants emphasised the challenge of implementing a solution aimed at standardising production indicators and need for horizontal integration:

I would say the main need was to be able to develop a system that would be the source of truth of the production site. We needed to standardise indicators among all sites and of course add useful functions for the performance management process overall (Project A, informant 3)

When we were designing the prototype of this system we were looking for a technology that would not collect a dataset to interpret but rather one that could provide a green light to decision-making. Our initial technology scouting in fact, also uncovered the importance of cyber-physical systems which are a key component of this form of digitalisation (Project B, informant 3)

Based on the secondary sources that we coded, Fig. 5 provides the

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representation of the all key processes in a Pharmaceutical context. This was part of a documentation of the ecosystem leader used to illustrate the challenge of integration. The visual in fact, provides evidence that in reality manufacturing and business operations are logically connected. However, technologically they are supported from different applications (e.g. in a silos form) creating a “technology jam”. Most importantly, these technologies are developed from diverse vendors and placed on different technology platforms which are not natively integrated.

Although Fig. 5 relates to a pharmaceutical environment, we find that in both projects this integration requirement fits the same logic. Both technological systems in fact are based on the need of a single point of access along the workflow of shop-floor employees or other stakeholders. Ultimately, a control tool that clearly visualises heterogeneous data of relevant operations.
However, in order to enable a more collaborative environment the technology also needed to represent different levels of data granularity for each of the management levels. For example, the type of data needed from the shop-floor operator differs from the data needed from plant managers or more than one plant:

The tool we designed addresses different levels of data visualisation: real-time information which is linked to the single plant. However, the manager of ten plants will need a less granular type of information and of a higher level (Project A, informant 4)

The second theme we identified (ii) is linked to the need of creating a scalable solution. This entailed the need for data models that could be scaled to different plants. Ultimately, it reflected the adopter’s strategy to share the requirements of one plant with other plants to create a pool effect of requirements which facilitates the scaling up process:

We started with a proof of concept with some requirements but we also conducted a functional scale up and several technological capabilities were added along the way to different plants. Obviously, you can imagine that the requirement pipeline is very wide as every plant has its own requirements (Project A, informant 1)

The scalability of the technology is a very important aspect because usually large manufacturers will attempt to diffuse the technology in different plants. So, we tried to build a data model which was as general purpose as possible. When you go into another plant the solution needs to be implemented without too much effort. (Project B, informant 7)

4.2. Ecosystem technology value co-creation capabilities

Our data uncovered the importance of co-creating the technology value proposition among ecosystem actors. This capability is characterised by scouting innovative technologies and the collaborative activities to improve the value proposition. Respectively, encompassing activities orchestrated by the leader firm to search for new technologies; activities related to the ecosystem complementors and hub-firm learning from projects; activities related to the co-design of solutions based on interoperability. To better describe this, the two second-order themes identified are (iii) Leveraging technology search and learning opportunities (iv) Developing solutions through dynamic technology integration.

Starting with the technology search and learning capabilities (iii), findings reveal the capability of the hub-firm to scout and either select start-ups or develop technology ideas with industry experts or research institutes, within the long-term commitment of creating an evolving value proposition. Specifically, the firm relies on routines characterising different stages: Market selection (e.g. IoT opportunities), idea discovery, pre-validation (e.g. start-up creation), and through different funding rounds characterising incubation, acceleration, and growth.

We not only aim to find start-ups but also developing them through industry experts which can be the starting point to develop a specialised technology for the market. We constantly look for innovative entrepreneurs, or collaborate with Universities to identify technological opportunities. This has enabled us to design complex solutions to problems and build on the capabilities of the ecosystem over time (Projects A-B, informant, 6).

In order to further illustrate the above quote, we coded the secondary data (e.g. Fig. 6 below) to highlight the routines related to the technology idea discovery process lead by the ecosystem leader.

Linked to this scouting process, is the guidance provided to search for highly specialised technologies that can be patentable or covered by trademarks. This aspect characterises the overall value proposition

<table>
<thead>
<tr>
<th>Source</th>
<th>Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Industry expert interaction</td>
<td>- Required technology</td>
</tr>
<tr>
<td>- Start-ups</td>
<td>- Innovation potential</td>
</tr>
<tr>
<td>- Universities</td>
<td>- Market size</td>
</tr>
<tr>
<td>- Techno Parks and R&amp;D facilities</td>
<td>- Exit potential</td>
</tr>
<tr>
<td>- Other incubators and accelerators</td>
<td>- Current competition</td>
</tr>
</tbody>
</table>

We not only aim to find start-ups but also developing them through industry experts which can be the starting point to develop a specialised technology for the market. We constantly look for innovative entrepreneurs, or collaborate with Universities to identify technological opportunities. This has enabled us to design complex solutions to problems and build on the capabilities of the ecosystem over time (Projects A-B, informant, 6).

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Fig. 5. Macro-processes of a Pharmaceutical production ecosystem.

Fig. 6. Technology idea discovery process.
which addresses the complexity of industry requirements with a highly competitive offer:

Each of our technologies is covered by a registered trademark and patent which gives us an advantage when it comes to building on each other’s strengths to create more competitive and reliable technological offers (Project A-B, informant 6).

Another critical dynamic capability is linked to the routines forming the ecosystem strategy to improve the technological offer as it learns within projects. The quote below illustrates the processes supporting the growth of the knowledge base to ensure an improved technological value proposition.

In Project B the requirements from the firm were very challenging because we were not certain on how to develop the overall predictive maintenance solution. However, we leveraged active discussions with the partners in the project as part of the ecosystem project management approach to improve technology design. Over time, this knowledge base has allowed us to address the requirements of even bigger projects in diverse industries (Project B, informant 7).

The second order theme (iv) relates to the ecosystem capability of developing solutions through a natively connected and modular technological system. Specifically, by dynamically integrating different technologies for diverse process applications. This forms a critical technological capability to innovate the product value proposition. Firstly, it allows the ecosystem to design a solution that supports interoperability (Fatorachian and Kazemi, 2018). This aspect has been further explained from the CEO of the ecosystem leader firm:

“We support interoperability because we can design a system on data models which address a process integration requirement. To give a simple example, the “condition monitoring of equipment” in project B is a process requirement supported by our artificial intelligence firm, but also the IoT platform creating the digital twins of machines and the app composer developing user interface and data visualisation logic (Project A-B, informant 6).”

Fig. 7 further illustrates the above quote through the available secondary data documents we examined and reported through a visual diagram. As it can be seen, both of the examined projects are based on specific interoperability requirements. These reflect specific types of process integration requirements such as “priority task management” or “intervention scheduling.” To address such process integration problems, data inputs came from machines, planning systems, and newly digitalized procedures. This further demonstrates the complexity of adopter requirements and how the provider ecosystem is able to support interoperability building upon different technology capabilities.

Secondly, our findings also show that the integration of technology leverages the high level of technology specialisation which allows the system to expand the solution over time. This was evident in one of the projects requiring a sharing and collaboration tool.

Our messaging platform firm was born as a specific sharing and collaboration tool which for the collaborative decision-making project was key. It is basically a window within the app composer addressing the need of better communication flow within the required applications (Project A, informant 5).

4.3. Ecosystem project implementation capabilities

Another advantage of the ecosystem here examined is not only related to technological capabilities (Kahle et al., 2020) but also to the management of activities to address the different implementation stages. The nature of this dynamic capability has its focus on the management and coordination of project activities throughout the lifetime of the project alongside the need of integration and modifying data management models (Fatorachian and Kazemi, 2018). This capability advantage is further analysed in section 4.5 within the process innovation outcomes for adopters. Our construct focuses on (vi) Dynamic integration of ecosystem actors for projects (vi) Coordinating and reconfiguring implementation activities.

Theme (v) applies to the capability of an ecosystem to collaborate through a project team which is dynamically configured around project requirements. For example, in Project B there were three main teams from the involved ecosystem firms, and related sub-teams. Moreover, building on pre-established contractual agreements regulated from the ecosystem leader. Further, this also includes Allocating a project orchestrator role for ecosystem innovation, which relates to the ecosystem leader rule determining the project’s flexible allocation of complementors to lead the project. The project orchestrator, in fact, becomes the single point of contact with the adopter firm and leads the project activities according to the specific requirements. In doing so, project orchestrators also improve their managerial capabilities contributing to the overall growth of the ecosystem. This aspect adds evidence to the nature of experiential routines based on flexible resource allocation (e.g. Eisenhardt and Martin, 2000), and complementor involvement shaping the functioning of an ecosystem (e.g. Autio, 2022).

The firm who identifies the market opportunity becomes the project orchestrator and main contractor. From a business side it facilitates the relationship with the adopter. At the same time, it is an incentive for firms to be main contractors, because it is an opportunity to improve managerial capabilities and build on the overall value of the ecosystem (Projects A-B, informant 6).

Alternatively, the second order theme (vi) regards the capability of...
the provider to coordinate technology implementation activities from the proof of concept to the lifetime improvements and maintenance of the system. Alongside this process, the coordination of activities regarding formulation of requirements and budget, involvement of operators to schedule testing, and prototype design. Activities in the proof of concept can also present challenges and thus require increased coordination and time.

The activities during the proof of concept required a great level of collaboration between us and the adopter firm due to the challenging nature of the technology design process. In this case we spent around 8–10 months just to complete the proof of concept (Project B, informant 4).

In the later stages of the project there was instead the need to manage activities related to system testing and maintenance and improvements. For example, during implementation our informants stressed the need to coordinate on the job training and system check along the initial requirements. Subsequently, once the system has been installed the provider may also identify potential issues such as the need to integrate novel functionalities or modules. Among some of the changes, the adopter required the application of the smart manufacturing system to other production lines and tailoring it to solve data integration challenges. Moreover, innovation opportunities arising from additional needs along the adopter’s value chain or the scalability to different plant’s requirements. During these activities the ecosystem firms were coordinated by the orchestrator firm with the monitoring role of the ecosystem leader.

4.4. Ecosystem knowledge transfer capabilities

Another critical set of capabilities regard the provider’s capability to interact with the customer for different project and innovation objectives. Specifically, it reflects the capability to effectively communicate with multiple stakeholders of the adopter firm to set the vision of the project during critical phases (e.g. Eisenhardt and Martin, 2000), activities to co-create the solution, and providing knowledge to help the customer formulate a business case. Respectively, the two second-order themes are (vii) Managing customer communication and (viii) Building a smart manufacturing business case.

In theme (vii) we analysed the provider’s capability to effectively communicate with multiple stakeholders of the adopter firm to stimulate commitment to the project. One of the common capabilities of communication in management is to establish a common language between different firm functions. In both of our projects, our ecosystem informants stressed the importance of being able to communicate with different stakeholders of the adopter firm to retrieve requirements, stimulate commitment and deliver comprehensive training. For example, being able to communicate with both information technology (IT) and operational technology (OT) stakeholders. The quote below illustrates this capability with regards to the importance of communicating the vision of the innovation alongside the critical activities of the project:

In order to drive the innovation of the project we generally communicate with multiple stakeholders and deliver a holistic vision of the project during training, and top management discussions. This gets even more complicated when the project diffuses in more plants as we need to communicate with additional stakeholders. I believe this is a critical innovation capability for us. (Projects A, informant 4)

Lastly, another side of communication is more related to technology co-development into a synergistic effort with the adopter (Szalavetz, 2019). In both projects, being able to understand customer requirements alongside the process of co-developing the solution was a critical knowledge transfer capability to address evolving process needs.

We established a close relationship with the customer who provided us with the knowledge on the working logic of machines. So, we worked around that and at the same time we shared knowledge on what artificial intelligence could do to solve their process needs. This overlapping knowledge area was critical to co-develop the solution and also created the basis for evolving requirements (Project B, informant 4).

The second order theme (viii) is instead related to the capability of the provider to support the adopter firm in formulating a business case. More specifically, the provider was successful in both formulating a comprehensive financial projection and delivering knowledge aimed at stimulating a long-term vision of the smart manufacturing solution based on the ecosystem structure. For the financial aspect, the provider informants stressed the importance of being able to outline the return on investment of the project and its added value along its development and use:

In the proof of concept stage, the critical point is to build a business case. The challenge is to design what we call a customer value added (CVA) and in both projects we helped the customer to outline this value in order to support the customer to create a stronger business case (Projects A-B, informant 6).

In addition, the provider firms also stressed the importance of delivering specific technological knowledge on the long-term benefits of the technological value of the ecosystem through interactive sessions with top managers and operators. This aspect was beneficial in both of our cases where the technology was integrated with new capabilities and scaled to different plants. However, additional insights emerged throughout the different waves of interviews also revealed that not all large manufacturers have the same innovative capabilities and thus may be reluctant to understand the long-term potential of smart manufacturing in its modular advantages that the ecosystem analysed provides:

In these cases, the project managers were real innovators and had a long-term vision of the project. However, the reality is that, aside from a small proportion of firms like these, usually innovation is an objective given from the top levels of the firm as opposed to being related to the risk-taking culture of managers. We try to provide the firm with a long-term vision of the technology through our knowledge and experience, especially in the initial stages of the project (Projects A-B, informant 6).

4.5. Adopters process innovation outcomes and dynamic ecosystem capabilities

In this section we summarise the main process innovation outcomes achieved from both projects relatively to (ix) process performance outcomes (x) process sustainability outcomes (xi) evolving process sustainability outcomes. Based on the prior discussion, the following outcomes demonstrate the moderating role of the technology provider ecosystem capabilities as illustrated in Fig. 4. Each of the outcomes in fact also proves that the dynamic capabilities involved addressed the complexity of adopter requirements, enabling the adopter to benefit from the smart manufacturing solution. This aspect reinforces the key fact that adopters also need to implement significant adaptations and develop capabilities when adopting complex manufacturing technologies (Bessant and Buckingham, 1993; Stornelli et al., 2021; Szalavetz, 2019).

Alongside this view, the requirement of integration to improve efficiency is reflected in theme (ix) resulting from key performance indicators such as Overall Equipment Effectiveness (OEE) as well as production cost reduction which were significant for both projects:

Our OEE improved by 2–3% with a significant impact on general cost savings which also had performance impacts throughout the
manufacturing network because we optimised different production phases (Project A, informant 1)

Another outcome related to the need of a tool for decision-making is the theme (x) highlighting process sustainability outcomes. These outcomes relate to the by-product of improved decision-making and reduced use of paper alongside production operations (Sjödin et al., 2018). Overall, our provider informants also stressed that this encompasses the critical benefit of agile reaction to unattended problems for manufacturers because of a more systematic management of production disruptions. From this view, the external ecosystem capabilities supported the adopter’s process adaptations through the ability to co-create the solutions, the related knowledge transfer, and the high level of specialisation of the involved technologies. The latter characteristic was evident from our findings on the co-development of technology between the provider and adopter or the delivery of on the job training for interpretation of data. Overall, these provider capabilities supported the implementation of escalation of best practices, and decision-making procedures.

Data transparency, decision-making, and escalation are the three fundamental elements of the project’s innovation. Some of the processes used to be monitored through paper and this was a barrier to escalation of decision-making which we have now solved through the digitalisation of relevant operations (Project A, informant 3)

The process is more sustainable because predicting machine failures is not only about the maintenance process itself but about the whole production logic and the related people involved which can benefit from the related data for decision-making (Project B, informant 1)

Finally, theme (xi) relates also to the evolving improvements over time that the adopter is able to implement building on the interdependency of ecosystem capabilities. Searching for novel technologies to expand the ecosystem value proposition and resource base, is critical in dynamic contexts where both manufacturing and business process expand the ecosystem value proposition and resource base, is critical in dynamic contexts where both manufacturing and business process (Barreto, 2010). Our study addresses this by characterising the capabilities based on the activities between specialised technology firms. Consequently, this depends on the collaboration with the provider, and the adopter’s process management capabilities (Weigelt, 2013). Provider and adopter informants highlighted that it is often a bottom-up process supported by top management where operators are the first decision-makers in the production flow and may uncover different applications or ways of using the technology. From a theoretical stance this links to the importance of technological “reinvention” which facilitates the identification of opportunities to improve the technology use and leading to different innovation outcomes (Stornelli et al., 2021).

The decision-making process was clearly transformed and overtime brought the organisation from a phase were operators used to spend 80% of their time collecting data, to a post-implementation phase where they had data and could spend the available time to continuously improve operations (Project A, informant 1)

In exploring the benefits and improvements of decision-making we are now planning to develop a toolkit with the provider that would allow operators the opportunity to compose their improvement to the technology, namely an instrument to improve the data analysis focused on decision-making (Project B, informant 2)

More importantly, the scalability of the technology contributed to a higher level of network diffusion (Battisti and Stoneman, 2003). This in turn enhanced both the subsidiary plant’s innovation capabilities as well as the knowledge base of the manufacturing network resulting in enhanced innovation competitiveness:

We basically eliminated the cost of paper related to production operations. This provided both environmental benefits and operational efficiency which different plants of the manufacturing network could benefit from. And I also believe it acted as a key enabler to solve other production problems (Project A, informant 1)

5. Discussion and theoretical implications

Our work provided insights into how technology providers can address adopter firms’ challenges orchestrating an innovation ecosystem to deliver smart manufacturing solutions. In doing so, we contribute to studies on technology provider ecosystems (Benitez et al., 2020), the emerging dialogue on the related dynamic capabilities (Helfat and Raubitschek, 2018; Linde et al., 2021), and the role of ecosystem complementors (Mieh et al., 2023; Tavalaei and Cennamo, 2021). The structure of the examined innovation ecosystem case provides evidence on how each actor of a smart manufacturing ecosystem may in turn be a project orchestrator and thus shape the functioning and growth of an ecosystem (Auto, 2022; Tavalaei and Cennamo, 2021). This also reinforces the view of Nambisan and Sawhney (2011) where the ecosystem leader should ensure that the ecosystem firms can interact and accelerate product development (e.g. innovation leverage). Moreover, the leader firm is also the pivot that rallies other complementor partners by interpreting the needs of industrial markets (e.g. innovation coherence). Lastly, our findings have also shown that the ecosystem is regulated by several contractual agreements and freedom to exploit their intellectual property independently (e.g. innovation appropriability).

By empirically analysing how an innovation ecosystem of technology providers manages two smart manufacturing projects, we address the need to further understand the complex requirements and challenges to smart manufacturing (Stornelli et al., 2021). Despite agreeing that the challenges to adopt smart manufacturing technologies are likely to be greater for SMEs (Mittal et al., 2020; Müller et al., 2018), we also find that even large manufacturers need to address critical challenges (Fatorachian and Kazemi, 2018), that require a high degree of technological specialisation. Thus, we also agree that adopter firms benefit from an ecosystem of provider firms to address the need of complex technological requirements (Benitez et al., 2020).

The second contribution of our study is to dynamic capabilities theory (Teece et al., 1997). Prior studies have identified the need to examine such capabilities in different contexts and for different kinds of firms (Barreto, 2010). Our study addresses this by characterising the capabilities based on the activities between specialised technology firms. Moreover, it adds evidence to the commonalities of capabilities related to scouting partners and technologies (Linde et al., 2021), alongside the specific set of capabilities to operate within projects. Our data uncovered the nature of the highly experiential routines characterising dynamic capabilities in dynamic markets (Eisenhardt and Martin, 2000, p.1106), illustrating the processes involved for the integration of teams, technology co-development, driven by the response to complex and evolving requirements (Helfat and Winter 2011).

In addition, we provide evidence on how technology provider dynamic capabilities facilitate innovation for the adopter firm. This does not only depend on technological capabilities (Kahle et al., 2020), but it also draws upon the long-term strategy of sensing technologies, developing solutions and creating new knowledge from project experience. This analytical approach differs from focusing on the capabilities to identify the risks of ecosystem strategies and design (Adner, 2006) or on platform leadership from large corporations (Cusumano, 2002; Gawer and Cusumano, 2014; Gawer, 2014). In adding evidence to studies examining dynamic capabilities against the innovation outcomes (Ellonen et al., 2009; Sheehan et al., 2023), we provide a framework that explains the mechanism through which adopter firms build on external provider capabilities (Lorenzoni and Lipparini, 1999; Weigelt, 2013), to improve smart manufacturing system configuration and use over time. Ultimately, illustrating how the interdependency of such capabilities stimulated three main types of process innovation outcomes for adopter
firms. Respectively, process performance outcomes, and different types of process sustainability effects add evidence to the streams of literature on smart manufacturing and sustainability (Kiel et al., 2017b; Jaspert et al., 2021; Ren et al., 2019).

5.1. Managerial implications

Our study provides several implications for managers of both adopter and provider firms. First, we demonstrate that manufacturing adopter firms are constantly in need of complex solutions and thus require providers with a high level of technological specialisation. Managers can build on our study when selecting and managing ecosystems for technological innovation. This in our view has critical implications when evaluating the capabilities of a smart manufacturing provider. Following the capabilities view, we provided evidence that an established ecosystem is able to provide both customised technology solutions and coordinate activities throughout the lifetime of a smart manufacturing project. This fact is one of the key moderators for innovation since lack of capabilities from the provider side can be a significant barrier to implementation (Stornelli et al., 2021).

From the provider stance, the ecosystem we analysed provides an example of how different types of firms can accelerate their product development process and open the way to new market opportunities when being part of ecosystems. Our findings reveal that it is the ecosystem itself that through dynamic capabilities can address the requirements of large manufacturing firms. Thus, being part of an ecosystem also means being able to build on shared technological knowledge and assets (Nambisan and Sawhney, 2011). Moreover, our findings offer a summary of the key activities such as team integration and coordination activities that these capabilities encompass. Thus, managers from technology start-ups or firms delivering services to manufacturing firms may benefit from our findings when considering to be part of such ecosystems.

6. Limitations and future research

Our study has several limitations that need to be considered when interpreting the results. For example, we only focused on two cases of smart manufacturing implementation projects. Thus, both the ecosystem structure and the capabilities identified are limited to the cases explored. To compensate this gap, future research could attempt to compare and contrast different smart manufacturing projects to further explore ecosystem structures, capabilities, and learning processes. This aspect is also linked to policy agendas fostering network collaboration to resolve challenges to AMT adoption, whilst facilitating learning and implementation (World Economic Forum, 2023). Although our study highlights the importance of learning within ecosystems, we believe there is a need to further examine the overarching learning process within ecosystems and technology adopter firms. How does learning through different projects impact the evolution of an ecosystem? And how do adopter firms develop capabilities to achieve different innovation outcomes? These are some of the questions that could be addressed also building on recent academic work (Battaglia et al., 2023; Chirumalla, 2021; Szalavetz, 2019; Stornelli et al., 2021).

Since our study is qualitative, future studies could also build on surveys to explore the taxonomy of different types of ecosystems in manufacturing projects. This would also build on studies attempting to uncover the attributes of ecosystems (e.g. Gomes et al., 2021) and the ecosystem characteristics uncovered in our study.

Another limitation of our study is the intended technological development focus of the analysis. Parting from this view, future studies could focus on how different ecosystem leaders developed an ecosystem (Dattée et al., 2018). In the case of multi-sided platforms, Helfat and Raubitschek (2018) argue that leaders are required to develop dynamic capabilities such as sensing capabilities or integrative capabilities (e.g. integrating product innovations). However, this may differ according to the platform or ecosystem analysed. For example, we find that a growing best practice for large corporations is to create ecosystems within a platform-based strategy by acquiring specialised firms and enhance their digital service offers. This aspect also falls into the opportunity called from recent studies on the need to further examine the overlap between entrepreneurial and innovation ecosystems where corporations such as the ecosystem leader here analysed, may build on regional entrepreneurial ecosystems selecting several firms to create new technological solutions (Autio et al., 2018). Following this view, future studies could examine how specific technological ecosystems have been developed overtime, examining both the entrepreneurial capabilities of the ecosystem leader and the overall technological vision.

Data availability

The data that has been used is confidential.

Appendix A. Case Study Protocol and Interview guide

We constructed a case study protocol building on the steps linked to case study research (Voss et al., 2002; Yin, 2018). Below is summary of the actions taken from the choice of cases to the development of the research framework and the coding process.

(i) Cases and informant Selection: Outlining an overview of the ecosystem and case projects selected also within the experience of adopter and provider firms with smart manufacturing and the complexity of solutions being considered. For example, building on evidence showing that experience of firms with such implementations is an enabler of successful implementation (Stornelli et al., 2021). This also determined the selection of informants with the required knowledge and experience with smart manufacturing projects.

(ii) Interview approach: Based on a semi-structured interview approach the team considered a structured procedure from an initial set of questions to a tailored approach driven from the longitudinal process (Section 3.1). This evolved from an initial set of question to more specific ones into a funnel approach (e.g. Voss et al., 2002):

- An initial set of questions was shaped by the broad themes in ecosystem research. Hence, relevant to the structure and roles of ecosystem actors and hub firms (e.g. Nambisan and Sawhney, 2011).
- Subsequently, questions were tailored to the individual case study considering the type of informant for each project. This also allowed to evolve the specific lines of questioning based on the interviewee’s responses (e.g. as explained in section 3.1).
- Different waves of interviews were also undertaken to pursue various themes and evolution of projects based on our longitudinal approach. Hence seeking for additional detail alongside the evolution of the projects analysed.

(iii) Archival source from ecosystem hub firm: Researchers established the need to collect secondary data in the form of presentations from the ecosystem hub firm, illustrating how the technology was structured and developed overtime. This linked to the aim of reinforcing the construct validity.
Appendix B. – additional quotes and codes definition table

<table>
<thead>
<tr>
<th>Second order codes</th>
<th>Complexity of Adopter Requirements</th>
<th>Need to implement an integrated solution for decision-making</th>
<th>Need to develop a scalable technology solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Definition</td>
<td>An adopter’s need for a technology that can solve decision-making challenges enabling production management improvements. This results from the need of a smart manufacturing tool that can be used by multiple stakeholders of the manufacturing firm.</td>
<td>An adopters’ need for a smart manufacturing solution that can also be scaled to the different plants of the manufacturing network and thus increase multisite adoption. This entails the need of data models that can be close to the needs of other plants of the manufacturing network.</td>
<td></td>
</tr>
<tr>
<td>Example quotes for first order codes</td>
<td>Challenges linked to standardisation of production indicators</td>
<td>Requirement to increase multisite adoption</td>
<td>Requirement to create scalable data models</td>
</tr>
<tr>
<td></td>
<td>The challenge we were facing was to manage the decision-making flow starting with the shift-hand over. To solve this, we were looking for a very easy visualisation tool to monitor what was happening on site and provide a standardisation of indicators.</td>
<td>Our strategy is that a specific requirement for just one site runs the risk of remaining isolated. On the contrary if the requirement is shared we can create a standardised pool of requirements which was what happened in the year this project started (Project A, informant 1)</td>
<td>Once we implemented the technology system in one of the plants we also uncovered the opportunity to deploy it in several other plants. In this situation we benefited from scalable data models (Project B, informant 7)</td>
</tr>
<tr>
<td></td>
<td>Challenges linked to horizontal process integration</td>
<td>Requirement to create scalable data models</td>
<td>Requirements for enhancing project implementation activities from the pilot project to the post-installation phase.</td>
</tr>
<tr>
<td></td>
<td>The main problem we had in our site was mainly related to integrating data from different elements of the process. This was key for the specific monitoring of production management activities and speeding up the decision-making process.</td>
<td>Requirement to create scalable data models</td>
<td>Requirement to create scalable data models (continued on next page)</td>
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Ecosystem technology value co-creation Capabilities

<table>
<thead>
<tr>
<th>Second order codes</th>
<th>Leveraging technology search and learning opportunities</th>
<th>Developing solutions through dynamic technology integration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Definition</td>
<td>The ecosystem capability to search for novel technologies, guide the process of patent and trademark protection, alongside the improvements driven from the learning involved within the management of projects.</td>
<td>The ecosystem capability to design a technology solution supporting interoperability by leveraging the specialised technology knowledge of the ecosystem firms and the modularity capability of the technological system.</td>
</tr>
<tr>
<td>Example quotes for first order codes</td>
<td>Search routines for innovative technology opportunities</td>
<td>Leveraging the natively integrated technologies to enhance interoperability</td>
</tr>
<tr>
<td></td>
<td>Since we started, we had this technological vision of recruiting either start-ups or developing highly innovative technologies with experts or techno-parks. This type of technological innovation strategy was critical to address the requirements of complex projects (Project A-B, informant 6)</td>
<td>Leveraging ecosystem technology specialisation and modularity</td>
</tr>
<tr>
<td></td>
<td>Utilising ecosystem knowledge base for technological improvement</td>
<td>Initially this project was all about the shift-hand-over, but over time it presented additional requirements which we were able to face because of our experience in many different manufacturing firms. This knowledge base is critical to manage projects in addition to the native integration (Project A, informant 5)</td>
</tr>
</tbody>
</table>

Ecosystem Project Implementation Capabilities

<table>
<thead>
<tr>
<th>Second Order Codes</th>
<th>Dynamic integration of ecosystem actors for projects</th>
<th>Coordinating and reconfiguring implementation activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Definition</td>
<td>The capability of the ecosystem firms to dynamically configure a project team according to adopter requirements and the critical role of the project orchestrator seeking opportunities for the ecosystem and enhancing project management skills. It also reflects the management of ecosystem relationships regulated by contractual agreements.</td>
<td>The capability of the ecosystem firms to coordinate technology implementation activities from the pilot project to the post-installation phase. This entails scheduling of tasks, on the job training, and project budgeting.</td>
</tr>
<tr>
<td>Example quotes for first order codes</td>
<td>Configuring ecosystem project team</td>
<td>Coordinating activities during Proof of Concept (PoC)</td>
</tr>
<tr>
<td></td>
<td>According to the requirements firms can require an additional firm for the project. This allows the firms to also leverage different contractual agreements though a licensing agreement for the actual use of the technology and service contract. The licensing contract is referred to as an OEM contract. Whereas, all the activities developed in the project reflect revenue (e.g. service contract) (Projects A-B, informant 6)</td>
<td>Reconfiguring technology during lifetime maintenance and improvements</td>
</tr>
<tr>
<td></td>
<td>Allocating a project orchestrator role for ecosystem innovation</td>
<td>Over time we noticed how the involvement of partners is as critical as giving them freedom to operate. This is the key aspect in the innovation vision of our ecosystem where partners can become an orchestrator and build on the ecosystem strengths and develop additional skills (Projects A-B, informant 6)</td>
</tr>
</tbody>
</table>

Ecosystem Knowledge Transfer Capabilities

<table>
<thead>
<tr>
<th>Second Order Codes</th>
<th>Managing customer communication</th>
<th>Building a smart manufacturing business case</th>
</tr>
</thead>
<tbody>
<tr>
<td>Definition</td>
<td>The capability of provider ecosystem firms to manage different levels of communication with the customer to set the innovation vision in different time points of the project. This includes communicating with different corporate levels, developing a single communication interface with the customer, and managing communication for technological co-development.</td>
<td>The capability of provider ecosystem firms to support the adopter firm in formulating a business case as well as supporting the adopter with the technology knowledge on how to further benefit from the capabilities of the smart manufacturing system.</td>
</tr>
<tr>
<td>Example quotes for first order codes</td>
<td>Communicating with different stakeholders for project vision setting and training</td>
<td>Building customer value added proposition</td>
</tr>
</tbody>
</table>
Ecosystem Knowledge Transfer Capabilities

<table>
<thead>
<tr>
<th>Second Order Codes</th>
<th>Managing customer communication</th>
<th>Building a smart manufacturing business case</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>For the design of the solution the adopter was mainly involved for the user experience development. They explained to our team how their information sharing method works (Project A, informant 4) We also provided a demonstration of the potential of instant messaging, the benefits of touch screen use and everything that could be used to improve shift-handover time reduction (Project A, informant 5)</td>
<td>to justify for scalability of the system. The challenge is to build what we call a customer value added (CVA) and we helped the client to outline this value (Project A, informant 4) Providing knowledge on long-term value of the ecosystem technology adoption We provide specific knowledge on how the system can improve operations. In the perspective of the whole innovation process, we need to convince them about the long-term value of the system so that it can also address the need for the technology to eventually be scaled (Project B, informant 5)</td>
</tr>
</tbody>
</table>

Adopter Process Innovation Outcomes

<table>
<thead>
<tr>
<th>Second Order Codes</th>
<th>Process performance outcomes</th>
<th>Process sustainability outcomes</th>
<th>Evolving process sustainability outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Definition</td>
<td>A smart manufacturing system enables different forms of process performance outcomes, resulting mainly in cost reduction and overall equipment effectiveness improvement</td>
<td>A smart manufacturing system enables sustainability outcomes through improved management of the manufacturing process: improved decision-making, and reduced use of paper. Improved decision-making The instrument we created is undoubtedly a tool which leads to improved decision-making for all levels. It’s not just about production but about the different levels of the manufacturing decision pyramid. (Project A – informant 1) Reduced use of paper Our solution simply allowed to instantly exchange information on the shop-floor and transformed the paperwork into digital operations (Project A, informant 4)</td>
<td>A smart manufacturing system continuously improves the sustainability of processes by enabling collection of ideas from operators and delivering greater innovation competitiveness to the manufacturing network Improved idea collection process The opportunity for idea collection here really is bottom up. It’s the operator that through the technology capability uncovers how different pieces of information can be retrieved, ultimately reinventing the way a system can be utilised (Project B, informant 1) Enhanced network innovation competitiveness The manufacturers of the future will gain their competitiveness based on how well connected their network is. Both projects demonstrate the benefits of scaling up which provided also other plants with greater innovation competitiveness (Projects A &amp; B, informant 6)</td>
</tr>
</tbody>
</table>

Example quotes for first order codes

| Cost reduction | In almost all projects like these the outcome is primarily cost reduction. If you think about reducing the shift-handover by over 30 min and the machine breakdowns, this really impacted on the overall cost categories involved (Projects A-B, informant 6) OEE improvement The OEE improvement was something that not only was achieved but also a key driver of the project and also part of the data models we created (Project A, informant 4) |

References

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