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"Chicken or the egg": the interplay of non-technological and technological innovations in a high-tech high-growth context

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ABSTRACT

Understanding how technological and non-technological innovations interact remains a critical, yet underexplored challenge in innovation management. Some scholars argue that technological advances trigger organizational change, while others claim the reverse. To address this tension, we conducted an inductive, grounded theory case study of a high-tech, high-growth laboratory that specializes in control systems for particle accelerators. We complemented the primary data collected via interviews and observations in 2013 with a post-hoc digital netnographic and historical analysis based on secondary data for the decade following. The findings show that in the mentioned context technological innovations often precede and necessitate non-technological innovations—such as managerial, marketing, and open innovation practices. In turn, the latter enable successful exploitation and scaling. We also identify the presence of a supportive regional or national innovation ecosystem as a critical boundary condition of this interplay. The study contributes to theory by proposing a context-dependent model of innovation sequencing and highlighting the role of managerial practices in integrating the dispersed knowledge held in inter-organizational networks.

Introduction

Innovation is recognized as a vital element of competitiveness (Mansury & Love, 2008) because it is an important source of economic growth (Im & Workman, 2004; Zhao, 2024). In particular, firm-level innovation is a critical source of competitive advantage in an increasingly changing environment (Crossan & Apaydin, 2010; Mubarak et al., 2025). Innovations are thus not surprisingly found in the center of policy discussions and at the top of the academic research agenda.

Firm-level innovation has traditionally been closely associated with technological breakthroughs, with much less attention paid to the roles of management, organizational, or other non-technological forms of innovation (Alänge, Jacobsson & Jaryehammar 1998; Chenhall, 2003; Damanpour & Aravind, 2012). This 'technology-first' view, often grounded in contingency theory and technological determinism, suggests that new technologies demand organizational adaptation if they are to be effectively implemented and commercialized. Nevertheless, this perspective is increasingly questioned by scholars calling for a 'management-first' or complementarity view, one that stresses that organizational and managerial innovations—such as new structures, processes, or business models—can in themselves be prerequisites for the development and deployment of technological innovations to be successful (Birkinshaw, Hamel & Mol, 2008; Sanidas, 2004; Černe et al., 2024).

The main purpose of this research is accordingly to better understand the interplay of non-technological innovation and technological innovation. First, we built upon innovation theory, relying on the distinction between technological and non-technological innovation (cf. Černe, Jaklič & Škerlavaj, 2013a; Damanpour & Aravind, 2012; Damanpour, Walker & Avellaneda, 2009; Stundziene et al., 2024) to define the way these two basic innovation types interact. We also built on different non-technological innovation types (Chesbrough, 2010, 2006; Damanpour & Aravind, 2012; Schmidt & Rammer, 2007) and described them in greater detail using examples from our study. The difference between an exploration and an exploitation strategy (Tushman & O'Reilly III, 1996; Tushman & Rosenkopf, 1992) was considered while examining which type of innovation occurs chronologically before the other, and to determine what kind of interplay occurs when creating new knowledge.

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Even though it is broadly acknowledged that both technological and non-technological innovation are essential for firm performance and long-term growth, their dynamic interplay remains under-theorized and empirically underexplored, notably in high-tech, high-growth settings. This study intends to help address this deficiency by empirically examining the sequence and mutual influence of innovation types in a range of contextual conditions. Our research question is thus: How do technological and non-technological innovations influence each other in high-tech, high-growth firms, and in which conditions is one type the antecedent of the other?

To that end, we attempt to add to the literature concerning how dispersed knowledge held by various partners in the co-creation of value (cf., Öberg & Alexander, 2019) is transferred, integrated, and applied in the innovation processes through managerial practices. In this article, we focus on how this happens in a high-tech high-growth firm that makes control systems for particle accelerators. The firm forms part of a national ecosystem and together with different parties (users, customers, and particularly government-owned research institutions) is willing to participate in innovation processes that are openly collaborative. The aim is to inductively build theory (using grounded-theory building with a case-study approach) and provide exploratory insights into the boundary conditions determining when non-technological innovation enables (is an antecedent to) technological innovations and, vice versa, in which circumstances technological breakthroughs stimulate new technological solutions.

The article is structured as follows. After reviewing the literature on the interplay of technological and non-technological innovations, we present arguments for the two mentioned views concerning this matter. Second, we describe the case study organization, its context, and our research methodology. We then we outline the case study findings and apply the grounded-theory-building approach by offering propositions based on the field evidence. In the final section, the findings and their implications for both theory and practice are discussed.

Literature review

(Non-)technological innovation types

Recent research has expanded the scope of innovation studies by emphasizing non-technological innovations—those activities within a firm that do not involve a technical component (Damanpour & Aravind, 2012). This shift has moved the field beyond purely technology-based perspectives to more intangible dimensions of innovation (Černe, Kaše, & Škerlavaj, 2016; Stundziene et al., 2024). Several widely accepted typologies are helpful for clarifying this domain. Innovations can be categorized by subject (product vs. process), scope (new--to-the-world vs. new-to-the-firm), pace (incremental vs. radical), or nature (technical vs. administrative) (Gopalakrishnan & Damanpour, 1997; Santos-Vijande & Álvarez-González, 2007).

Product and process innovations are typically considered technological (Schmidt & Rammer, 2007), even though process innovations often include non-technological elements (Dodgson, Gann & Salter, 2008). An important distinction lies between technical and administrative innovations: technical innovations relate to products, services, processes, and technologies (Daft, 1978; Damanpour & Evan, 1984), whereas administrative innovations concern organizational structures, human resource management, and managerial processes (Daft, 1978). Some scholars regard administrative innovation as being synonymous with non-technological innovation (Sanidas, 2004), encompassing changes in routines, roles, structures, and internal relationships (Kostova & Roth, 2002; Naveh, Meilich & Marcus, 2006). In this article, we consider the broad sense of the term non-technological innovation.

Defined as non-technical process changes, organizational process innovations impact internal communication, structure, and management practices (Damanpour & Evan, 1984; Edquist, Hommen & McKelvey, 2001). These innovations include the adoption of high-performance work systems like decentralized decision-making and teamwork (OECD, 2005; Mothe & Thi, 2010), as well as knowledge management systems that foster internal and external knowledge flows (Darroch, 2005; Jang et al., 2002).

Among key subtypes, management innovation is defined as the introduction of new practices or structures that change how managerial work is performed so as to advance the organization's goals (Kimberly & Evanisko, 1981; Damanpour & Evan, 1984; Černe et al., 2015; Hamel, 2007). Management innovation encompasses structural, strategic, and procedural changes aligned with the Oslo Manual's definition of organizational innovation (OECD, 2005; Mol & Birkinshaw, 2009).

Marketing innovation, another form of non-technological innovation, entails making considerable changes in product promotion, placement, design, or pricing (OECD, 2005; Rust et al., 2004). These innovations differ from product innovations as they focus on customer interaction and market positioning more than technical specifications.

Finally, open innovation refers to the deliberate harnessing of external and internal ideas and paths to market, which calls for collaboration beyond the organization's boundaries (Damanpour, 1987; Chesbrough, 2003). Such innovations depend on external networks and amplify firm performance, especially when developing new products (Leskovec, Černe & Peljhan, 2025; Mubarak et al., 2025). The ability to successfully implement open innovation hinges on firms' dynamic capabilities—the capacity to sense, seize, and reconfigure knowledge and resources (Teece, 2007)—and also their absorptive capacity to recognize, assimilate, and apply external knowledge (Cohen & Levinthal, 1990). In addition, managing the tension between exploiting internal resources and exploring external opportunities often requires organizational ambidexterity (O'Reilly & Tushman, 2013), notably in high-tech environments where both technological and non-technological innovations must evolve in tandem.

Conflicting or complementary views on the non-technological–technological innovation relationship

To sustain their competitive advantage, firms must pursue continuous innovation, which comprises both technological and non-technological components (Damanpour et al., 2009). Although critical, by itself technological innovation is no guarantee of business success (Teece, 2010). Its benefits—such as improved productivity, flexibility, and quality (Goldman, Nagel & Preiss, 1995; Womack, Jones & Roos, 2007)—often require complementary changes to be made in management and organizational practices. In certain contexts, non-technological innovations themselves can act as immediate sources of competitive advantage. Firms that effectively integrate technological capabilities with competencies in marketing, organizational design, and management tend to be more innovative (Mothe & Thi, 2010; Lokshin, Gils & Bauer, 2009). This makes it essential to properly understand the interplay of technological and non-technological innovation.

Two dominant theoretical perspectives attempt to explain this relationship. The first one, often based on technological determinism, suggests that technological innovations work to trigger non-technological adaptations. In this view, organizational structures, management practices, and/or marketing strategies are modified in response to new technological breakthroughs to ensure their effective implementation and commercialization (Armbruster et al., 2008; Barañano, 2003; Osterwalder, 2004; Schmidt & Rammer, 2007). This implies a sequential logic is at play: technology first, organization second. Some scholars also claim that non-technological innovations lag behind technological ones and function primarily as facilitators (Askarany & Smith, 2004; Chenhall, 2003). This logic aligns with literature on business models, where technological developments influence managerial decisions (Osterwalder & Pigneur, 2010), and value creation depends on the successful integration of technology into an operating model (Chesbrough & Rosenbloom, 2002; Chesbrough, 2010).

In contrast, the second perspective questions this sequence, arguing that non-technological innovations—particularly management and organizational changes—can precede and enable technological breakthroughs (Damanpour et al., 2009; Read, 2000). Here, the focus is on firms' internal capabilities to restructure, reconfigure, or adopt new processes in ways that increase their ability to innovate technologically. Here, non-technological innovation is not a passive response, but an active driver.

Even though both perspectives offer compelling arguments, the innovation types' relationship is still under-theorized and rarely tested empirically—most evidently in high-tech, high-growth settings, where technological innovation is central to firm strategy (Sanidas, 2004). Moreover, many studies treat non-technological innovation as a monolithic construct, overlooking critical distinctions between its subtypes (e.g., managerial, organizational, marketing, open). There is a growing need for a more integrative, contextual understanding of this interplay—one that considers the timing, types, and boundary conditions of these innovation forms.

Methods

Given the limited theory regarding the interplay of technological and non-technological innovations in high-tech firms (i.e., those engaged in the design, development, and introduction of new products and/or innovative manufacturing processes via the systematic application of scientific and technical knowledge; cf. Hecker, 2012), we used *grounded theory building* and the *inductive case study approach* to better understand the non-technological innovation–technological innovation relationship. According to Strauss and Corbin (1994), grounded theory is a general methodology for developing a theory based on systematically gathered and analyzed data. We built theory according to case study research because this approach allows an explanation of the relevance and cause-and-effect relationships of observations by way of deep and detailed insights with consideration paid to the qualitative information and subjectivity that arises from the idiosyncrasies of individual cases (Kodama, 2003).

Research context

The organization chosen for this study is the Control Systems Engineering Laboratory (CSEL) ,[1] one of five autonomous laboratories (the others deal with biotechnology, bioanalytics, advanced materials, and open innovation systems) operating within a Centre of Excellence in an EU member state. The CSEL is directly managed by the private high-tech firm ContSyst, a world-leading firm that supplies control systems for particle accelerators. They primarily offer software solutions, high-tech products and accompanying services, but also hardware for large physics experiments such as nuclear accelerators using beamlines. Their clients are large laboratories in Europe, the U.S.A., Japan, and Australia. Notwithstanding that the private firm ContSyst exhibits direct governance, the CSEL is funded by the European Union (Regional Development Fund) through the mentioned member state's Ministry of Education. Apart from ContSyst and two research and two higher education institutions, three other high-tech companies from the same member state founded the Centre of Excellence.

The CSEL's location at the intersection of high technological intensity and institutional complexity makes this dual embedding—within a high-tech industry and a national innovation ecosystem—a compelling site for studying the parallel evolution of technological and non-technological innovation. On one hand, the CSEL's competitive edge rests on delivering cutting-edge, technically sophisticated products to elite scientific institutions around the world. On the other hand, the organization has increasingly relied on non-technological innovations—including open innovation practices, internal academies, and service-based business models—to scale, sustain, and commercialize its core technological breakthroughs. As such, the CSEL offers a unique vantage point for investigating how innovation types interact in practice and how their interplay is affected by ecosystem-level boundary conditions. The case exemplifies how a contextually embedded, project-based, high-tech, and mixed public-private entity with a direct goal to innovate (Fig. 1) manages the recursive technology development–managerial adaptation relationship in the conditions of rapid growth and complexity.

Data collection

We used the data triangulation technique to strengthen confidence in the accuracy of the findings (Jick, 1979). The main method for collecting the primary data was semi-structured interviews, which were conducted with several employees in the second half of 2013. To revisit the case study one decade later, we employed a hybrid methodological approach that combines digital netnography (Kozinets, 2010) with a historical case study extension. This entailed systematically gathering and analyzing publicly available digital traces of the subject organization and its ecosystem—such as official websites, project documentation, press releases, social media activity (e.g., LinkedIn, Twitter, ResearchGate), R&D grant databases, patent filings, and media coverage—for the period 2013–2023. The described digital and archival corpus enabled us to trace the chronological trajectory of organizational narratives, strategic positioning, and innovation discourse over time. We applied a time-based bracketing strategy, placing the material in three main periods (2013–2015, 2016–2019, 2020–2023). The mentioned approach allowed us to examine how earlier grounded theory propositions have held up, evolved, or been contradicted by fresh developments. In addition, it supports post-hoc theorizing, in turn leading to the original model's refinement or extension by interpreting shifts in innovation practice and contextual embeddedness over time.

In 2013, we conducted five interviews with individuals from the CSEL: the CEO, one of the vice presidents, and three product developers. The interviews lasted 40 to 60 min.

The interview guide had three sections. First, we asked questions about the importance and the relationship between technological and non-technological innovations at the CSEL, where focus was given to views on which type stimulates (is an antecedent to) the other. Second, informants were asked to describe the most important non-technological innovations, being prompted with questions on aspects like how non-technological innovations contribute to the laboratory's success, which specific activities could be related to certain non-technological innovation types, how they support those activities, and who (which organizational unit) engages in them. Third, questions were raised concerning the influence of innovation ecosystems, with a stress on establishing how their owners (ContSyst) and the relatively high levels of autonomy (and financing) within the CSEL influence the innovation process.

In addition, one of the researchers spent some time at the case study site (entailing the method of observation by involvement), working on a collaborative project with employees of the CSEL within the Centre of Excellence, to obtain a better perspective on the laboratory's everyday functioning. Secondary data sources (e.g., business publications, Internet sources, corporate project reports, employee lists, etc.) were also reviewed to add to the researcher's understanding of the innovation process in the case study organization, along with their collaborations with outside partners (firms and public institutions). Overall, we obtained rich and useful qualitative and quantitative data for conducting detailed research into the case.

In an effort to reduce potential information bias, the interview data were collected in several waves over 3 months. We initially conducted three interviews, collected the secondary data, and participated in a joint research project, and reviewed the triangulated data so obtained.

[1] The names Control Systems Engineering Laboratory and ContSyst have been altered to keep the respondents anonymous.

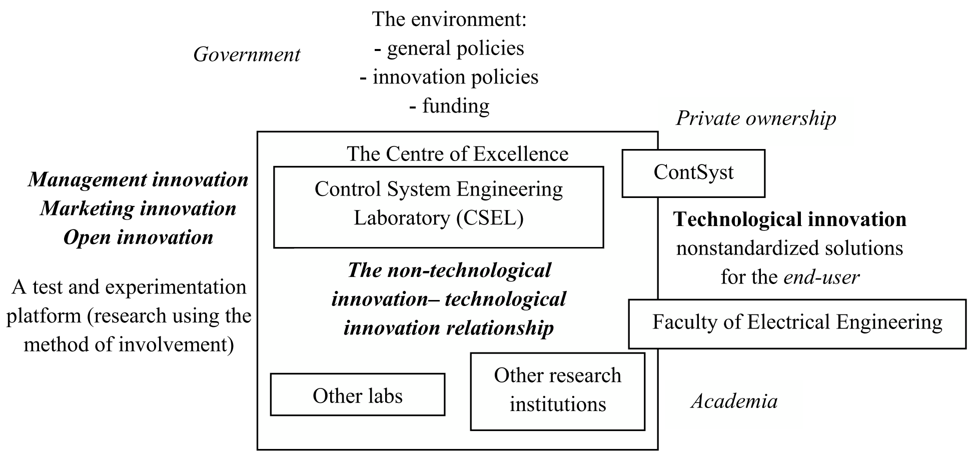

Fig. 1. Overview of the research setting.

Data were then analyzed by emphasizing themes supported by both different data collection methods and several informants (Jick, 1979). Next, we conducted additional two interviews to provide missing details. Two researchers reviewed the data to form independent views on the process of forming the collection of materials. The case description was about 30 pages in length, including quotes (vignettes) and timelines. The views expressed therein were synthesized with secondary data provided by the firm. Tables and other cell designs were developed to compare several types of technological and non-technological innovation, and the respective activities entailed. Finally, tentative relationships between the constructs and themes were established, together with the propositions presented in the section below.

Results

The findings are organized so that evidence is first provided regarding how technological innovations encourage the need for novel non-technological solutions, before briefly describing examples of different types of non-technological innovation that support technological innovations in this studied high-technology context. We then continue to explore how a regional or national innovation ecosystem can serve as a key success factor for enabling non-technological innovation to support technological ones.

The interplay of technological and non-technological innovations

The CSEL is a high-tech laboratory specializing in software and hardware solutions for turnkey control systems used in large-scale physics experiments. Its core technology powers nearly 100 radio telescope labs worldwide, and it maintains a competitive edge by delivering advanced solutions for use with automotive and nuclear accelerators. The CSEL can maintain its competitive advantage because the laboratory's core activity to do with such intended uses entails increased product technological complexity, coupled with the generating of innovative technological ideas and implementing them in a new product. As one interviewee stated:

> *"We build our competitive advantage on providing only the best, cutting-edge technologies of the highest quality and reliability to one of the most technologically demanding markets."*

The list of the CSEL's projects reveals that the laboratory innovation processes have chiefly focused on technological innovations. Namely, the list only shows key technological achievements and breakthroughs, without attention to any non-technological innovations. This makes it unclear whether technological innovations are a key competitive advantage and the CSEL's central focus is to convince prospective customers that it possesses all the necessary technological capabilities. The importance of technological innovation is also reflected in the staff structure. While the CSEL employs around 40 scientists mostly specialized in physics, engineering, mathematics, or computer science, it does not currently employ anyone with a background in the social sciences. One interviewee stated, "*In order to remain competitive, the company must continuously invest its efforts in keeping its control systems up to date with the latest developments in technology*."

Accordingly, the CSEL only employs experts specialized in, or at least holding some experience with, control systems to make sure they can respond quickly to any challenge in the control system. The CSEL's key experts also must have first-hand experience and a deep understanding of facilities for physics, notably particle accelerators, synchrotron radiation beamlines, and radio telescopes. In this way, they can be up-to-date with technological breakthroughs in all areas related to the control system. However, the interviewees suggested that even though technological innovations are the most important, after the laboratory began to grow it soon realized that it also needed non-technological innovations to support the technological ones. As a key employee of the CSEL noted:

> "*When setting up our company we were mainly focused on technological innovations. These allowed us to enter these demanding markets and get the first customers. However, as soon as the company began to grow, we realized we would also have to pay attention to some non-technological innovations, especially managerial ones, so as to become the best control system in the world and be able to support our technological innovations. Managing the implementation of several demanding projects in different countries for various customers truly calls for some creative non-technological solutions.*"

The temporal dimension is highlighted more strongly below:

> *"When we launched our adaptive control module for synchrotron beamlines in 2012, we soon realized that our internal coordination processes couldn't keep up with the number of simultaneous international deployments. That's when we had to completely redesign our project management framework—setting up dedicated integration teams and standardized implementation protocols."*

A consequence of the CSEL's success with technological innovations was that it added to the awareness of how important non-technological innovations are. The CSEL realized that "*added value for the company is not just doing a few months of engineering work* [technological innovation], *but really providing a full service that includes project management* [non-technological innovation]":

> *"In a way, it was a learning-curve for us. Through experience and the passing of time, we identified new global markets with established*

competitors, we came to grasp the fact that only being the best at innovating technologically is not enough."

This led staff at the CSEL to realize they must meet all of the customers' demands: by possessing new, advanced, and high-quality technologies able to be implemented at the lowest possible cost, and working with customers that are flexible and reliable. And that this also requires some non-technological solutions. The CSEL therefore introduced a business approach which permits it to sell its technological discoveries in a way that addresses these demands. For example, today they offer whole control system integrations encompassing both technological and non-technological innovations. It describes its business model with the following catch-phrase: "*A sale in a supermarket: pay one* [technological innovation], *get many* [including non-technological innovation]." Namely, the CSEL sells its innovations (based on a technological solution) as a complete solution. Its standard package includes full project management, the installation and turnkey handover of control the system at a fixed price. It is thus clear that staff at the CSEL are aware of the need to support their technological discoveries with some innovative non-technological approaches, principally aimed at optimizing development processes and ensuring efficient management. The CEO of the CSEL stated:

"They [our customers] get a complete service. If that means that one of our guys has to live there [on the customer's premises] for a couple of months, so be it! We adapt fully to the wishes of our customers—if they're willing to pay for them to be fulfilled."

Taken together, the CSEL realized that to be competitive the laboratory's technological innovations had to be supported with some non-technological ones. Even though its key competitive advantage is knowledge and expertise regarding control systems and system engineering, it must at the same time develop knowledge about processes and project management. The CSEL's internal analysis shows that in order to achieve the set goals it was necessary to work more intensively on developing non-technological innovations.

There are thus two key challenges for it concerning non-technological innovations. First, the CSEL must work on its management innovations so as to allow it to successfully manage its complex business model. Second, the CSEL discovered that it is important to employ people who have the right selling competencies, as that will permit them to successfully sell the laboratory's technological innovations. While there were no obvious instances in the data where managerial or organizational innovations had independently initiated new technological developments, we interpret this as a sign of the CSEL's position as a deeply technology-driven organization embedded in a science-based ecosystem. We expressly acknowledge this absence, bolstering our argument that the directionality of the interplay of the innovation types is likely to be context-dependent.

The abovementioned evidence leads to the first proposition considered in our study:

P1: *Technological discoveries spur on the need for new non-technological solutions to better exploit innovation.*

Specific non-technological innovation types as mechanisms to support the exploitation of technological innovation

Multi-source evidence shows that one of the most important managerial non-technological innovations is the *ContAcademy*, directly run by ContSyst (the CSEL's owner), that introduces every new employee to the laboratory and its practices. One interviewee stated, the CSEL "*puts great emphasis on its staff and human resource procurement and development since the best products can only be delivered by the best experts.*" The CSEL namely uses ContSyst's in-house academy to test new and promising students with various tasks, and thereby assure the transfer of knowledge, and especially to maintain the organization's culture and values. The acquisition of new personnel is based on recruiting the leading students from various faculties of the country's main university. Collaboration with higher education institutions helps the CSEL to obtain the very best students in a given research field.

The selected students then undergo a three-stage education and training process. Step one in the process is a teaching phase where chosen students are given tasks to solve. Each student is assigned a mentor who reviews their performance, directs them towards success, and generally represents the link between the laboratory and the students. In step two at the *ContAcademy*, the CSEL assigns students to work on less demanding tasks. After learning the work somewhat more, students receive concrete roles in the project, yet without any strict time limit. If they complete these tasks successfully, they are paid a predetermined amount of money. If the tasks were not completed, an expert at the firm does it instead. Finally, in step three, students are allowed to work on production tasks. When employees at the CSEL become familiar with the students and trust has been established, students become directly involved in current projects. Students either work full- or part-time. Through the Academy, the CSEL forms employees familiar with what the organization does and able to spot opportunities to apply their knowledge, skills, and capabilities to establish new business opportunities for the laboratory, even a new spin-off.

Organizational culture change is another non-technological innovation fostered by ContSyst. In the opinion of one interviewee, ContSyst's organizational culture is "*based on very capable and skilled staff, the continuing professional development of employees, who also know the basics of entrepreneurship, and the relaxed attitude in a friendly work environment where everyone is committed to achieving the common goals and helping each other*." When it comes to the employees' professional development, on average each employee devotes about 5 % of their working time to training and education. The training programs in place show the employee training activities are designed for different types of workers.

The laboratory organizes ongoing annual courses that are held over 1 week. On offer are courses are in which employees can learn and improve their knowledge of foreign languages (e.g., French, German) and upgrade their managerial skills (e.g., work efficiency, finance, time management, human resource [HR] management, growth). These courses provide ContSyst employees with the knowledge they need to implement the non-technological innovations required. For example, at present ContSyst does not employ a full-time HR expert. Therefore, technical people and managers with good 'people skills' deal with the selection process, make employment decisions, and support new employees' organizational socialization. Nonetheless, employees with technical backgrounds do not possess the proper knowledge to deal with HR issues. To equip technical employees with the necessary HR management knowledge and skills, the company organized training on HR management. In addition, as required, ContSyst organizes technology-based trainings at which employees can learn about the most recent breakthroughs in the field. The company also arranges mentorship programs for newcomers, such as JavaAcademy, EPICSacademy, FPGAcademy, LabViewAcademy, and TANGOAcademy. The overall purpose of these training and education activities is to maintain the organizational culture that values knowledgeable and skillful employees. Namely, regardless of the type of work performed, every employee must be fully equipped with knowledge that allows them to be the best at whatever they do.

The importance of the organization's culture is also visible in the fact that despite the company being willing to employ excellent people from outside, it prefers to employ 'home-grown' individuals (it has around 80 % of such employees)—those who first worked in the company as students and completed the in-house Academy. The result for ContSyst is that it has a somewhat unexpected employment structure for a high-tech company: besides 50 full-time employees, about 30 students are also working for the company. The great advantage of 'home-grown' employees is that they are already aligned with the company's values, in turn lowering the risk of a cultural mismatch. One interviewee opined:

"Unfortunately, in the past, we experienced the negative consequences of cultural mismatch through which we learned that the organizational culture is really important. Organizational culture and the company's values have a tremendous impact on the company's success. Therefore, it is very important to obtain the right people compatible with the company's organizational culture."

Further, CSEL employees must respect ContSyst's values because those values serve as unwritten rules, promoting familiarity and respect, accessibility, fun, hard work, autonomy, and participation. Finally, the CSEL has also introduced a few marketing/sales innovations, which mostly can be attributed to the view held by the CSEL and ContSyst on their product. Although offering what is predominantly a high-tech solution, they constantly advertise and sell it as a service. Through experience, they have namely learned that it is easier to sell technological products if you package them together with service activities. The CSEL discovered that the learning curve for installing its technology is very steep because knowledge must be acquired from a wide range of different areas. Thus, alongside the technology, the CSEL also 'sells' customers its knowledge with respect to implementing the technology for control systems. This has seen CSEL employees travel all over the world on service missions, working on the customers' premises for a few months, and returning after they have successfully implemented their control systems and taught their customers how to operate them. According to one interviewee:

"The collaboration of the company's experts with the in-house experts proved to be a very efficient way to sell our control systems. In that way, our customers see us as more reliable as they personally know the personnel who are developing their control system. On the other hand, since our employees personally know our customers, they generally have no problem working overtime and on the weekend when they go and help a customer. And this has a huge impact on the quality of the customer relationship and consequently on the company's competitive advantage and profit."

Table 1 illustrates the co-existence of different innovation types at the CSEL based on this evidence. This leads to the second proposition considered in the study:

P2: *Technological product innovation is supported by three non-technological innovation types (open, management, marketing). In a high-technology context, these are not antecedents and instead act as mechanisms enabling the technological innovation to be exploited.*

The influence of a national innovation ecosystem on the interplay of technological and non-technological innovations

As already described, the CSEL is institutionally embedded in two entities. First, there is the private ownership of ContSyst, a world-leading firm in producing control systems. Second, there is the organizational involvement in the Centre of Excellence that is funded partly by the EU Regional Development Fund and partly by the member state's Ministry of Education. Besides the private firm ContSyst, three other high-tech companies founded the Centre of Excellence, in addition to two research and two higher education institutions. This ownership and governance structure of the Centre of Excellence facilitates the flow of knowledge among crucial actors in this national innovation ecosystem, but also beyond through the connections provided by the parent firm ContSyst.

Connections within the CSEL's national innovation ecosystem are accordingly largely related to the abovementioned collaborations with higher education institutions (where they target the best students) and its embeddedness at the Centre of Excellence (which enables access to research and education institutions). Still, they are also related to other private high-tech firms from the same or different industries (the Centre of Excellence was partly funded by four high-tech firms and it is collaborating with around 40 more). This network position also permits access to entrepreneurial education platforms, thereby supporting the CSEL's academic start-ups to flourish and any spin-off initiatives that emerge from the laboratory or ContSyst. Although we also examined other contingencies that could influence the focal non-technological innovation–technological innovation relationship, this embeddedness was shown to be one of the most important success factors in the case study.

The CSEL's success was also related to start-up initiatives by the member state's government, largely through the capital available at the Technology Park, which assisted the CSEL with infrastructure, advice, and cheaper services. The institutional embeddedness with higher education and research institutions meant it was able to obtain quite a large sum of grant money by applying for various R&D projects. This helped the CSEL enrich its understanding of industry value chains, maintain its outsourcing policy, and comprehend the industry structure. In particular, it sees value in better understanding the nature of industries in need of complex technology integration (such as what it supplies). Are these industries flat or growing, are capital investments predicted, and *who* is investing? As one of the funding bodies of the CSEL through the Centre of Excellence, the government has also stepped up, making payment and support procedures for exporting activities easier in the 2009–2013 period.

Interviewees at the CSEL described their institution as a small player in a small market, and hence that the market's size and growth are not limiting factors. Even if the market does not grow, they are perfectly happy to obtain niche business because they sell services and are able to do this across markets provided that the markets have used similar technology, with information on the latter from their environment being needed. CSEL employees also use their connections to analyze companies in a similar stage of growth as theirs to make sure they understand how the laboratory can develop from a group of professionals/ enthusiasts to become a larger company. In the opinion of one

Table 1
Key innovation types present in the case study.

Innovation type	Technological innovation	Management innovation	Marketing, service, and sales innovation	Open innovation
Specific innovation in the CSEL, scope (new to the world or new to the firm) and radicalness (radical or incremental)	Software solutions and hardware basis used in turnkey control systems for particle accelerators (new to the world, both incremental and radical)	Student recruitment procedures, collaboration with academia (new to the firm, incremental) The three-stage process of education and training at the ContAcademy (new to the firm, radical) Fostering the organizational culture and the CSEL's values (new to the firm, incremental)	Providing a full service - whole control system integrations: full project management, installation, and turnkey handover of control system at a fixed price (new to the firm, radical) Employees going on service-missions all around the world, working on their customers' premises (new to the firm, radical)	Participation in the Centre of Excellence and strategic collaboration with other laboratories, founders, high-tech companies, and academia (new to the firm, radical) Participation in entrepreneurial education platforms to support spin-offs (new to the firm, radical) The Ljubljana Technology Park collaboration on infrastructure, advice, and cheaper services (new to the firm, incremental)

interviewee:

"The key role is played by the employees, their knowledge and skills, and subsequent technological innovations. However, almost equally important are the enabling mechanisms that help to transform these technological breakthroughs into marketable and successfully implemented innovations; namely the connections within the national/regional innovation system, and the organizational and marketing solutions we have produced since innovating technologically."

Combined, the above combined evidence leads to the third proposition that guided our study:

P3: *The presence of a strong regional or national innovation ecosystem is emerging as a critical boundary condition concerning the extent to which non-technological innovations can effectively support and amplify technological breakthroughs. Such ecosystems facilitate vital inside-out and outside-in knowledge flows, notably in high-tech contexts where collaboration, funding infrastructure, and institutional links add to the capacity to integrate and scale innovations.*

All three propositions are displayed in Fig. 2, which includes the research framework for studying the central constructs in future research. The figure conceptually illustrates the dynamic and context-dependent interplay of technological and non-technological innovation. Rather than depicting a linear cause-and-effect path, what is shown is a recursive feedback loop in which technological breakthroughs in high-tech settings often act as initial triggers, prompting the development of complementary non-technological innovations—such as managerial structures, marketing models, and open innovation practices. These non-technological responses are not simply reactive but play an enabling and amplifying role, allowing for the effective implementation, scaling, and commercialization of the original technological advances.

Over time, this interplay becomes cyclical: the successful deployment of innovations often generates new learning, market pressures, and/or organizational challenges which, in turn, spark off further rounds of both technological and non-technological innovation. Crucially, the innovation ecosystem is not presented as a causal driver in this loop, but as a boundary condition—a contextual enabler that determines the extent to which this interaction can unfold productively. A supportive ecosystem facilitates knowledge flows, resource access, and inter-organizational collaboration, thus influencing the direction, intensity, and timing of innovation sequences. This interpretation is in line with our broader contribution: a contingent, integrative model of innovation that accommodates both sequencing patterns and ecosystem-specific dynamics, offering a flexible framework for understanding innovation processes across a range of organizational and sectoral settings.

Ten years later: revisiting the case through digital netnography and historical extension

So as to consider how relevant our original propositions are today, we revisited the CSEL case one decade after the initial data collection. For this, we adopted a hybrid methodological approach combining digital netnography and a historical case study extension, concentrating exclusively on secondary data sources available in the public domain. This included digital traces such as updated websites of the CSEL, ContSyst, and the Centre of Excellence, as well as publicly accessible project reports, news articles, social media content (primarily LinkedIn), participation in R&D consortia, and patent databases. The goal with this process was to track the evolution of the organization's innovation practices, strategic orientation, and ecosystem positioning from 2013 to 2023.

Our revisit was structured with a time-based bracketing strategy that divided the collected material into three broad periods: 2013–2015 (immediate post-study phase), 2016–2019 (mid-term evolution), and 2020–2023 (recent transformation) – see Table 2 for an overview. In the first phase, we observed continuity in the CSEL's core strategy, with technological innovation as the main pillar and the increasing formalization of managerial processes like employee onboarding and training. Between 2016 and 2019, public records and LinkedIn content revealed the scaling of non-technological innovation activities, especially the expansion of the in-house academies, mentorship structures, and market-facing project integration models. These developments align with and reinforce proposition 2, supporting the view that management and marketing innovations proved to be vital for enabling the exploitation and internationalization of the technological advances.

The most notable shift came in the 2020–2023 period. Responses to the COVID-19 pandemic appear to have accelerated the virtualization and modularization of the CSEL's offerings. Digital platforms for system testing, remote installation, and long-distance collaboration—previously peripheral—gained prominence. Simultaneously, the CSEL's participation in EU Horizon programs and innovation consortia grew more visible, suggesting a strategic repositioning within a broader transnational innovation ecosystem. Rather than relying solely on the national ecosystem, the CSEL increasingly tapped into European-level structures for funding, knowledge exchange, and collaborative development. This trajectory confirms proposition 3, which stressed the enabling role of national ecosystems, yet it also refines it: over time, the ecosystem embeddedness appears to have expanded beyond national boundaries, with the organization ever more leveraging multi-level innovation systems to scale, adapt, and sustain its activities.

Discussion with contributions

The case study in a high-tech, high-growth, and institutionally-embedded context led to three propositions based on grounded-theory building (cf. Strauss & Corbin, 1994). First, after analyzing the case study data, we proposed that technological product innovation encourages the need for new non-technological solutions. This finding is in harmony with the technology-first perspective, which argues that technological breakthroughs often precede and necessitate complementary changes in management, organization, and service design (cf. Chenhall, 2003; Askarany & Smith, 2004). However, rather than decisively siding with one view, our findings were interpreted via a

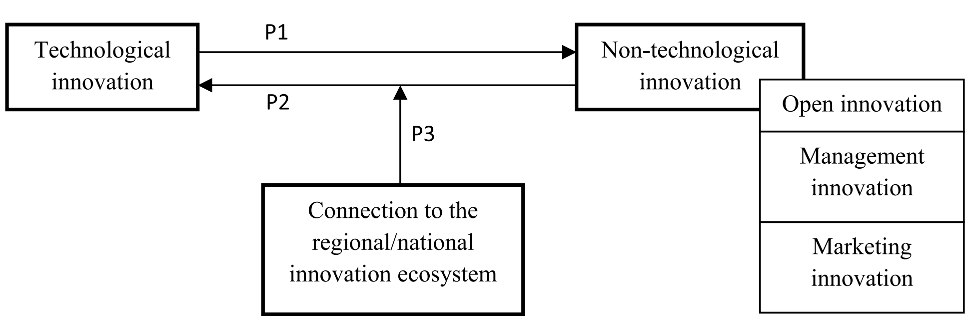

Fig. 2. Research framework with the propositions.

Table 2
Netnographic evidence behind the evolution of innovation practices at the CSEL (2013–2023).

Time period	Key developments	Netnographic sources	Relationship to the propositions	Example quotes
2013–2015	A continued focus on technological innovation; the formalization of onboarding and technical training via internal programs	Archived versions of the CSEL website (2014); an employee training manual (available in a 2015 blog post); LinkedIn posts announcing new hires	*Supports* Proposition 1: Tech innovations created the need for managerial structures.	"We've just launched our structured onboarding process for junior engineers to ensure project readiness from day one." – CSEL internal blog, Oct 2014
2016–2019	Expansion of the *ContAcademy*; increased LinkedIn postings on mentorship and student recruitment; market-facing integration models mentioned in blog posts	LinkedIn company updates (2017–2019); blog articles on mentoring and training programs; news featuring partnership projects	*Supports* Proposition 2: Non-tech innovations enabled global tech deployment.	"Mentorship through the ContAcademy has become our strongest pipeline for talent—students transition into lead roles faster than ever." – LinkedIn post, June 2018
2020–2023	Launch of virtual integration platforms; remote implementation services highlighted in white papers; joined the Horizon Europe transnational consortium focused on vaccine development technologies; resulting in spin-offs for sensor calibration and real-time control systems	The CSEL's LinkedIn posts on completing remote projects; Horizon Europe project listing (cordis.europa.eu); a webinar transcript on a vaccine consortium (2021); patent filings on sensor-based control systems (2022)	*Refines* Proposition 3: The ecosystem moved from being national to transnational.	"Our expertise in real-time control systems found an unexpected application in vaccine cold-chain tracking—this pivot opened up new product lines." – CSEL presentation at the EU consortium summit, March 2022

contextual and integrative lens. While our evidence supports a 'technology-first' sequence in this particular high-tech, high-growth setting, it must be emphasized that this does not invalidate the alternative 'management-first' or complementarity perspective. On the contrary, we suggest that in fast-paced, R&D-intensive environments like the CSEL's, technological advances might more frequently trigger the need for non-technological adaptations. Yet, this pattern may vary in other contexts—such as in service-dominant or process-driven industries—-where organizational or managerial innovation may take the lead. For example, Černe et al. (2024) focused on the industry 4.0 context (manufacturing-heavy) and found an interaction between technological and non-technological innovation elements driving performance rather than a sequential causal view. We thereby we contribute to innovation literature not just by offering empirical support for one side of the longstanding debate, but also by clarifying the boundary conditions limiting when different innovation sequences can emerge.

Further, we established that technological innovation is supported by three non-technological innovation types: open, management, and marketing. In this manner, we contributed to the fast-growing research area of non-technological innovation (cf. Černe, Jaklič & Škerlavaj, 2013b; Damanpour & Aravind, 2012; Stundziene et al., 2024) by specifying and evaluating the most important non-technological innovation types applied in the high-tech context of a laboratory engaged in control system engineering. Our study lends support to recent findings concerning the importance of the non-technological innovations. Namely, the case study research suggests that even high-tech companies who primary focus is on technological innovations need at least managerial and marketing innovations to sustain their competitive advantage. Technological innovations have a significant impact on a company's business model and so new non-technological solutions are required to support the changes they bring and ensure successful innovations in the long run.

In our efforts, we distinguish the sequencing of innovation types (P1) from the specific functional roles (P2) played by non-technological innovations in supporting technological advancements. The findings suggest that in high-tech, high-growth contexts, technological breakthroughs often act as initial triggers, creating challenges that demand non-technological responses. At the same time, we showed that it is not just any non-technological change that matters. Instead, distinct forms like managerial innovations (e.g., project coordination and human resource development), marketing or service innovations (e.g., solution bundling and customer integration), and open innovation practices (e.g., participation in consortia) must be strategically mobilized to transform technological potential into performance outcomes. This layered perspective builds on and extends prior research that highlights the importance of disaggregating innovation types (Schmidt & Rammer, 2007; Damanpour & Aravind, 2012), and it responds to calls for more empirical grounding regarding how these types function together (OECD, 2005). By combining temporal insights with a typological lens, we provide a more nuanced understanding of how innovation unfolds across domains—revealing both the order in which innovation types may emerge, and the distinct purposes they serve within the broader innovation process.

We also discovered a case-specific finding shaped by the CSEL's institutional embeddedness—being situated at the intersection of private ownership and EU-funded, project-based governance within a Centre of Excellence. In this setting, having a connection to a regional or national innovation ecosystem (P3) emerged as a key boundary condition that enables non-technological innovations to effectively support technological breakthroughs. This finding is consistent with the open innovation paradigm (cf. Chesbrough et al., 2006; Chesbrough, 2007; Leskovec et al., 2025), which underscores the importance of exchanging inter-organizational knowledge for innovation and value creation (Cabrilo, Dahms & Tsai, 2024; Wang, Wang, Pan & Mata, 2024), while reinforcing and extending it by stressing how openness serves not simply to generate ideas, but also to operationalize and scale them within complex, high-tech ecosystems. Drawing on innovation ecosystem and national innovation systems literature (Lundvall, 2007; Edquist, 2010), we interpret the CSEL's ecosystem embeddedness as an enabling context rather than a causal driver—one that provides access to funding, talent, and knowledge flows, while facilitating risk-sharing and cross-organizational learning. These conditions are especially consequential in high-risk, R&D-intensive sectors where the ability to experiment with and institutionalize managerial and organizational innovations hinges on external support structures. Even though this embeddedness generally functioned as a strategic asset in our case, we also acknowledge that such arrangements can bring the risk of double-governance and potentially conflicting institutional logics—albeit no such tensions were observed in the case study.

Our findings echo early organizational theories which pointed to the technological imperative in shaping organizational structures and practices. Classic studies by Burns and Stalker (1961) and Woodward (1965) claimed that technological complexity and change drive the need for corresponding structural and managerial adaptations within firms. This perspective is reflected in our case where technological breakthroughs repeatedly put pressure on the CSEL to develop new management processes, project coordination structures, and external-facing service models. Nevertheless, our study adds an important contextual element to this established view. Rather than treating technology as an isolated driver, we found the organization's responses to technological advances were deeply embedded in and enabled by the broader innovation ecosystem. Public funding instruments, strategic partnerships, and transnational project networks provided not only resources but also legitimacy and templates for managerial innovation. This indicates that it is not technological innovation alone, but its *interaction* with the surrounding institutional and network context, that influences how organizational change unfolds—a layer not considered in earlier technological determinism accounts (Burns & Stalker, 1961; Woodward, 1965).

The post-hoc analysis conducted 10 years later underlines the fact that while the original grounded model continues to hold significant explanatory power, innovation ecosystems are inherently dynamic and their boundaries permeable (Granstrand & Holgersson, 2020). Firms like the CSEL actively navigate and reshape these ecosystems in response to technological advancements, market dynamics, and geopolitical changes (Dhanaraj & Parkhe, 2006). Of note, non-technological innovations—such as managerial and marketing strategies—have become ever more pivotal, moving from supportive roles to central components of strategic differentiation, even within technologically focused organizations (Chesbrough & Bogers, 2014). This evolution shows the need for further research into the progression of multi-level ecosystem integration as high-tech firms mature, expand internationally, and confront systemic disruptions.

Managerial implications

Alongside its theoretical contributions, the presented research provides several actionable insights for innovation managers in high-tech firms. First, the findings suggest that by themselves technological breakthroughs are insufficient for sustaining a competitive advantage unless complemented with targeted non-technological innovations. Managers should proactively invest in developing managerial innovations—such as project coordination mechanisms, onboarding and training systems, and/or cross-functional collaboration routines—that support the implementation and scaling up of technological advancements. Second, marketing innovations, including the bundling of services and customer co-creation strategies, should be embedded early on in the product development cycle to assure that high-tech solutions are market-ready and user-centered. Third, managers should actively cultivate open innovation capabilities by establishing structured partnerships with public institutions, research centers, and ecosystem consortia. This includes participating in transnational programs (e.g., EU Horizon), joining innovation networks, and setting up internal roles dedicated to managing external collaborations. Finally, innovation managers are encouraged to regularly evaluate the alignment of the internal organizational structures and the evolving demands of their technological portfolio to make sure that managerial and marketing practices develop in step with R&D intensity.

Limitations, future research suggestions, and a conclusion

Naturally, despite the aforementioned contributions, our study is not without limitations. The first and perhaps most salient one relates to generalizability concerns – our findings can most likely be applied in similar high-tech contexts, yet are only based on a single case study. The observed sequence—whereby technological breakthroughs stimulate the need for managerial, organizational, and marketing innovations—might be seen especially in R&D-intensive, high-tech environments like that of the CSEL, where rapid technological change demands agile non-technological adaptation. In contrast, in more traditional or low-tech sectors the sequence may be in reverse, with managerial innovation or business model transformation preceding and enabling the adoption of new technologies. Moreover, the CSEL's institutional setting is atypical even within the high-tech domain: it is a semi-public, project-based organization embedded in a public–private innovation ecosystem, with strong links to government research institutions and supported by EU regional funding. These features have likely shaped the organization's innovation dynamics and might not be generalizable to private start-ups or more isolated tech ventures.

We therefore reiterate the exploratory and theory-building nature of our study. Our propositions are intended as analytical generalizations that offer conceptual insights. Future studies may test and refine them in other contexts, perhaps in a different sector/industry or by conducting a meta-synthesis study across industries and institutional context. Another limitation concerns relying predominantly on qualitative data. Quantitative approaches (e.g., via questionnaires for company employees who innovate technologically and non-technologically) could prove to be useful for testing the propositions, perhaps on a larger sample, and be able to offer more generalizable results. Applying this approach, different dimensions of openness might also be considered as playing a role in shaping innovation ecosystems (Öberg & Alexander, 2019) and hence in our boundary-oriented P3.

Nonetheless, our study entailed a novel empirical investigation focused on adding detailed insights with respect to the relationship between non-technological and technological innovation in a high-tech high-growth context. We showed that non-technological innovations are valuable for supporting technological solutions, but also emphasized that technological breakthroughs are the key driver or reason that non-technological (open, management, marketing) innovations occur. In summary, this study adds to innovation management theory by inductively exploring how innovation types co-evolve within this specific context. By tracing this interplay, the study helps to bridge the long-standing divide between technology-push and organization-pull perspectives, offering a more nuanced, context-dependent understanding of innovation sequencing and integration.

CRediT authorship contribution statement

Olivera Vlahović: Writing – review & editing, Writing – original draft, Validation, Conceptualization. **Darija Aleksić:** Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Matej Černe:** Writing – original draft, Resources, Project administration, Formal analysis. **Tomislav Hernaus:** Writing – review & editing, Validation, Supervision, Resources, Project administration. **Miha Škerlavaj:** Writing – review & editing, Visualization, Supervision, Project administration, Conceptualization.

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