Technological Forecasting & Social Change 162 (2021) 120378

Contents lists available at ScienceDirect

Technological Forecasting & Social Change

journal homepage: www.elsevier.com/locate/techfore

The genesis of public-private innovation ecosystems: Bias and challenges☆

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ARTICLE INFO

Keywords:
Public-private cooperation
Innovation ecosystems
Ecosystem genesis
Cyber-physical systems
Loose coupling
Application domains

ABSTRACT

The emergence of technology increasingly depends on innovation ecosystems and frequently involves actors from both industry and academia. However, value creation may experience challenges due to bias formed during public-private innovation ecosystem genesis.

This empirical study of bias in a new pan-European public-private initiative provides results regarding innovation ecosystems and the individuals typically active during their genesis: value creation is biased towards the selection of incumbent firms and complement challenges, and participation is biased towards engineers with knowledge of exploitation from multiple domains and researchers with knowledge of exploitation from single domains.

This suggests that the implications of the loose coupling emphasised by the innovation ecosystems discourse and the knowledge of the different contexts in which firms capture value are more complex than previously acknowledged. The practical implications are that the ability of public innovation ecosystem leadership to act early on novel technology might be offset by the inability of involved firms to commit to bringing the technology to market and that individuals typically active during public-private innovation ecosystems genesis are not ideal for handling this challenge. In fact, increasingly connected public leadership could smother the innovation ecosystem unless well-connected and multidisciplinary researchers are brought in as brokers.

1. Introduction

The concept of innovation ecosystems has garnered much interest in recent years and in many ways offers a new and potentially fruitful perspective on innovation activities (Autio and Thomas, 2014). However, the associated theory is still at an early stage of development, and a number of critical voices concerning its usefulness have been heard (Gomes et al., 2016; Oh et al., 2016; Valkokari, 2015). This indicates a need for further empirical investigations and testing of theory. Two areas with especially noticeable investigation needs are the genesis of the phenomenon (Dedehayir et al., 2018; Suominen et al., 2019) and its applicability to the cooperation between public and private organisations (Oh et al., 2016; Ritala and Almpanopoulou, 2017). In regard to the former, the roles that different actors take on are understudied (Dedehayir et al., 2018), and thus by extension which and why organisations are drawn into innovation ecosystems early. Some types of organisations might thus be overrepresented, and vice versa, during innovation ecosystem genesis. In regard to the latter, public organisations have been argued to play an important role in the innovation ecosystem discourse, especially in the early-stage assembling of constellations of organisations that aim to achieve value creation that the private sector is not yet fully willing to commit to (Dedehayir et al., 2018; Dedehayir and Seppänen, 2015; Oh et al., 2016). Being part of an innovation ecosystem can also improve the innovative performance of small, resource-constrained firms during public procurement (Leckel et al., 2020). However, public and private organisations have different incentives when engaging in innovation ecosystems, as they are driven by different “economies” (Oh et al., 2016; Ritala and

☆Declarations of interest: none

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https://doi.org/10.1016/j.techfore.2020.120378
Received 11 October 2019; Received in revised form 26 September 2020; Accepted 30 September 2020
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Almpanopoulou, 2017). That participants have different strategic aims, with private firms aiming to maximize economic value and public organizations putting emphasis on for instance employment and overall economic growth, could influence both the initial composition of an innovation ecosystem and subsequent public-private cooperation (Tsujimoto et al., 2018).

These issues are cause for concern, as they suggest that an innovation ecosystem might not be able to properly balance the involved activities, organisations or individuals to prepare it for unexpected events. Organisations frequently carry out such balancing acts to increase their chance for survival, for instance, by ensuring that they carry out activities focused on exploitation *and* exploration – lest they, for instance, disrupt their successful routines needlessly (Centobelli et al., 2019) or are replaced by a competitor able to disrupt their market (Lavie and Rosenkopf, 2006). Similarly, individuals make use of both rational and non-rational approaches to decision making when balancing resource allocation towards different types of innovation – lest they become unable to react in time to market changes (Gutiérrez and Magnusson, 2014). Without such precautions, the result can be a bias that might be beneficial in the moment but detrimental as circumstances change (Christensen and Rosenbloom, 1995). Potential bias that could have such effects have already been identified in the innovation ecosystems literature, such as the frequent focus on complementors when organising innovation ecosystems (Dedehayir and Seppänen, 2015). Similarly, public-private cooperation seems to select for firms that focus their R&D on technological recombination rather than scientific research, as this can improve the value created in cooperation with academia (Soh and Subramanian, 2014). However, it is unclear whether these types of potential bias will appear when public organisations take strategic decisions to organise an innovation ecosystem. In the case that they do appear, it is also unclear what type of effect they will have during innovation ecosystem genesis – when management mechanisms and connections between those involved are new and most likely weak. However, we know that overlap in terms of resources and expertise can result in knowledge redundancy and higher coordination costs (Soh and Subramanian, 2014), while clear specialization can have negative effects for innovations that benefit from knowledge overlap and redundancy (Cohen and Levinthal, 1990; Nooteboom, 2000). Arguably, participants in an innovation ecosystem can choose to leave if circumstances no longer allow for paying high costs, or if innovation that is more relevant is produced elsewhere.

As the roles of governments, academia and industry have been evolving with the increase of strategic alliances (Powell et al., 1996), public-private cooperation has grown as traditionally separate areas of responsibility have increasingly become shared (Etzkowitz, 2003). The European Commission has, for instance, supported the creation of digital innovation hubs (DIHs) across Europe, building towards a network of organisations jointly able to provide a diverse set of business and technology competencies to small and medium-sized enterprises, start-ups and midcaps. This effort started by each DIH gathering their regional academic and firm partners, identifying needs and connecting partners to competencies available at other DIHs (CPSELabs, 2020). Recently, these connections have grown into a Europe-wide innovation ecosystem (HUBCAP, 2020). In addition to giving firms access to competencies in technology and business development not available to them locally, this innovation ecosystem also works towards evolving business models and identifying appropriate governance mechanisms. It is thus an increasingly pressing issue to understand possible limitations in public-private innovation ecosystem genesis, as these might lead to challenges to ensuring value creation and capture as innovation ecosystems evolve. If proper guidance is not at hand, this might lead to underperforming or even failed innovation ecosystems and a loss of the associated investments by both public and private organisations.

To address this need for improved understanding of innovation ecosystems, the primary aim of this paper is thus *to investigate bias in early-stage public-private innovation ecosystems and related challenges*. As the innovation ecosystem concept is still forming, this can be characterised as early phase phenomenon-based research (von Krogh, Rossi-Lamastra, and Haefliger, 2012). The appropriate methods for studying innovation ecosystems are thus still being defined (M. A. Phillips and Ritala, 2019). Rather than adopting a purely exploratory approach, we pull together literature on innovation ecosystems, public-private collaborations and closely aligned discourses into a theoretical framework. This framework suggests a set of associated hypotheses that outline different types of bias that could be found in public-private innovation ecosystems. Although the theory is still immature, we can thus report on the innovation ecosystem concept in a way that helps guide further studies (von Krogh et al., 2012). The theoretical framework is followed by the method and results sections that describe tests for the existence of the identified bias. To allow readers to orientate themselves more easily, the data collection, data analysis and outcomes in these sections are organised into subsections that mirror the way the hypotheses are presented in the theoretical framework. The paper ends by eliciting theoretical and management implications based on the outcomes.

2. Exposition of theory

Value creation often benefits from cooperation between organisations (Ozman, 2009; Pyka, 2002), and recent research has paid particular attention to the potential value deriving from cooperation between public and private organisations (Ankrah and Omar, 2015; Lin, 2017; Mansfield, 1995). These benefits have resulted in recent attempts by governmental agencies in the European Union (EU) and United States (US), aiming to increase innovation by connecting groups of public and private organisations that are situated close to markets and customers and simultaneously focused on developing novel technology. These efforts fit well with the definition of innovation ecosystems as *"interconnected organizations, organized around a focal firm or a platform, and incorporating both production and use side participants, and focusing on the development of new value through innovation"* (Autio and Thomas, 2014). However, the conceptualisation of innovation ecosystems is still immature (Gomes et al., 2016; Valkokari, 2015). Researchers have even questioned the rigour and novelty of the concept, suggesting that more established terms could be used to a better effect (Oh et al., 2016). One such established term is that of networks, which have been studied extensively in the innovation discourse (Borgatti and Halgin, 2011). While there are similarities between ecosystems and networks, they are not the same (Shipilov and Gawer, 2020). Using the innovation network discourse to further the innovation ecosystem discourse might thus be possible but requires care as the assumptions and limitations on which network theory has been established may not remain valid. However, as the purpose of this paper is not to integrate these two discourses, we will not aim to analyse their interplay in detail. Instead, we note that the network discourse has often supplemented the study of formal relationships with that of informal coordinating mechanisms and that the study of how these informal mechanisms play out between individuals does not seem to be contradicted by the innovation ecosystem concept (Shipilov and Gawer, 2020). Rather, it seems to be an area in which the discourses could actually learn from each other. In fact, the need for studies on innovation ecosystems that address multiple levels and the heterogeneity of the actors at these levels have been noted (M. A. Phillips and Ritala, 2019).

This section consists of three parts. These lay out hypotheses for the implications of early formation and public-private cooperation in innovation ecosystems. The first and second part discuss these implications based on the innovation ecosystems literature. Hypotheses are formulated based on the actors likely to engage and the challenges they are likely to emphasise. The third part draws on findings from the network literature regarding informal relationships between individuals, suggesting how these relationships might influence the early formation of public-private innovation ecosystems. Hypotheses are formulated based on how individuals' extrinsic motivation and communication capacity might exclude organisations from innovation ecosystems when their members do not fit particular knowledge profiles.

Furthermore, two concepts recur throughout this section, as they have received some attention in the innovation ecosystem literature but still have aspects that are understudied.

The first concept is *loose coupling*, i.e., that relationships between the involved entities are few and weak (Weick, 1976). Loosely coupled entities can influence each other. However, this influence can in the short run be seen as relatively unimportant, slow and easily dissolved (Simon, 1962; Weick, 1976). Loose coupling has been a part of the innovation ecosystem concept since the inception of the discourse, either found at its core (Dattée et al., 2018; Iansiti and Levien, 2004; Li, 2009; Scaringella and Radziwon, 2017) or as a prominent characteristic of the phenomenon (Pagani, 2013). Emphasis has been on the capability of the involved organisations to act and construct meaning separately from each other despite their wish to cooperate, i.e., the effect of loose coupling towards engendering behavioural and cognitive distinction (Orton and Weick, 1990). Arguably, one important aspect of loose coupling then lies in how it allows organisations to be viewed both as entities that order their members and as entities that are made up of their members (Orton and Weick, 1990). Both of these perspectives have implications for the ability to act autonomously and the wish to cooperate that are intertwined with *bias*. On the one hand, organisations will order their members towards certain activities, suppliers and customers. Such strategic decisions might mean that organisations are biased towards certain innovation ecosystems or predisposed towards leaving an innovation ecosystem as activities it invests strongly in decrease in number. On the other hand, organisations foster separate perspectives, reasons for acting and skill sets amongst their members. As members of each organisation are thus biased, they might find it difficult to comprehend or work with members from the other organisations. This might mean that it is not easy or even possible for them to initiate cooperation across organisational boundaries or that they prefer cooperating with members of certain organisations. Loose coupling thus suggests that both the organisational and individual levels can have implications when organisations enter innovation ecosystems, when they stay engaged with them, and how they collaborate within these ecosystems. This further motivates the need to engage both with the discourses on innovation ecosystems and innovation networks.

A second concept of particular importance is *application domains*, i.e., different contexts in which firms capture value with their products. The defining characteristic of an application domain is that there exists unique knowledge that is required to exploit value capture opportunities in it. That firms have to balance the pursuit for new knowledge and the use of what is already known has been discussed in depth (Levinthal and March 1993). That an uncertain environment and the preferences of experts can bias firms towards exploitation is thus well known (Afuah and Tucci, 2012; Stuart and Podolny, 1996). However, what types of knowledge that are required for a firm to know enough to be able to exploit opportunities have been less studied. While having enough technological capability to build a product is a part of it, the contexts in which this product will be deployed will also have to be understood. Furthermore, this knowledge is not limited only to that associated with the functionality required to operate in these contexts but also to, e.g., that of associated manufacturing processes (Meng et al., 2019). As an example, a firm could, due to differences in the associated certification processes, be able to manufacture electrical components for use in the automotive industry but not be able to manufacture components providing the same functionality to the aerospace industry. This can also be true for specialised fields within an industry, such as the helicopter business within the aerospace industry. Whereas the overall importance of knowledge for innovation has been discussed extensively, not least in the innovation ecosystem literature where earlier works have pointed to the importance of combining knowledge and business ecosystems, the potential difficulties in applying knowledge to a certain domain have received much less attention.

2.1. Actors engaging in public-private innovation ecosystem genesis

Gomes et al. (2016) and Valkokari (2015) suggest that innovation ecosystems depend on other types of ecosystems: knowledge ecosystems that focus on knowledge generation and are often dominated by public research organisations; and business ecosystems that focus on value capture and thus have a strong presence of private organisations. However, both types of organisations can be part of either type of ecosystem. Private organisations can make substantial contributions to early knowledge exploration (Järvi et al., 2018), and public organisations can provide direct input to fruitful value capture (Etzkowitz, 2003). As innovation ecosystems focus on value creation (Valkokari, 2015), they can overlap with both of these types of ecosystems. Activities in innovation ecosystems can, for instance, draw on the expertise of both knowledge creators and those already capturing value in associated ways. There is nothing that requires an organisation participating in one of these ecosystems to participate in overlapping ecosystems of other types (Clarysse et al., 2014). However, it is well known that firms are limited both geographically and technologically in regard to how they search for new knowledge (Lavie and Rosenkopf, 2006; Rosenkopf and Almeida, 2003). These factors should thus increase the likelihood that overlapping ecosystems contain the same organisations. Furthermore, when firms actually attempt to explore new technology, they are primarily constrained by their *absorptive capacity* (Lavie and Rosenkopf, 2006), i.e., by their ability to recognise, integrate and apply external knowledge (Cohen and Levinthal, 1990). Business ecosystems can contain special knowledge important to value capture, such as knowledge regarding associated application domains. While a few agile firms might thus be able to search for new knowledge in completely unknown contexts, the vast majority are more likely to be bound by their familiarity with and access to spill-overs in the application domains they are currently active in. The application domains that a firm engages with thus imply which innovation ecosystems it can most easily identify opportunities in.

Furthermore, Dedehayir et al. (2018) note how lifecycle changes also include the roles of the actors in the ecosystem, which can change and transition between public and private organisations. Uncertainty and technological infancy can, for instance, imply that public organisations have to assume early leadership until commercialisation prospects improve (Dedehayir et al., 2018; Dedehayir and Seppänen, 2015). During this early ecosystem genesis, the leadership role is concerned with establishing governance, partnerships and the management of value, whereas the expert role that provides specialist knowledge and transfer technology is seen as value creation support (Dedehayir et al., 2018). While academia traditionally provides expert knowledge on new discoveries to lead firms (Dedehayir et al., 2018), a reverse in roles suggests expert knowledge will rather be required in what academia lacks. In other words, firms would have to supply knowledge and skills in exploitation (Valkokari, 2015), such as how to apply their knowledge in a particular application domain to generate value for customers. A firm is thus also more likely to be invited into innovation ecosystems that target the application domains that it is already active in.

Hypothesis 1. *Firms are more likely to become involved in a new innovation ecosystem as incumbents, rather than entrants, of an application domain.*

2.2. Challenges emphasised in public-private innovation ecosystem genesis

During their study of networks characterised by simultaneous cooperation and competition (Afuah, 2000), Adner & Kapoor (2010) indicated the need to not only consider the structure of ties in ecosystems but also the flow of activities. With this in mind, a product that is produced by a *supplier* and used by a focal firm to build its products can be referred to as a *component*. A product produced by another firm and bundled together with the focal firm's product to enhance its value can be referred to as a *complement* provided by a *complementor*. From the perspective of a focal firm, innovation challenges to a supplier´s ability to produce a component can be referred to as *component challenges*, and innovation challenges to a complementor's ability to provide a complement can be referred to as *complement challenges*. Component challenges have been shown to enhance the value of a focal firm's technology leadership, while complement challenges erode it (Adner and Kapoor, 2010). This is based on the opportunities to learn provided by component challenges and the adoption delays related to complement challenges. The former involves focal firms overcoming hurdles early to bring products to market, as well as learning to coordinate efficiently with suppliers. The latter involves competitors catching up, as well as reduced opportunities for focal firms to gain experience ahead of others. Historically, focal firms have been known to organise complementors into loosely coupled innovation ecosystems as a way of removing obstacles to and improving value creation (Dedehayir and Seppänen, 2015). Arguably, component challenges rather suggest that a focal firm would coordinate closely and privately with its suppliers to avoid rivals catching up by free riding on what it has learnt. Innovation ecosystems led by private firms are thus more likely to focus on complement challenges than component challenges.

Public organisations are known to be less negative to others learning from their solutions, which should suggest that component and complement challenges would be treated more equally in innovation ecosystems led by public organisations. However, we argue that this is not the case and that this bias is also present in these innovation ecosystems. Certainly, if value creation through technology transfer is the only aim of engaging with industry, then other approaches are both encouraged more by technology transfer offices and easier to manage. Arguably, public organisations approach innovation ecosystem building as definers or implementers of policy, most likely based on the wishes of others funding this specific activity. As an example, in the European DIH network, a strong underlying driver is the wish of the European Commission to support smaller companies due to their importance to job creation. With technology transfer not being the (sole) focus, firms will have more leeway to emphasise and resist changes to their own technological trajectories (Dosi, 1982). Novel technology will be more strictly accepted on the terms of the receiving firms. This suggests that there will be pushback from firms if public entities position themselves as focal service or product providers (Lindgren et al., 2015) or involve themselves in such activities as technology leaders. This suggests that it will be easier for academia and industry to cooperate on challenges to complementing each other's products than challenges to making them fit together as components in a product.

Hypothesis 2. *Public-private innovation ecosystems are more likely to cooperate on value creation related to complement challenges than component challenges.*

2.3. The network of individuals underlying public-private innovation ecosystem genesis

Firms align their employees to a common way of thinking and a shared knowledge base (Nooteboom, 2000). This is reinforced by the employees themselves, as most people tend to favour communicating with those who are similar to themselves (Rogers, 1995). The resulting misalignment between individuals who belong to different organisations makes it more difficult for them to understand each other, cooperate and reach a common goal. This dilemma is captured by the loose coupling of innovation ecosystem genesis (Orton and Weick, 1990). On the one hand, organisations maintain their members' behavioural and cognitive distinction to stay efficient at their day-to-day business. On the other hand, they wish to cooperate with other organisations to achieve value creation, and this cooperation both comes at a cost and brings cognitive change limiting their autonomy. The brunt of this dilemma is borne by the individual members of the involved organisations. While the previous subsections have discussed bias from the perspective of *organisations*, this subsection thus discusses it from the perspective of the *individuals who* make up these organisations.

Naturally, there are differences between the types of knowledge primarily generated by academic institutions and firms (Boon, 2011). The specialisation of academic researchers and employees at private firms can decrease the value of public-private cooperation: engaging in *several* complementary activities to access scientific knowledge has been proven to affect innovative performance negatively (Hess and Rothaermel, 2011); and the broader a university´s collaboration breadth, the more negatively increasing public-private cooperation reflects on academic innovation (Lin, 2017).

Soh & Subramanian (2014) suggest that the optimal knowledge overlap for public-private collaboration occurs when firms focus their R&D on technological recombination rather than scientific research. In other words, value creation is optimal when a firm collaborating with academia focuses on technology exploitation within application domains the firm knows well (Soh and Subramanian, 2014). The underlying explanation is that firms that focus many internal resources on the search for new knowledge through scientific exploration will build a structural and knowledge overlap that decreases the additional value of complementarities that they are expected to generate when engaging in external, public-private collaboration (Soh and Subramanian, 2014).

This has implications concerning which relationships formed during innovation ecosystem genesis will be most likely to persist. As the lack of a common understanding will make it difficult for researchers from academia and employees from private firms to communicate, the way they are extrinsically motivated by their respective organisations will be important for continued engagement. Governments exert strong pressure on academia to act on value creation opportunities, and firms often frame the relationship to academia specifically as a means to improve efficiency (Ankrah and Omar, 2015; Perkmann et al., 2013). Therefore, the larger the potential for value creation that researchers and engineers perceive, the stronger their motivation will be to continue collaborating. As mentioned, the literature thus suggests that the strongest relationships formed during public-private innovation ecosystem genesis will be built from academia to firms that focus their internal resources on technology recombination across application domains rather than scientific research (Soh and Subramanian, 2014).

In fact, in the more tentative, informal relationships of innovation ecosystem genesis, the small knowledge overlap between firms that do not focus on their own scientific research and academia can in itself be a reason for building and sustaining engagement. Several discourses suggest that a small knowledge overlap can both create urgent, strong motivation to engage with external knowledge and limit the need for managerial involvement in this engagement (Bloodgood, 2015).

Hypothesis 3.A. *Firm employees with exploitation knowledge from a combination of application domains will be more motivated to participate in public-private innovation ecosystem genesis.*

However, establishing relationships during innovation ecosystem genesis depends not only on the motivation of the innovation ecosystem participants but also on their capacity. Different people will be able to maintain a different number of relationships, as each relationship implies a time commitment (Granovetter, 1973; Miritello et al., 2013). Furthermore, it requires more effort to engage with new relationships in a heterogeneous network, i.e., when those becoming involved are dissimilar in regard to, for instance, professional origin or knowledge (Obstfeld et al., 2014). In fact, this problem of heterogeneity is especially likely to exist when comparing distinct groups of actors in a network who do not share any local connections, i.e., those separated from each other by a structural hole (Obstfeld, 2005).

Reagans et al. (2015) thus identify associated implications for third parties as loosely coupled networks are formed: unshared third parties reduce the likelihood that a knowledge transfer relationship will be initiated and sustained over time, especially when these third parties are heterogeneous in regard to knowledge and expertise. The underlying explanation is that limited knowledge overlap requires more effort to bridge, leaving less time available for interactions outside the group of unshared third parties.

This has implications for the possibility of forming a new underlying network by linking separate network parts during innovation ecosystem genesis. Achieving a sustainable knowledge transfer relationship is less likely when there are substantial differences in the knowledge important to innovation ecosystem activities both *between* and *within* these parts. This suggests that if certain innovation ecosystem participants are part of a highly heterogeneous network part in regard to important knowledge, then other participants have come from network parts that are less heterogeneous in this regard. Therefore, if employees from private firms involved in innovation ecosystem genesis are likely to come from network parts with a high heterogeneity in regard to application domains, the complementing network parts of researchers are likely to be less heterogeneous in this regard.

Hypothesis 3.B. *Academic researchers engaging in public-private innovation ecosystem genesis are less likely to possess exploitation knowledge from a combination of application domains compared to firm employees in the same ecosystem.*

Having offered hypotheses associated with both the systemic perspective of the innovation ecosystem concept and the relationships of the involved individuals, the next section turns to the empirical context of our study: the birth of a pan-European innovation ecosystem focused on Cyber-Physical Systems. By showing empirically how the hypotheses can be connected to significant bias, we pave the way for investigating and discussing challenges to governing the early stages of public-private innovation ecosystems.

3. Methodology

In the following subsection, the context of the study is presented, followed by the methodological approach used and validity and reliability concerns related to each part of the study.

3.1. Research context

The European Commission (EC) and US Government have put considerable resources into supporting firms to achieve leading positions in the manufacture of Cyber-Physical Systems (CPS), i.e., systems that integrate "physical and embedded systems with communication and IT systems" (Törngren et al., 2017). The reason behind these investments is that CPS promise to deliver solutions for future key application domains, such as transportation, energy and infrastructure (Geisberger and Broy, 2015; Reimann et al., 2017). The increasing complexity and reach of CPS has led to an increased focus on the associated standardisation, tools and services for, e.g., *safety* (Törngren et al., 2017). There is thus an increasingly important core of technological skills related to cross-cutting concerns such as safety, which CPS manufacturers need to possess to succeed in deploying products. In the past, application domains have normally been targeted separately. More recently, however, the EC has supported multidomain initiatives, such as the creation of public-private innovation ecosystems that accelerate the realisation of CPS through cross-domain learning and technology transfer (CPSELabs, 2020; EuroCPS, 2020; FED4SAE, 2020; gateone-project, 2020). Simultaneously, there are large firms that by themselves offer CPS products across several domains. These firms create and maintain internal networks to enable the type of value creation that the EC would like to see emerge in the innovation ecosystems they support. Although the prerequisites for establishing internal and external networks are different, the novel and exploitation knowledge that their members then have to possess to enable successful value creation is the same.

This study focuses on the ecosystem built by the CPSELabs project, a pan-European initiative to link innovation ecosystems concerned with CPS (CPSELabs, 2020). This linkage is established through design centres (DCs), i.e., central, often partly if not completely public-owned, organisations in the innovation ecosystems. One of the primary functions of CPSELabs was to financially and technically support initiatives within the innovation networks that link CPS engineering infrastructure. These initiatives, termed "experiments" within CPSELabs, were chosen based on open calls targeting one or several of three goals: (a) Completing Value Chains (CVC), (b) Transferring Technology to New Domains (TTND), and (c) Supporting the Use of Technology in New Use Cases (SUTNUC). The intention was thus that the experiments should form a nucleus out of which a viable pan-European innovation ecosystem could emerge. The result was an innovation ecosystem consisting of public, private and hybrid organisations loosely coupled by the engineers and researchers involved.

In close alignment to the CPSELabs innovation ecosystem, we found a multinational engineering company developing CPS, henceforth called the Firm. The Firm employs approximately 50,000 employees in 150 countries developing products for both civil and defence purposes within the aerospace, automotive, marine, rail and nuclear domains. Engineering is arranged in organisationally separate business sectors focused on different domains. Public-private cooperation is organised through centres established and funded by the Firm at various academic institutions across the world. These centres focus on research fields of key importance to the Firm and form the interface between the business sectors and these fields. However, certain functions and initiatives such as innovation management have an enterprise-wide reach, and experts within the company are connected through, for instance, communities of practice. This Firm thus forms a model example of a company that explicitly focuses on technological recombination while organising its public-private cooperation towards academia with a narrow focus. Furthermore, while the Firm is loosely coupled to the CPSELabs innovation ecosystem, it did not actively participate in the calls for experiments outlined in the previous paragraph – making it unlikely that any comparative analyses are influenced by confounding factors.

As previously mentioned, safety is a fundamental property within the CPS domains with the potential to dictate the structure, processes, culture and external relationships of firms even in the face of high productive demands (La Porte, 1996; Reiman et al., 2015; Roberts et al., 2001). While the far-reaching implications of safety have mostly been studied in regard to firms active in the operations of complex systems, safety has been noted to imply similarly drastic requirements on design and project organisations (Rollenhagen, 2010; Saunders, 2015). Indeed, safety practices are often a base to which all other development activities have to relate. Knowledge on safety practices is codified in different safety-relevant standards, such as DO-178C (aerospace software) (RTCA Inc., 2011), ISO 26,262 (automotive) (International Organization for Standardization, 2011), IEC 60,987 (nuclear hardware) (International Electrotechnical Commission, 2007), ECSS-Q-ST-40C (space safety assurance) (ESA-ESTEC, 2009) and EN 50,129 (rail electronics) (CENELEC, 2003). These standards are extensive, based on fundamentally different approaches to achieving assurance, partitioned differently, range from guidance to regulation, are issued by different types of organisations, and use different ways of classifying systems. Nevertheless, an understanding of the contents of these standards is often required for successful exploitation in each CPS domain.

3.2. Research design

Although the theory on innovation ecosystems is arguably immature, we have through the use of nascent and related theory outlined hypotheses regarding the bias to be expected in public-private innovation ecosystems. We have designed tests for these bias to allow us to report on the phenomenon and guide further studies in a more focused way (von Krogh et al., 2012). The emerging CPSELabs public-private innovation ecosystem and the Firm were thus subjected to three tests concerning (a) the type of actors involved and (b) the funding provided in the public-private innovation ecosystem and (c) the knowledge of exploitation within the underlying networks of individuals. The tests are described in three subsequent subsections that mirror the three (sets of) hypotheses found in Section 2.

3.2.1. Investigating actors engaging in the innovation ecosystem

The CPSELabs public-private innovation ecosystem encompasses several application domains. This makes it suitable for evaluating whether Hypothesis 1 is significant. If academia is bringing the technology to be exploited, then firms will be most likely to identify the need for it within application domains they already know well; and if the leadership role adopted by researchers is meaningful, then they will be pulling experts on exploitation in each application domain into the network. To study any bias in the pull of incumbents and entrants into the CPSELabs public-private innovation ecosystem genesis, we thus analysed the funded experiments by comparing the firms in funded experiments with the distribution of firms expected from the emphasis of the DCs in the CPSELabs project description.

The CPSELabs project description indicated that one of the DCs expected to focus primarily on entrants, either by starting up new firms or by bringing already existing ones to new domains. The other DCs were not as explicit, but ascribed to key performance indicators, suggesting that one-fourth of all experiments should involve an entrant in the form of a start-up. To arrive at a conservative estimate, we assumed that, beyond what was explicitly stated, there were no aspirations by the DCs to bring existing firms to new domains. The proposals of the funded experiments were rigorously collected and evaluated as part of an externally audited process stipulated by the EC. A complete and verified set of detailed descriptions of all involved organisations was thus available. Incumbent firms were identified as having at least three years of experience in the targeted domain (most having at least a decade).

The correct statistical method for identifying a bias when addressing this type of data is the chi-square goodness-of-fit test (Sheskin, 2000a).

3.2.2. Investigating challenges emphasised in the innovation ecosystem

The three aforementioned goals of the funding of experiments by CPSELabs focus on different sides of an innovation ecosystem: CVC focuses on the supplier-side; TTND has to address both the supplier- and user-side; and SUTNUC addresses user-side challenges. This makes the CPSELabs public-private innovation ecosystem suitable for evaluating whether Hypothesis 2 is corroborated or not. If the involved stakeholders find it more suitable to use public-private innovation ecosystems to share information and cooperate on complement challenges, then this should lead to a bias towards SUTNUC experiments. To identify any such bias, we compared the distribution of funded projects with the distribution of experiments expected based on the emphasis of the DCs in the open calls.

Most experiment call descriptions explicitly indicated the targeted goals, but a few described the goals implicitly. Two of the latter could not be unambiguously attributed to the three goals. Therefore, to ensure a correct analysis, we decided to test all possible interpretations on how to attribute these descriptions to goals and only claim a significant result if this was supported by all interpretations.

The correct statistical method for identifying a bias when addressing this type of data is the chi-square goodness-of-fit test (Sheskin, 2000a).

3.2.3. Investigating the network of individuals underlying the innovation ecosystem

The public-private innovation ecosystem was built through competitive calls aimed at value creation in engineering domains. Hypothesis 3.A suggests that value creation will be most readily found in submissions to these calls where engineers with knowledge of exploitation across several application domains cooperate with researchers with a more narrow focus. Value creation will thus drive participation in the innovation ecosystem to include engineers that already exist in networks that span multiple application domains in regard to knowledge of exploitation. Hypothesis 3.B then suggests that a lower fraction of the involved academic researchers will have knowledge of exploitation from across several application domains compared to the engineers in the involved firms.

Therefore, to study the differences between researchers and engineers in regard to knowledge of exploitation, we piloted a questionnaire with researchers and engineers and then administered it to the networks underlying the public-private innovation ecosystem and the Firm. Respondents from the former were identified by asking those responsible for each of the Design Centres for those most active within their part of the innovation ecosystem as defined by the calls. These were then, in turn, also asked to provide the contact details to their collaborators within the innovation ecosystem. All those identified were invited to participate in the questionnaire. Respondents from the latter were identified by asking one of the Firm's excellence centres for centrally located experts and managers in each business sector. These were then, in turn, also asked to provide the contract details to their collaborators within the business sector. All those identified were invited to participate in the questionnaire. The questionnaire was thus sent to 55 respondents in the public-private innovation ecosystem and 116 respondents in the Firm. From the former, there were 36 responses (65%), and from the latter, 86 responses (74%).

The questionnaire, as indicated by Table 1, included 75 questions distributed across 7 sections. Sections B and C gauged the impact of safety standards in the primary domain of the respondent. In Section B,

Table 1
Questionnaire Sections.

Section	Number of Questions	Motivation for Section
A	10	Initial questions to profile the respondent in regard to role, primary domain, discipline of work, years spent at work, etc.
B	12	Questions regarding the importance of safety standards written for the primary domain of the respondent. In other words, standards to which the respondent could be expected to certify work products during commercialisation.
C	14	Questions regarding the actual influence of safety standards written for the primary domain of the respondent on his work. In other words, standards to which the respondent could be expected to certify work products during commercialisation.
D	14	As in Section B, but for standards written for other domains than that of the respondent. In other words, standards that the respondent is not expected to certify work products to, but which address similar products in other applications.
E	11	As in Section C, but for standards written for other domains than that of the respondent.
F	2	Open questions to elicit perspectives on Section D and E.
G	12	Generic statements on the effects of safety standards for the respondents to agree/disagree with. Statements included assertions that safety standards make designs more complex, made designing products cumbersome and decreased technology reuse.

questions were asked from the perspective of the perceived importance of these standards in regard to enabling product characteristics or tasks that might support technology transfer. In Section C, similar questions were asked from the perspective of the actual influence of these standards on the work by the respondent. Sections D and E mirrored Sections B and C but gauged the impact of safety standards from outside the primary domain of the respondent. Each question was answered on a seven-point Likert scale, with a "not applicable" option included. Respondents were asked to self-report on their work role.

The respondents' answers thereby allow the underlying networks to be contrasted in two ways: with regard to the differences of the actual responses and in regard to differences in ability to respond to the questions.

With enough respondents, and thus enough statistical power, the former contrast supports validity: it can indicate whether the two underlying networks differ in regard to how they perceive the importance and impact of safety in the CPS domains. This is a good control mechanism for validating the idea that understanding the standardisation, tools and services associated with safety is a core skill for CPS manufacturers.

The Kruskal-Wallis H-test is appropriate for the ordinal data of the questionnaire responses across three groups (Draper and Smith, 1998; Montgomery, 2000). It is frequently used with small sample sizes but has less power than its parametric counterpart. Furthermore, it is difficult to establish a required sample size for this method (Ryan, 2013), although as a rule-of-thumb, it can be done using its parametric counterpart and adding an extra 15% to the sample size. A statistical significance of 0.05 and a statistical power of 0.8 were chosen. The smaller groups were expected to be more uniform, but we also expected that they might respond more similarly. Therefore, the effect size was based on an estimated standard deviation of 1 and a difference in means larger than 1. The required sample size was then calculated to 10 respondents in the smallest group.

The latter contrast can be used to test whether researchers have less knowledge important to exploitation than engineers outside their primary domain, meaning that we should see significant differences in their ability to respond to the questions in Sections D and E. As expected, none of the experts in the intrafirm network self-reported being researchers. Therefore, when separating out those in researcher roles from others in the network underlying the public-private innovation ecosystem, the resulting comparison was across three groups.

Regarding the ability to respond to questions, the proportion of "not applicable" responses can be compared across groups. The appropriate tests are then either the chi-square test of homogeneity (Sheskin, 2000b) or Fisher's exact test (Agresti, 2002). Both can be used for the two and three group cases, but Fisher's exact test is preferred when the expected size of a proportion is less than five (Agresti, 2002; Sheskin, 2000b). The expected size of the proportions can only be established when the responses have been gathered.

To summarise, the two analyses planned for the questionnaire results are listed in Table 2 together with their motivation.

4. Results and analysis

The results from the three analyses are presented in the order established in the previous section, i.e., in regard to the type of actors involved, the existence of funding bias and the differences in the knowledge of exploitation within the underlying networks. By identifying the participants likely to be found in emerging public-private innovation ecosystems, why they become involved, and how they differ from each other, we can form a base for discussing challenges to governing the early stages of public-private innovation ecosystems. The results are thus also partitioned into three subsections mirroring the three sets of hypotheses found in Section 2.

4.1. A bias amongst the actors

Based on the emphasis of the DCs in the CPSELabs project description, 65% of the funded experiments were expected to involve incumbents and 35% entrants. Using the experiment proposals, the 23 experiments funded in the open calls were divided into 20 conducted by incumbent firms, 2 conducted by entrants and 1 conducted solely by an academic partner.

A chi-square goodness-of-fit then indicated that the distribution of firms involved in the experiments was statistically significantly different from the proportions expected based on the emphasis of the DCs in the CPSELabs project description ($\chi^2(1) = 5.033$, $p = 0.025$). The minimum expected frequency was 8.1.

These results indicate a significantly unbalanced pull of incumbents into the public-private innovation ecosystem. In line with Hypothesis 1, this suggests that academia favours incumbents due to their knowledge and that incumbents are more easily drawn into innovation ecosystems based on their previous business-as-usual activities.

4.2. A bias in regard to the emphasised challenges

Based on the experiment call descriptions, the 36 experiments proposed in the open calls were divided into 14 TTND, 12 CVC, 8 SUTNUC and 2 either TTND or SUTNUC experiments. Of the funded experiments, 6 targeted TTND, 5 CVC and 12 SUTNUC. Two chi-square goodness-of-fit tests were executed:

- Assuming that the two ambiguous observations were TTND, the expected distribution was 16 TTND experiments to 12 CVC experiments to 8 SUTNUC experiments. A chi-square goodness-of-fit test then indicated that the distribution of funded experiments was statistically significantly different from the proportions expected based on the emphasis of the DCs in the open calls ($\chi^2(2) = 11.957$, $p = 0.003$). The minimum expected frequency was 5.1.
- Assuming that the two ambiguous observations were SUTNUC, the expected distribution was 14 TTND experiments to 12 CVC experiments to 10 SUTNUC experiments. A chi-square goodness-of-fit test then indicated that the distribution of funded experiments was statistically significantly different from the proportions expected based on the emphasis of the DCs in the open calls ($\chi^2(2) = 6.825$, $p = 0.033$). The minimum expected frequency was 6.4.

Due to the number of cells being more than 2, the standardised residuals for the SUTNUC cell were calculated, resulting in values of $R = 3.06$ and $R = 2.37$ (Sheskin, 2000a). This indicates that the funded SUTNUC experiments are major contributors to a significant chi-square value in both cases. SUTNUC experiments only addressed user-side

Table 2
Questionnaire Analyses.

	On Responses	On Ability to Respond
(1) Group with an academic role in the network underlying the public-private innovation ecosystem, (2) Group with an engineering role in the network underlying the public-private innovation ecosystem, and (3) Group from the intrafirm network.	Kruskal-Wallis H Test to establish that there are no large differences in practices and priorities amongst the groups.	Chi-square test of homogeneity or Fisher's exact test to establish differences in knowledge of exploitation.

Table 3
Significant differences from Comparisons Across Ecosystems and Role. G(1) indicates the group with an Academic Role in the network underlying the public-private innovation ecosystem, G(2) indicates the Group of those with an Engineering role. G(3) indicates the group from the intrafirm network.

Section	Significant Differences in Responses		Significant Differences in Ability to Respond	
B	**Section Summary:** No significant differences regarding any specific questions were found.		**Section Summary:** On average, 6.3% of respondents in G(1), 5.4% in G(2) and 4.7% in G(3) were not able to answer these questions. There were no significant differences regarding any specific questions.	
C	**Section Summary:** No significant differences regarding any specific questions were found.		**Section Summary:** On average, 33.5% of the respondents in G(1), 1.4% in G(2) and 11.2% in G(3) were not able to answer these questions. There was a significant difference in the ability to respond to 10 questions. All 10 questions were significantly different between G(1) and G(2). Six questions were also significantly different between G(1) and G(3).	
			Q. 10.1	Of the respondents, 7 (43.8%) in G(1), 1 (5.0%) in G(2) and 10 (11.6%) in G(3) were not able to answer this question, $p = 0.004$. Post hoc analysis revealed statistically significantly differences between G(1) and G(2), $p = 0.012$, and G(1) and G(3), $p = 0.005$.
			Q. 10.2	Of the respondents, 7 (43.8%) in G(1), 0 (0%) in G(2) and 9 (10.5%) in G(3) were not able to answer this question, $p < 0.001$. Post hoc analysis revealed statistically significantly differences between G(1) and G(2), $p = 0.001$, and G(1) and G(3), $p = 0.003$.
			Q. 10.3	Of the respondents, 7 (43.8%) in G(1), 1 (5.0%) in G(2) and 9 (10.5%) in G(3) were not able to answer this question, $p = 0.003$. Post hoc analysis revealed statistically significantly differences between G(1) and G(2), $p = 0.012$, and G(1) and G(3), $p = 0.003$.
			Q. 10.4	See Q. 10.3.
			Q. 10.5	See Q. 10.3.
			Q. 10.6	Of the respondents, 5 (31.3%) in G(1), 0 (0%) in G(2) and 10 (11.6%) in G(3) were not able to answer this question, $p = 0.017$. Post hoc analysis revealed statistically significantly differences between G(1) and G(2), $p = 0.012$.
			Q. 10.8	Of the respondents, 6 (37.5%) in G(1), 0 (0%) in G(2) and 10 (11.6%) in G(3) were not able to answer this question, $p = 0.004$. Post hoc analysis revealed statistically significantly differences between G(1) and G(2), $p = 0.004$.
			Q. 10.9	Of the respondents, 5 (31,3%) in G(1), 0 (0%) in G(2) and 9 (10.5%) in G(3) were not able to answer this question, $p = 0.011$. Post hoc analysis revealed statistically significantly differences between G(1) and G(2), $p = 0.012$.
			Q. 10.10	Of the respondents, 6 (37,5%) in G(1), 0 (0%) in G(2) and 9 (10.5%) in G(3) were not able to answer this question, $p = 0.003$. Post hoc analysis revealed statistically significantly differences between G(1) and G(2), $p = 0.004$, and G(1) and G(3), $p = 0.013$.
			Q. 10.12	Of the respondents, 6 (37,5%) in G(1), 0 (0%) in G(2) and 13 (15.1%) in G(3) were not able to answer this question, $p = 0.008$. Post hoc analysis revealed statistically significantly differences between G(1) and G(2), $p = 0.004$.
D	**Section Summary:** The responses to 4 questions were significantly different between G(1) and G(2) but in no other group combination.		**Section Summary:** On average, 35.7% of respondents in G(1), 7.1% in G(2) and 10.5% in G(3) were not able to answer these questions. There was a significant difference in the ability to respond to 9 questions. Seven questions were significantly different between G(1) and G(3). Four of these questions were also significantly different between G(1) and G(2).	
	Q. 12.7	$\chi^2(2) = 6.128$, $p = 0.047$. Post hoc analysis revealed statistically significantly differences between G(1) and G(2), $p = 0.045$.	Q. 12.1	Of the respondents, 8 (50.0%) in G(1), 2 (10.0%) in G(2) and 10 (11.6%) in G(3) were not able to answer this question, $p = 0.001$. Post hoc analysis revealed statistically significantly differences between G(1) and G(2), $p = 0.011$, and G(1) and G(3), $p = 0.001$.
	Q. 12.8	$\chi^2(2) = 7.058$, $p = 0.029$. Post hoc analysis revealed statistically significantly differences between G(1) and G(2), $p = 0.026$.	Q. 12.2	Of the respondents, 6 (37.5%) in G(1), 1 (5.0%) in G(2) and 9 (10.5%) in G(3) were not able to answer this question, $p = 0.012$. Post hoc analysis revealed statistically significantly differences between G(1) and G(3), $p = 0.013$.
	Q. 13.2	$\chi^2(2) = 6.167$, $p = 0.046$. Post hoc analysis revealed statistically significantly differences between G(1) and G(2), $p = 0.045$.	Q. 12.3	Of the respondents, 7 (43.8%) in G(1), 2 (10.0%) in G(2) and 9 (10.5%) in G(3) were not able to answer this question, $p = 0.006$. Post hoc analysis revealed statistically significantly differences between G(1) and G(3), $p = 0.003$.
	Q. 13.4	$\chi^2(2) = 6.958$, $p = 0.031$. Post hoc analysis revealed statistically significantly differences between G(1) and G(2), $p = 0.050$.	Q. 12.4	Of the respondents, 6 (37.5%) in G(1), 2 (10.0%) in G(2) and 9 (10.5%) in G(3) were not able to answer this question, $p = 0.025$. Post hoc analysis revealed statistically significantly differences between G(1) and G(3), $p = 0.013$.
			Q. 12.6	Of the respondents, 5 (31.3%) in G(1), 1 (5.0%) in G(2) and 8 (9.3%) in G(3) were not able to answer this question, $p = 0.047$. Post hoc analysis revealed no statistically significantly differences between groups.
			Q. 12.7	See Q. 12.6.
			Q. 12.8	Of the respondents, 7 (43.8%) in G(1), 1 (5.0%) in G(2) and 11 (12.8%) in G(3) were not able to answer this question, $p = 0.004$. Post hoc analysis revealed statistically significantly differences between G(1) and G(2), $p = 0.012$, and G(1) and G(3), $p = 0.007$.

(*continued on next page*)

Table 3 (*continued*)

Section	Significant Differences in Responses	Significant Differences in Ability to Respond
		Q. 12.9 Of the respondents, 8 (50.0%) in G(1), 1 (5.0%) in G(2) and 10 (11.6%) in G(3) were not able to answer this question, $p < 0.001$. Post hoc analysis revealed statistically significantly differences between G(1) and G(2), $p = 0.004$, and G(1) and G(3), $p = 0.001$.
		Q. 13.1 Of the respondents, 8 (50.0%) in G(1), 1 (5.0%) in G(2) and 11 (12.8%) in G(3) were not able to answer this question, $p = 0.003$. Post hoc analysis revealed statistically significantly differences between G(1) and G(2), $p = 0.011$, and G(1) and G(3), $p = 0.002$.
E	**Section Summary:** The responses to 1 question were significantly different between G(1) and G(2) as well as G(1) and G(3).	**Section Summary:** On average, 54.5% of respondents in G(1), 14.0% in G(2) and 17.1% in G(3) were not able to answer these questions. There was a significant difference in the ability to respond to all 11 questions. Ten questions were significantly different between G(1) and G(3). Seven questions were also significantly different between G(1) and G(2).
	Q. 14.10 $\chi^2(2) = 7.134$, $p = 0.028$. Post hoc analysis revealed statistically significantly differences between G(1) and G(2), $p = 0.037$, and G(1) and G(3), $p = 0.035$.	Q. 14.1 Of the respondents, 10 (62.5%) in G(1), 3 (15.0%) in G(2) and 15 (17.4%) in G(3) were not able to answer this question, $p < 0.001$. Post hoc analysis revealed statistically significantly differences between G(1) and G(2), $p = 0.005$, and G(1) and G(3), $p < 0.001$.
		Q. 14.2 See Q. 14.1.
		Q. 14.3 Of the respondents, 10 (62.5%) in G(1), 4 (20.0%) in G(2) and 14 (16.3%) in G(3) were not able to answer this question, $p < 0.001$. Post hoc analysis revealed statistically significantly differences between G(1) and G(2), $p = 0.016$, and G(1) and G(3), $p < 0.001$.
		Q. 14.4 Of the respondents, 8 (50.0%) in G(1), 4 (20.0%) in G(2) and 14 (16.3%) in G(3) were not able to answer this question, $p = 0.017$. Post hoc analysis revealed statistically significantly differences between G(1) and G(3), $p = 0.006$.
		Q. 14.5 Of the respondents, 8 (50.0%) in G(1), 3 (15.0%) in G(2) and 14 (16.3%) in G(3) were not able to answer this question, $p = 0.012$. Post hoc analysis revealed statistically significantly differences between G(1) and G(3), $p = 0.006$.
		Q. 14.6 Of the respondents, 9 (56.3%) in G(1), 3 (15.0%) in G(2) and 17 (19.8%) in G(3) were not able to answer this question, $p = 0.008$. Post hoc analysis revealed statistically significantly differences between G(1) and G(2), $p = 0.014$, and G(1) and G(3), $p = 0.004$.
		Q. 14.7 Of the respondents, 9 (56.3%) in G(1), 2 (10.0%) in G(2) and 16 (18.6%) in G(3) were not able to answer this question, $p = 0.003$. Post hoc analysis revealed statistically significantly differences between G(1) and G(2), $p = 0.004$, and G(1) and G(3), $p = 0.003$.
		Q. 14.8 Of the respondents, 9 (56.3%) in G(1), 2 (10.0%) in G(2) and 15 (17.4%) in G(3) were not able to answer this question, $p = 0.002$. Post hoc analysis revealed statistically significantly differences between G(1) and G(2), $p = 0.004$, and G(1) and G(3), $p = 0.002$.
		Q. 14.9 Of the respondents, 8 (50.0%) in G(1), 3 (15.0%) in G(2) and 13 (15.1%) in G(3) were not able to answer this question, $p = 0.010$. Post hoc analysis revealed statistically significantly differences between G(1) and G(3), $p = 0.004$.
		Q. 14.10 Of the respondents, 7 (43.8%) in G(1), 2 (10.0%) in G(2) and 15 (17.4%) in G(3) were not able to answer this question, $p = 0.033$. Post hoc analysis revealed no statistically significantly differences between groups.
		Q. 14.11 Of the respondents, 8 (50.0%) in G(1), 2 (10.0%) in G(2) and 14 (16.3%) in G(3) were not able to answer this question, $p = 0.007$. Post hoc analysis revealed statistically significantly differences between G(1) and G(2), $p = 0.011$, and G(1) and G(3), $p < 0.006$.
G	**Section Summary:** The responses to 1 question were significantly different between G(2) and G(3) but in no other group combination.	**Section Summary:** On average, 9.4% of respondents in G(1), 2.1% in G(2) and 1.7% in G(3) were not able to answer these questions.
	Q. 17.10 $\chi^2(2) = 9.356$, $p = 0.009$. Post hoc analysis revealed statistically significantly differences between G(2) and G(3), $p = 0.010$.	Q. 17.6 Of the respondents, 3 (18.8%) in G(1), 0 (0%) in G(2) and 2 (2.3%) in G(3) were not able to answer this question, $p = 0.036$. Post hoc analysis revealed no statistically significantly differences between groups.
		Q. 17.7 See Q. 17.6.

challenges, while CVC and TTND experiments also addressed the supplier-side challenges. The result thus indicates a significant bias towards information-sharing and cooperation on complement challenges in public-private innovation ecosystems, in line with Hypothesis 2.

4.3. A bias in the underlying network of individuals

To support validity, differences between the responses to the same questions were analysed across both networks, with the public-private innovation ecosystem divided into those filling an academic role and those filling an engineering role. The required sample size was achieved for all Kruskal-Wallis H-tests, even though the "not applicable" responses were not included. The results are provided per significant difference in Table 3, with results per pairwise comparison using Dunn's procedure with a Bonferroni correction for multiple comparisons. The results indicate that there are very limited differences in regard to responses provided by those able to respond in the studied groups: only six statistically significant differences were identified. While there might be individual disagreement between those able to answer the questions, similar patterns repeat themselves across the groups – supporting the validity of the primary analysis.

The same questions were then compared across the two networks in regard to the ability to respond to the questions. The test of two proportions used was Fisher's exact test, since the minimum expected frequency of 5 respondents in each proportion was not met in any significant case. Again, the results are provided per significant difference and summarised per section in Table 3, with results per pairwise comparison using Dunn's procedure with a Bonferroni correction for multiple comparisons. Most respondents are comfortable answering the questions in Section B, i.e., with regard to the importance of safety standards that directly impact their primary application domain. However, for Section C, i.e., the actual influence of these standards, the respondents in the public-private innovation ecosystem with an academic role were much less able to respond – significantly so, to a large degree, in comparison to those in the same underlying network but with an engineering role (in 10 out of 14 questions) and to a noticeable degree compared to the respondents from the in-firm network (in 6 out of 14 questions). This pattern repeats itself in regard to the importance and influence of safety standards that do not directly impact the primary application domain of the respondents. However, here, the differences between those with an academic role in the public-private innovation ecosystem become clearer in comparison to the respondents from the in-firm network (in 7 out of 14 questions in Section D, i.e., with regard to the importance of safety standards outside the primary domain of the respondent, and 10 out of 11 questions in Section E, i.e., with regard to the influence of these standards), even if it remains noticeable in regard to those from the same network underlying the public-private innovation ecosystem (in 4 out of 14 questions in Section D, and 7 out of 11 questions in Section E).

We find that the empirical results corroborate Hypotheses 3.A and 3.B. Value creation in public-private innovation ecosystem genesis is to a large extent furthered by engineers who have acquired knowledge from a broad set of application domains, i.e., come from contexts focused on technological recombination. The difficulty in combining heterogeneous network parts is also clearly seen in the results, where the differences between engineers and researchers can be observed. As shown, the latter frequently have significantly less knowledge of exploitation across several application domains.

5. Discussion

As the academic discourse still has to arrive at a theory that accounts for the innovation ecosystem phenomenon in a more comprehensive manner (Autio and Thomas, 2014; Gomes et al., 2016; Oh et al., 2016; Valkokari, 2015), this paper set out to explore bias and challenges in early-stage public-private innovation ecosystems. In our study, we focused on a case that matches many of the aspects highlighted by the innovation ecosystem discourse: it contains both supplier- and user-side participants (Autio and Thomas, 2014); it focuses on value creation through innovation (Autio and Thomas, 2014); and it has an open approach to combine technology into new products and services (Oh et al., 2016). Our hypotheses spring from the loose coupling characterising innovation ecosystem genesis and the special knowledge required to establish value capture in different application domains. Building on these factors, several aspects of innovation ecosystem theory could be empirically corroborated. In the next subsection, the implications of corroborating Hypotheses 1 and 2 are discussed with regard to theory. This is followed by a discussion of the corroboration of Hypotheses 1, 3.A and 3.B in relation to innovation ecosystem management and policy.

5.1. Theoretical implications for innovation ecosystem design and development

The intent of this paper is not to discuss the conceptualisation of innovation ecosystems in general. However, we note that although loose coupling has figured extensively in the discourse (Dattée et al., 2018; Iansiti and Levien, 2004; Li, 2009; Pagani, 2013; Scaringella and Radziwon, 2017), the reasons for the loose coupling are seldom discussed. At most, the loosely coupled relationships are motivated by referring to the need for flexibility and different communities to meet (Li, 2009). As it is known that initial conditions can shape the continued evolution of innovation ecosystems (Shipilov and Gawer, 2020), it is worthwhile to consider whether such a strong characteristic of innovation ecosystems does not follow from frequently occurring initial conditions. In the studied context, the need for academia to shoulder a new leadership role is likely one explanation for the loose connections. This puts focus on the organisational aspect of recruiting incumbents for the sake of their complementary knowledge on exploitation. However, as this need stems from the fact that public organisations do not steer their members towards such knowledge, it will represent an obstacle as employees at private firms and researchers attempt to communicate. This will likely lead to weaker and more sporadic relationships than would have been the case if the involved organisations aligned their members in a more similar way. In fact, if public organisations disengage from the innovation ecosystem, private organisations will have to take on their leadership responsibilities. This implies that private firms will have to seek out other experts that can bring in the knowledge lost as researchers leave. This might explain examples of more mature, but still loosely coupled, innovation ecosystems found in the literature. In other words, the loss and lack of expertise as certain types of organisations come and go in the innovation ecosystem could also prolong the time during which it will be loosely coupled. This study cannot offer evidence regarding why innovation ecosystems solely consisting of private firms are predominantly described as loosely coupled. However, it can suggest that the answer might not necessarily be found at the organisational level and based on strategic decisions concerning flexibility and coordination but rather on the interactions between the organisational and individual levels. Perhaps there are also roles that private organisations take on during innovation ecosystem genesis that mean there will be misalignment between their employees. This is at least implied by observations of incumbents during the genesis of the FinTech disruptive innovation ecosystem. While still dominant, they partnered with new ventures from other industries to exploit new technology (Palmié et al., 2020).

While the bias towards complement challenges appears to be shared between entirely private and public-private innovation ecosystems, it most likely has different implications for them. Logic suggests that a firm that competes in markets for complementary products to a technology can increase its chance for value capture if it also controls this technology (Schilling, 2009). However, public leadership will, through licensing and standardisation, want to ensure that the control of any novel technology generated in an innovation ecosystem is not just given away to private firms. This licensing can be a strong positive force during innovation ecosystem genesis, but it also likely contributes to ecosystems eventually becoming dominated by public organisations to the detriment of innovation dynamics (Vlaisavljevic et al., 2020). Even when public leadership leaves an innovation ecosystem, such factors will mean that it takes time for private complementors to exert control over technology. Therefore, incumbents face a conundrum when deciding on whether to engage with a public-private innovation ecosystem: it could eventually leave them dependant on a large group of firms for a long time. This will decrease the chance that the innovation ecosystem in question will be viewed favourably. Furthermore, exerting control over core technology is one of the most important ways through which a focal firm can derive value from an innovation ecosystem by, e.g., decreasing inefficiency and quality issues (Boudreau and Hagiu, 2009). The focus on complement challenges, combined with well-intended licensing to ensure fair access during innovation ecosystem genesis, could in the long run evolve into a large source of risk. In the worst case, it will leave an innovation ecosystem unable to react as it becomes associated with inefficient products of low quality.

5.2. Implications for innovation ecosystem policy and management

Researchers are not necessarily concerned about which application domains they engage with during value creation activities, as it is not uncommon that their motivation for this engagement is grounded in furthering research for its own sake (Ćulum et al., 2013; Perkmann et al., 2013). Public governance in the early phases of innovation ecosystems seems to favour the inclusion of incumbents due to their involvement and expertise in closely aligned application domains. However, while incumbents might find it easier to identify the possibility of value creation by use of novel technology in their application domains, their ability to achieve associated value capture is not ensured. Findings regarding *value networks*, a precursor to the concept of business ecosystems (Clarysse et al., 2014), highlight this phenomenon and a challenge to innovation ecosystems: Christensen and Rosenbloom (1995) show how the value networks that firms exist in can make them unable to engage with new technology of a disruptive nature. If the new technology relies on the formation of a new value network where customers' needs and perceived values are not the same as in the existing value network, then incumbents will have a disadvantage to entrants as they find it difficult to commit resources to innovations that do not meet the needs of already existing customers. These challenges could also be further aggravated by low trust, short-term commitment and limited communication that can characterise loosely coupled cooperation between firms where, for instance, it is important to avoid the risk of pursuing the wrong technology (Lambe and Spekman, 1997; Noke et al., 2008; W. Phillips et al., 2006). Our results thus point out that there is a potential cost to using public organisations to achieve value creation that the private sector is not yet willing to commit to (Dedehayir et al., 2018; Dedehayir and Seppänen, 2015; Oh et al., 2016) as it could make the transfer from value creation to value capture haphazard. In other words, even though public-private innovation ecosystems arguably can start acting earlier on opportunities related to novel technology, they might not be sufficiently interested in or able to turn these into new commercial offerings in a timely and efficient manner.

This leads us to a challenge related to the organisational level of public-private innovation ecosystem genesis. As firms foster their employees' abilities to think and act in specific application domains, loose coupling selects for easy access and complementary skills in regard to these domains and *at the moment*. Public R&D subsidies often target establishing more adventurous value creation and collaborations in innovation ecosystems (Ahn et al., 2020). However, there is neither a need for public leadership of innovation ecosystems to work towards enabling non-incumbents to act on business opportunities, nor does this seem to be likely to occur serendipitously. The associated challenge is for innovation ecosystem leadership to make this happen by instituting mechanisms at both an organisational and individual level. Leadership needs ways to coordinate across different stakeholders and constrain the evolution of an innovation ecosystem's technology and services (Baldwin and Woodard, 2009). This ability to control others is directly linked to organisations relinquishing or maintaining control based on, e.g., their ability to invest in improving the functionality of an important technology or their stake in any market for complementary products (Schilling, 2009). As shown by Boudreau and Hagiu (2009), leveraging this control to steer an innovation ecosystem away from market failure can include a wide range of non-pricing instruments. The literature on technology transfer offices and multidisciplinary research centres points to several such instruments that could also be beneficial for public-private innovation ecosystem leadership, including legal and licensing agreements (O'Shea et al., 2008; Steffensen et al., 2000) and performance measurement and management (Macho-Stadler et al., 2007). This implies that public leadership should start its involvement in innovation ecosystems by building a performance measurement and management system for value creation that selects less for ease, certainty and immediate monetary gains and more for novelty and the involvement of a broader set of organisations. Otherwise, they might eventually be unable to help steer firms clear of challenges to value capture. Arguably, this will require care, as the implications of licensing mentioned in the previous subsection in regard to complement challenges might make firms wary of relinquishing too much control.

The type of underlying network identified by our study as favoured by public-private innovation ecosystems also suggests a challenge related to the individual level. Academic institutions foster their employees' abilities to think and act in specific scientific disciplines, and the focus on exploitation knowledge in innovation ecosystems does not preclude any disciplines from becoming involved. As value creation comes out of private firms interacting with public organisations, the heterogeneity of the formers' employees in regard to application domain knowledge has implications for each individual network part of researchers. However, these network parts can come from different scientific disciplines. The sheer effort of maintaining connections to groups of researchers from other disciplines, further increasing knowledge heterogeneity, would likely work to dissolve these relationships (Reagans et al., 2015). Even more worrying, if academia retains its leadership role beyond the genesis phase, it would most likely force the loosely coupled cooperation between researchers to grow stronger as integration needs, as well as the corresponding administrative requirements and costs, increase. This implies the emergence of a more heterogeneous, potentially multidisciplinary network core of researchers that multidomain engineers would find it increasingly difficult to connect to (Reagans et al., 2015). In other words, changes to the underlying network to ensure that the innovation ecosystem can be governed effectively might eventually smother the innovation ecosystem, as the most fruitful combinations of network participants would be less able to connect.

Arguably, this challenge could be met by using well-connected or multidisciplinary researchers as a "glue", as they could act as brokers between participating researchers from different disciplines. These researchers would early on be a liability as they add to the heterogeneity of the academic network parts. However, researchers who occupy strong brokering positions (coordinating co-inventors from industry *or* academia) can also occupy strong gatekeeping positions (coordinating co-inventors from industry *and* academia) (Lissoni, 2010), and occupying a strong gatekeeping position in this context implies being able to maintain stronger ties with co-inventors from both industry and academia (Lissoni, 2010). This engagement does not seem to be tied only to monetary reward but also to a positive influence on reputations and careers (Lissoni, 2010). In other words, if the underlying network is seeded with well-connected and multidisciplinary researchers that start out as brokers, these could potentially be motivated to grow into gatekeeping roles. This could foster sufficient industry-academia engagement to avoid the innovation ecosystem smothering itself. While this is only a hypothesis that will need to be tested in future research, arguably such a seeding of well-connected and multidisciplinary researchers will have to include steps to decrease the probability of disrupting the existing networking. One such way would be by putting the onus of maintaining the relationship on the seeded researchers, e.g., by basing it on them opportunistically monitoring the activities of the other researchers. This suggests that they will have to work to form a close relationship, not only, e.g., sign up to the same research centre. This proposed way of integrating innovation through new academic broker- and gatekeeper roles offers a stark contrast to today's predominant practices for technology commercialisation, focusing primarily on a university-centric approach with a strong emphasis on IPR and licensing. However, especially in the development of multi-technological and complex systems, the outlined approach could constitute a valuable complement to existing structures and practices.

6. Conclusions

The results presented in this paper contribute to the extant knowledge about public-private innovation ecosystem genesis.

Our results suggest that the implications of the loose coupling emphasised by the concept are more complex than previously acknowledged, as it can be traced to the characteristics of both organisations and individuals. The need for exploitation knowledge can lead to a biased recruitment of incumbent firms by public leadership. The emphasis on knowledge that is treated differently by the involved organisations can be an obstacle as individuals communicate, leading to weaker and more sporadic relationships. Should public organisations leave the innovation ecosystem, firms will have to replace the knowledge that was lost. This specifically implies that public-private cooperation could prolong the time during which innovation ecosystems are loosely coupled. More broadly, it suggests that the expertise of certain types of organisations could be both the reason they fill or leave roles and the explanation for why they do not form stronger collaborations in innovation ecosystems.

Furthermore, we can corroborate that bias towards complementary challenges also exists in public-private innovation ecosystems. This is potentially problematic, as public leadership is likely to make it more difficult for firms to exert architectural control by making technology proprietary. Firms could look unfavourably upon engaging with public-private innovation ecosystems, as this difficulty implies becoming dependant on a large group of firms for a long time or even the possibility that the innovation ecosystem will not be able to mitigate threats in a timely manner.

Practically, our results suggest that there is a potential cost to using public organisations to achieve value creation that the private sector is not yet willing to commit to. The ability of public innovation ecosystem leadership to act early on novel technology might be offset by an inability to bring the technology to market. To meet this challenge, public ecosystem leaders need to consider building strategies for e.g., licensing, performance measurement and performance management early on, establishing the non-pricing instruments required to steer firms clear of challenges to value capture. Arguably, this will require care, as the implications of licensing mentioned in regard to complement challenges might make firms wary of relinquishing too much control. Furthermore, while an underlying network consisting of homogeneous groups of researchers in regard to application domain knowledge is optimal for value creation in this context, it is not necessarily ideal to establish a sustainable innovation ecosystem. As it does not preclude the involvement of researchers from different scientific disciplines, the effort of maintaining connections to dissimilar researchers could eventually serve to dissolve relationships. In fact, should academia overcome this challenge, it implies the emergence of a heterogeneous network core of researchers. This change to the underlying network might eventually smother the innovation ecosystem, as it becomes less able to generate new connections between the most fruitful combinations of network participants. Engaging well-connected and multidisciplinary researchers as brokers at an early stage could help address the challenge of maintaining connections between homogeneous groups of researchers, and if their role could be extended into gatekeeping, it should also help avoid innovation ecosystem stagnation. However, this suggests that the relationship between these researchers will have to be closer than is usually the case when, for instance, promoting such cooperation through research centres.

Acknowledgments

This study was supported by the European Commission through the FED4SAE innovation action under Grant Agreement No. 761708. Special thanks also go to Vicki Derbyshire for her help in proofreading.

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