Mechanisms of Innovation in Complex Products Systems: An Innovation System Approach

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RESUMO: *Uma estratégia bem conhecida no direcionamento da inovação em sistemas de produtos complexos (CoPS) é estimular instituições nacionais a seguirem uma determinada tecnologia usando-se estratégias de inovação aberta. No entanto, pouco se sabe sobre quais mecanismos as organizações CoPS utilizam para implementar estas estratégias, e como as empresas podem estimular o processo de maturação tecnológica. Baseado em um estudo sobre a indústria aeroespacial Sueca, este artigo se utiliza de uma macro-análise apresentando uma abordagem sistêmica em que a indústria aeroespacial Sueca juntamente com outros atores nacionais, como universidades, institutos de pesquisa e agências governamentais, impulsionam suas capacidades e a inovação.*

PALAVRAS-CHAVE: *Sistemas de Produtos Complexos, Colaboração em P&D, Inovação Aberta, Sistemas Nacionais de Inovação.*

ABSTRACT: *A well-known strategy for driving innovation in the complex product systems (CoPS) industry is to stimulate the national institutions to follow a particular technology by using open innovation strategies. However, less is known about the mechanisms that CoPS organizations use to implement such strategies and how firms can stimulate the technology maturity process. Based on a study of the Swedish aerospace industry, we use a macro-level analysis in this paper to report a systemic approach in which the Swedish aerospace industry together with other national actors, such as universities, research institutes, and governmental agencies, leverage their capabilities and innovation.*

KEYWORDS: *Complex Product Systems, R&D Collaboration, Open Innovation, National Innovation Systems.*

1. Introduction

A single organization cannot innovate in isolation. For a firm to stay competitive, it must recognize the permeability of its boundaries, where ideas, resources, and individuals flow in and out [1]. Many open innovation practices are strongly linked through organizations in the same system. To holistically understand interactions within this collaborative network made of different actors, we use the concept of innovation systems. This concept reflects that innovation can be considered as an evolutionary, non-linear and interactive process requiring intensive communication and collaboration among different actors, both within firms as well as between firms and other organizations, such as universities, innovation centers, educational institutions, financing institutions, standard setting bodies, industry associations, and government agencies [2].

The concept of national innovation system can be viewed as "the system of interacting private and public firms (either large or small), universities, and government agencies aiming at the production of science and technology within national borders" [3:212]. Thus, every innovating actor has some influence on the environment. However, firms have a main role in leveraging innovation performance, as their existence usually relies on the commercial success of new products and services. In comparison to other actors, firms are usually better suited for innovation activities because they have better structures, incentives, and resources to implement new technology opportunities in their new products. This is also supported by the fact that technology evolves through discontinuities and breakthroughs lead by industries that initiate an era of technical variations and culminate in dominant designs [4].

While a well-known approach to influencing national institutions to follow a particular technology or a standard is to use Open Innovation strategies [1] [5], less is known about what mechanisms firms use to implement them. For the aerospace or defense firms that are embedded in an intricate network of different types of actors, it is important to gain insight into how they can stimulate this network to set the direction of technology. Therefore, further theoretical development of open innovation and technological alignment mechanisms in complex product systems industries is necessary.

The purpose of this study is to identify and explore key strategic mechanisms used by the Swedish aerospace industry to align objectives with key stakeholders, such as universities and small medium enterprises (SMEs), attract support from governmental agencies, and consequently strengthen the aerospace technology industry. The study is based on an in-depth case of the Swedish aerospace industry.

One of the key actors in this industry is the Swedish firm SAAB AB. Based on a qualitative research study with explorative interviews and an abundance of secondary data, we show how the Swedish aerospace industry has successfully offered innovative and affordable products and has positioned itself internationally among the big players in this industry. The study is performed by using a macro-level approach in which we review the literature of innovation on a system level and connect it to our empirical data on the same level. Although we mainly explore inter-organizational interactions and relationships among national partners in a particular technology area, this research also considers the firm-level perspective and how industries can influence the development of their national innovation systems. This approach builds on five inter-organizational mechanisms: (1) embeddedness in a national innovation system context; (2) investment in demonstrators; (3) bridging the gap between universities and firms; (4) collaboration in an international network; and (5) encouraging an open climate.

2. Theoretical background

It has long been acknowledged that economic change revolves around innovation, entrepreneurial activities, and market power. Particularly, technological innovation fosters social welfare by incentivizing firms to develop new products and services [6]. Innovation can arise from many different sources, including organizations such as universities, firms, governmental entities and private non-profit institutions as well as individuals like independent inventors and users. From all sources, usually the most active and the primary one is the firm. Firms are suited for innovation activities because they have greater resources than individuals and a management structure to use those resources towards a useful product, process, or services [7].

A single organization cannot innovate in isolation. For a firm to stay competitive, it must emphasize the permeability of its boundaries, where ideas, resources, and individuals flow in and out [1]. The ability of firms to apply Open Innovation practices lies on several numbers of external factors. Dahlander and Gann [8] found that Open Innovation Strategies can be grouped in four processes, being two inbound: sourcing and acquiring, and two outbound: revealing and selling. In particular, the practices within each of those processes are positively affected by a continuous supply of outside knowledge, highly-educated personnel, financial resources, effective legal systems, institutions protecting IP rights, etc. Most of these factors are closely related to a country's national innovation system [9] [10] and have at least three critical effects on it: they reinforce its importance, they improve its effectiveness, and they diversify its networks [5].

2.1 The systemic nature of innovation

The study of this systemic approach, broadly called innovation system, argues that innovation should be seen as an evolutionary, non-linear, and interactive process. This innovation process requires intensive communication and collaboration, both within companies as well as between firms and other organizations such as universities, innovation centers, educational institutions, financing institutions, standard setting bodies, industry associations, and government agencies [2].

Many other systemic approaches were created according to geographic similarities and complexities such as: national innovation systems [10]; regional innovation systems [11]; cluster theories [12] which also consider the firm as having the leading role in innovation; continental and sub-national systems, as described in Nelson [13], that provide a broader perspective to the geographical criteria; the triple helix model, which emphasizes the role of the university in fostering innovation [14]; sectoral innovation systems [15], which group structures, agents, and dynamics in the same industry specialization; and technological innovation systems [17] [18].

The national innovation system is "an open, evolving and complex system that encompasses relationships within and between organizations, institutions and socioeconomic structures which determine the rate and direction of innovation and competence building emanating from processes of science based and experience based learning" [19:09]. Another even broader definition is: "All important economic, social, political, organizational, institutional factors that influence the development, diffusion and use of innovations" [2:14]. A fundamental notion of these definitions is that innovating firms are part of a wider socio-economic environment in which cultural and political factors, together with economic policies, influence the direction and scale of innovation activities, helping to determine their innovation success.

Because this paper has a macro-level perspective and analyses the national effort to achieve economic performance through innovation, we focus on the national institutions, their incentive structures, and their capabilities that influence the rate and direction of innovative performance [10].

2.2 National Innovation Systems

Many scholars agree that the national context is best suited to analyze the dynamic of learning within organizations as well as in the interactions among them. In the pursuit of R&D, it is important to understand national characteristics in terms of how firms interact with different actors and to what degree different firms give employees access to competence building in connection with on-going economic activities. Such deep understanding can help to identify the kinds of knowledge created and used in the innovation process [20]. In his comparative study of different innovation systems from 15 different countries, Nelson [10] strengthens the idea that the technological capabilities of firms are key sources of national economic performance, and that these capabilities are, in a sense, national and can be built by national action. In his Danish–Swedish innovation systems comparison, he shows that even in those very similar countries with close cultural, geographic, and economic aspects, it was encountered several differences in their innovation systems.

Porter [12] designates four interdependent, mutually reinforcing attributes of a nation as the major determinants of competitive advantages. They are as follows: 1) factor conditions, such as the availability of a skilled labor force and infrastructure; 2) demand conditions for the products of the industry; 3) related and supporting industries; and 4) firm strategy, structure, and rivalry. Therefore, when it comes to analyzing how technological capabilities are built, sourced, diffused, and harnessed, institutional configurations and, more specifically, national institutional contexts, matter [2] [10][21][22].

However, caution is needed when applying the national focus too rigorously, since there is much more innovation than public and private R&D inside the country domain. Also, science, pure or applied, has always been an international enterprise, implying that the boundaries that enclose the national level should be seen as permeable routes to interaction with the wider environment rather than as barriers [23]. This internationalization has created a tension between the global trend of technology and the continued relevance of national frameworks [24]. In that respect, some scholars argue that a more integrative approach is needed to investigate the relations between a country's specific innovation system and the global system [25].

Not all actors in the system have the same level of influence and impact on the innovation process. A national innovation system reflects the resources and institutions in a given country that domestic firms can leverage to support their own innovative efforts [9] [10]. This puts firms in the central spot. To support this idea, Nelson [10] describes the way that R&D evolves, giving some reasons why industrial research laboratories, rather than universities' laboratories or government facilities, became the dominant locus of R&D. Although universities and individuals are crucial sources of innovation, the majority of R&D and innovation, tends to be the business of incumbent firms. In general, national innovation systems case studies suggest that public and academic efforts can support, but may not substitute for the technological efforts of firms [10].

2.3 The role of firms

The system approach is that of a set of institutional actors who, together, play the major role in influencing innovative performance [10]. It follows that every source of innovation has some influence in the environment. In the case of firms, they usually adopt strategies and implement mechanisms to actively shape their innovation systems. Innovation systems also affect firms' R&D activities [21]. The influence of firms over the national innovation system and vice versa can be understood when considering the technology life cycle perspective [4]. In high technology industries, technological and evaluation standards play a central role. This is, for example, evident in telecommunication systems. Firms can gain advantages when other organizations and institutions use similar, compatible technologies. In the case of the aerospace industry, it may even be impossible to operate a product not conforming to industry standards.

Therefore, standardization issues bring strategic implications. Spencer [26] finds empirically that, by sharing technological knowledge with external researchers, a firm can shape the technological and evaluation standards in its institutional environment by directing the industry-wide conversation that takes place concerning the advancement of their technology.

2.4 The aerospace industry

The aerospace industry has long been used as some of the best-known examples of R&D collaborations between diverse partners such as suppliers, customers, etc. [27]. It can be better understood in the context of CoPS theory. The literature on CoPS distinguishes this type of products from commodity products along several dimensions. Complex product systems have unique characteristics, including innovation-paths, supplier–user relationships, product architecture, and project durations. The notion of complexity in CoPS is related to the number of sub-systems and customized components, the width of knowledge and skills required, and the degree of new knowledge involved in development and production [28].

Innovation in CoPS is shaped by the project-based nature of operation. Several key factors are necessary for successful project delivery, among them knowledge integration across organizations and technology and knowledge transfer among partner firms [27] [28]. Due to their long life cycle, high complexity, and cost, complex systems are in constant need of development and innovation. This industry's focus on collaboration has rapidly evolved during the last two decades. The civil aerospace sector has also followed this transformation and, as a result, the aerospace industry is much more competitive than it has been in the past, when competition was based mostly on differentiation and technical features. Today, this same industry is competing based on cost and value as well as innovation [31].

It has been argued that, in order to survive, CoPS firms need to adjust to the differing organizational requirements related to integral and modular innovations. For that, these firms need to maintain a loosely coupled network structure, which enables them to benefit from the advantages of both integration and specialization [32]. These networks have a key characteristic: "The presence of a systems integrator firm that outsources detailed design and manufacturing to specialized suppliers while maintaining in house concept design and systems integration capabilities to coordinate the work (R&D, design, and manufacturing) of suppliers" [32: 617].

Another difference in the CoPS industry is the government's role, which can be quite different from commodities products. That is because many CoPS firms are heavily regulated at both the domestic and international level. The government thus influences CoPS not only as a purchaser of products or policy incentives, but also in terms of establishing technical and safety standards and sometimes regulating excess concentration in the market. Nonetheless, Innovation, technological development, and economic performance are not only determined by government policies alone. The governmental influence in the national innovation system is, therefore, limited. To be effective, governmental policies need to take the specific technological path into account and need to address already existing social and market institutions that respond to the new incentives [33].

3. Methodology

In order to explore how organizations working with complex product systems drive innovation in their national context, we performed a case study with the leading firm of the Swedish aerospace industry, Saab AB. Saab is a Swedish firm active in the aerospace and defense sector. Case studies are generally considered to be an appropriate approach for studies with an explorative character [34], and can be a useful unit of analysis for theory building [35]. A single case study can help researchers to see new theoretical relationships, to question old ones, and to provide opportunities to understand the empirical context. Our aim to explore a transition and its implications on various aspects of innovation capability warrants a broad and deep approach.

We have, therefore, selected a unique case that not merely serves as an illustration of a particular phenomenon but represents what Siggelkow [36] refers to as a "talking pig." The Swedish firm Saab represents a unique case serving this purpose. There are four aspects that make Saab an interesting study object.

First, the firm has traditionally relied on internal technological knowledge of complex product systems, such as military aircraft. Due to changed contextual conditions, it has internationalized its strategy and transformed its predominantly closed innovation processes into one that is increasingly open and collaborative with a wide range of actors.

Second, the firm operates within the sensitive and secretive context of the defense sector, which is highly influenced by governmental forces. Saab has a long tradition of close relationships with its Swedish customer organization residing under the national government. However, its internalization has driven the firm to focus on new customer markets and create new partnerships. Its internationalization also requires a new focus on the standardization of solutions among different countries.

Third, the firm's complex products and systems rely on a variety of knowledge bases that require considerable attention to system integration. Further, as its products operate on the market for several decades, innovation requires a product life cycle approach.

Fourth, Saab relies on a distributed network of suppliers residing in different countries. In some projects, Saab acts as a system integrator and principal actor, but Saab also acts as a supplier to, for instance, commercial aircraft manufacturers. Despite the international focus of Saab, it is also largely embedded in a national network of universities, research institutes, small medium enterprises (SMEs), and governmental agencies to develop strategic technologies in order to attract international collaborations.

Saab has customers in over 100 countries and re-invests about 20 per cent of their annual sales amount (around 2.8 billion EURO) in research and development, which is mostly concentrated in Sweden. Most of the Group's employees (around 14000) work in Europe, South Africa, the US and Australia, but people are also on site in offices in more than 30 countries around the world.

The study is based on six interviews, two full days of study visits, several informal discussions with managers at Saab, and additional secondary information. In addition, one of the co-authors of this paper is employed by Saab and has provided detailed insights and reflections about Saab's innovative and collaborative capabilities. The six interviews were semi-structured and performed to capture Saab's innovation and collaboration strategy as well as provide in-depth examples of a collaborative project. The interviews took about 2 hours and were guided by an interview guide. We recorded and transcribed all interviews afterward. In order to get a deep understanding of the organization and its history, products, production processes, etc., data was also gathered during two full days of study visits and several informal discussions with managers at Saab. In addition, we collected an abundance of secondary information related with Saab's traditional relationship with its Swedish customer, several ongoing collaborative projects, internal documents and PowerPoint presentations, published articles and theses, etc. The secondary data consists of nearly two thousand pages.

Data analysis was performed by content analysis searching for recurring themes. We also triangulated our data from different sources in order to get an in-depth understanding and to increase reliability [37]. The third author, an employee of the firm, was excluded from the initial analysis but was involved in further discussions of our understanding to improve the validity of the findings [38].

4. Findings

Our initial analysis revealed five mechanisms as foundations for driving innovation in a CoPS industry. They are (1) embeddedness in a national innovation system context; (2) investment in demonstrators; (3) bridging the gap between universities and firms; (4) collaboration in an international network; and (5) encouraging an open climate.

4.1 Embeddedness in a National Innovation System Context

With the objective to create a broad national consensus regarding the goals, direction, and extent of Swedish aeronautics research, Saab, in collaboration with government agencies and academia, was one of the main actors initiating a program called The Swedish Aerospace Research and Innovation Agenda (NRIA) [39]. This agenda has been jointly elaborated within a Triple Helix context in Sweden, and in collaboration with:

- Universities and research institutes (i.e. Chalmers, Royal Institute of Technology, Linköping University, University West, Blekinge Institute of Technology, Swedish Defence Research Agency, and Swerea Swedish Research Institute)
- Companies and industrial organizations (Saab, GKN Aerospace, small medium enterprises [SMEs] and Swedish Aerospace Industries)
- and governmental authorities (Swedish Defence Material Administration, the Swedish Armed Forces, Swedish Defense Research Institute and the Swedish funding agency - VINNOVA).

The main objectives to write such national strategy are as follows:

- To agree on long-term objectives (industry, academia, government)
- To increase cooperation within Sweden between universities, research institutes, and industry
- To support small and growing niche companies
- To create interest and support for funding
- To explore cooperation opportunities with other industry sectors
- To form a common view among the participants writing the strategy

This agenda is updated regularly, which requires that the participating actors continuously create consensus on strengthening and renewing the Swedish aerospace capability. The agenda summarizes the long-term, as well as medium- and short-term, objectives for all leading actors in future international civil aerospace programs, as well as the future military aerospace programs in Europe. According to the director of future business at Saab, all aeronautics stakeholders in Sweden need, to some extent, to agree on recommendations and priorities of what and how to invest. Also, he stressed the advantages of having a strong national network to gain international visibility:

> *"In discussing R&D collaboration it is valuable to show to potential investors and partners what we are doing in Sweden and how aligned we are."*

4.2 Investment in Demonstrators

Saab also actively participates in national and international demonstrator programs. Discussing, evaluating, and developing demonstrators and scenarios enables users and stakeholders to participate in the innovation process and leverage existing and newly created knowledge. Demonstrators are a way to bring different disciplines and experts together so they can develop a shared understanding and contribute with their practical experience in the participatory design [40].

The NRIA recommends investing in five national demonstrators in the areas of system integration and concept studies, integrated wing structures, integrated propulsion, propulsion fan modules, and integrated concepts of air traffic management. The demonstrators were prioritized based on current knowledge and technology readiness levels (TRLs), combining civilian and military needs and benefits, and can be assembled in future demonstrator concepts at different levels of technology readiness. They also recommended the appropriate collaborative partners for each proposed demonstrator. The experience and knowledge acquired with the national demonstrators would contribute with expertise in future international projects.

The importance of building national demonstrators is exemplified by the project leader of the Mid-Air Collision Avoidance System (MIDCAS) project, an industrial consortium composed of 11 partners from five European countries. The experience and know-how acquired by the national demonstrators in previous projects such as the Auto Collision Avoid System (AUTO-ACAS) and the Ground Collision Avoidance project (GCAS) have a positive spin-off effect, as they helped legitimize Saab's role as a potential leading actor in international projects. According to the project manager of MIDCAS:

> *"I think, definitely our background having done the AUTO-ACAS, GCAS and the national sense and avoid demonstrator justified our ambition to take a leading role in MIDCAS."*

Although the experience with and competence acquired through the national demonstrators was an important condition, many other factors, including experiences in previous international collaborations and political factors, also affected the role of Saab in MIDCAS.

Another example of the positive effect of national efforts in demonstrators is the NEURON project of the Unmanned Combat Autonomous Vehicle (UCAV), which was a collaboration between Dassault, Saab, and several firms from other European countries. The director of future business explains:

> *"We did some subscale unmanned demonstrators in Sweden, which gave us know-how in autonomous flight that, together with the recognition as an important aviation industry, allowed us to get a key role in Neuron and gain knowledge that further contributed to the next generation of Gripen being developed subsequently."*

4.3 Bridge the Gap Between Universities and Firms

The Swedish National Innovation System is dominated by an internationally oriented industry and academia [41]. Saab, as a focal firm of the Swedish aerospace industry, is an example of a CoPS firm that uses university research to fill the gap between basic and applied research.

> *"When we cooperate with universities, we want to bridge the gap between low Technology Readiness Level (TRL) research at universities and medium TRL research at industry to pick up ideas from universities and mature that technology into something that could be inserted in product development later on." (Saab's Director of Future Business)*

One solution achieved with the main actors of the NRIA was to establish meeting places where basic and applied researchers could interact with each other and with companies who could set standards with the aim of clarifying the national structure for aerospace and its interaction with other technology areas, utilizing the six prioritized areas of research in aerospace recommended before. One of the expected results is that individual research practitioners will become part of a larger context, which will strengthen cross-functionality expertise.

In a long-term perspective, it has been reported that this proximity between industry experts and academic professionals is helping to avoid competition between universities in closely related fields and, in turn, is providing increased opportunities for different areas of expertise to work together in the same direction and for common abilities to increase the readiness of technologies in accordance.

Saab also has a close research collaboration with institutions such as Chalmers, the Royal Institute of Technology (KTH) and Linköping University. The Swedish National Aeronautical Program (NFFP), is an example of such collaboration funded by VINNOVA, Saab and GKN with industry financing around 50% of strategic projects on lower TRLs. This program generated crucial technology and knowledge that were central to the development of national demonstrators in Sweden.

4.4 Collaboration in an International Network

Increasingly, most actors in the Swedish National Innovation System have become internationally connected to some extent. This international collaboration increases access to, and benchmarking with, a technology developed by other state-of-the-art actors. It also creates networks of interpersonal relationships. This internationalization process generates more international collaboration. This is also the case for actors from academia who find new international partnering opportunities thanks to international programs. Moreover, according to the NRIA, three metrics can be used to identify how strong a national innovation system is: How competitive internationally, how attractive a partner in the global market, and how present in international projects.

From Saab, three main reasons for doing international collaboration were identified: cost sharing, knowledge access, and standardization.

First, in order to reduce R&D costs, the shared cost model is becoming increasingly important and common in complex systems. For instance, the MIDCAS was a 50 million-euro project shared among 11 partners from five countries. The Clean Sky is a project of 446 partners from 20 countries and has 149 million euros in funding. It had a finance share of 27.5% from industries, 19% from research centers, 35% from SMEs, and 18% from academia.

Second, a lot of experience and knowledge in systems integration, product development, and tests qualification was gained. Also, the desorptive capacity [42], which refers to a firm's outward technology transfer capability, was equally important to influence the standardization process.

Thirdly, this standardization becomes essential when a complex system aims for acceptability. In the MIDCAS project, for example, it was a necessity to provide a common Unmanned Air System (UAS) view to all airspace users and actors addressing interoperability, performance, and safety. For that, a strong coordination was necessary among the main stakeholders of the area to contribute to the elaboration of the standards and build a common broad European knowledge. The importance of the Standardization in an international context can be better understood with the following comments from the project leader of MIDCAS:

> *"If you're on your own and make some very smart thing, but don't tell the others, they're going to say that they don't*

understand what that is. And then, your very smart thing has no real value because if the standard goes in another way, your smart invention won't fulfill the standard."

4.5 Encourage an Open Climate in an Organizational Structure

Besides several collaborative aspects, Saab's internal climate and organization were also identified as key mechanisms. All interviewees agreed on the firm's open climate, which is not based strictly on hierarchy. According to the project leader of MIDCAS:

"I think that we have a quite open discussion climate and not a very hierarchical organization in that respect … here anyone can challenge anything and you can have a good open discussion on it. Then if turns out that that you as the manager did not have the good way to do it and it ends up that it becomes obvious that someone else idea was the good one or the good way to go, that's is not a problem."

Or, in the words of the chief engineer of MIDCAS project:

"We have this open climate, that everyone is considered an expert. Decisions and interactions are made on the specialist level, so we don't just tell our managers that this is how we want to do it and then the managers just meet and decide what to do. We do it in joint collaboration and the one who has the highest knowledge gets to speak.… I think this climate is encouraged very much at Saab."

Saab's open climate and management based on expertise rather than position has greatly facilitated collaborative efforts in national and international contexts. This has created a culture of trust, a curiosity for new technological developments, and, consequently, a willingness to learn from and share knowledge with collaboration partners.

5. Discussion and Analysis

Although the five identified mechanisms cover different levels of analysis, they are operating in tight connection. All explain part of the success of Saab to transform from performing internally oriented innovation to collaborative innovation. Its embeddedness in a national innovation system partly explains the transition that Saab has been able to make. This mechanism is country-specific [43] and has as a practical example, the Swedish National Research Innovation Agenda (NRIA), which also serves as guidelines for the other mechanisms to operate. Gradually, Saab has achieved a relatively high degree of collaboration with universities to stimulate innovation primarily on lower levels of the technology readiness level scale (TRL) and helped to bridge the research from lower TRLs to medium TRLs. University–Industry collaboration has also been discussed in previous studies that are stressing that knowledge may be transferred to firms through unintended flows that generate spill-overs from university-based research or through market-mediated interactions, such as contract and collaborative research [44]. Investment in demonstrators, particularly on a national level, has not only strengthened Saab's internal competence but also created consensus among important actors and allowed Saab to position itself in an international context. This internationalization enabled strategic international collaborations with other manufacturers, suppliers, and customers, which in turn contributed to the industry to achieve a stronger position in the market and potential to open up new markets. In addition, the national collaboration has been important to create consensus and trust, factors that have been argued as important to generate growth in Sweden and also strengthen the Swedish aerospace industry's influence internationally [43]. This trust is also one of the underlying strengths of Saab's internal climate, improving collaboration across firm boundaries by not being constrained by the "not invented here" syndrome and allowing the firm to absorb knowledge from its environment [45].

The five mechanisms operate simultaneously and connected. Together they contribute to a widespread consensus in a larger network of actors and facilitate innovation through the coordination and influence on the direction of technology development. They also reinforce each other in a sustainable, "symbiotic" environment, where relevant knowledge is constantly flowing from one mechanism to another in an iterative feedback loop. This is depicted in figure 1.

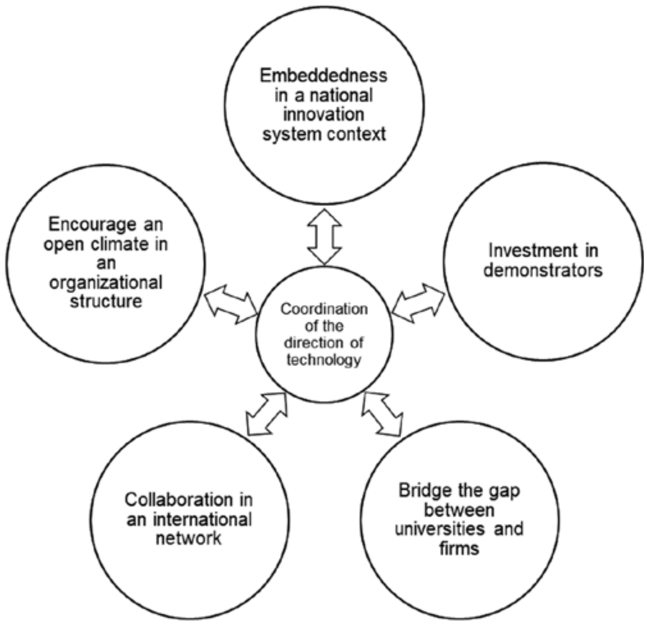

Fig 1. Five mechanisms that drive innovation in CoPS.

These five mechanisms have two main implications for the literature: First, the mechanisms can be viewed as a framework for the coordination of loosely coupled networks in which systems integrator firms need to balance specialization and integration [32]. Brusoni [32] argues that systems integration firms are the coordination mechanisms that bridge the gap between the distinctiveness of markets and the responsiveness from hierarchies, by developing products and technologies. They do that mainly by coordinating the work (R&D, design, and manufacturing) of external suppliers by outsourcing from them both design and manufacturing of components and technologies. Our approach, however, shows the breadth of their coordinating role by placing suppliers and other institutions, such as universities, governmental agencies, research institutions, and SMEs, at the same level of importance. We argue that these actors and national institutions are important elements of the loosely coupled network, essentially in early phases of technology development. The development of national demonstrators based on technologies previously agreed between different stakeholders, instantiates the level of coordination needed to align distinct objectives. The mechanisms, therefore, represent a higher level of coordination of the loosely coupled network in an early stage of the technology readiness level and are jointly implemented by large system integrator firms such as Saab and their network of partners. This coordination aims to set the direction of technology and builds the relevant capabilities in the national institutions in order to access this knowledge later and apply it in the product development stage.

Second, from the national innovation systems perspective, the results help to understand the dichotomy between global vs. national [24] and partially answer a relevant question of how the particular characteristics of the national systems of innovation form the basis for complex interdependence in the global system [25]. We argue that the five mechanisms can represent this link between national and international, and provide an integrative approach to minimize the tension between scholars who discuss the relevance of national frameworks. Our empirical data shows that receiving public finance in early stages of R&D with national demonstrators and research programs, achieving consensus with relevant stakeholders on the direction of technology, and bridging the gap between universities and industries are national efforts that represent a crucial step to attracting international interest and becoming inserted distinctively within the global context. Therefore, while we acknowledge that the competitive advantage of firms cannot be explained solely from a national level perspective and how they manage themselves internally might matter most, we also recognize and confirm that their competitiveness is also unavoidably contingent upon the country-specific conditions within which they operate [24]. In this sense, our data show these national conditions are shaped with public funding in strategic technologies and by strategic partners, which supports the argument that the competitive advantage of firms and of the economies as a whole is something that is and can be built up by conscious and deliberate policy actions [10].

6. Conclusion

This paper aims to develop a system-based understanding of how innovation is driven and supported through collaborative activities and practices in a national context. By studying the aerospace industry of the Swedish National Innovation System and, more specifically, its leading industrial firm (Saab), we have identified five mechanisms that are central to coordinate this large and complex network of interactions. These mechanisms represent different aspects on which a firm only partly and sometimes indirectly can influence. Even though our empirical data suggested positive outcomes from the use of the five mechanisms, it does not come without difficulties. Industry and university have different objectives. Innovation policies are country-dependent and subject to change. However, understanding the more complex context of how to build innovation capabilities in an open context requires a holistic study that includes more than only one aspect.

Pointing out the limitations of our qualitative in-depth study offers fruitful avenues for future research in other mechanisms and methodologies for innovation efficiency among the main actors in the aeronautical technology area. Regarding the generalization of this research, although we claim that these findings bear relevance to other CoPS based firms engaged in joint innovation activities in globally operating networks, further studies of other industry networks, in particular those of smaller firms, are necessary as they might employ different practices.

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