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From Hardware Spillovers to Systems Competence

Digitalization, intangible capital, and defense-to-civilian spillovers: evidence from the Gripen E program

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Abstract

Defense- and military-related R&D has shifted from component-centered hardware engineering toward software-defined, modular and continuously upgraded system architectures. This shift changes the nature of defense-to-civilian spillovers. We develop and probe a framework distinguishing between product spillovers, competence spillovers (know-how, system competence) and spin-in (civil-origin technologies integrated into defense systems). Using the SAAB Gripen fighter aircraft program (Gripen E) as a case, we combine survey data and interviews to assess the nature, magnitude and frequency of spillovers generated by the program. We find economically important competence spillovers (technology development benefits, quality-system tightening, production process improvements), while more traditional product spillovers are limited. The main conclusion is that programs based on modern digital systems-of-systems generate significant societal value primarily through spillovers of systems competence. These are economically significant but harder to observe and measure than traditional spillovers.

JEL codes: O31, O32, O33, H56, L52

Keywords: spillovers, systems-of-systems, digitalization, defense R&D, dual-use, intangible capital, absorptive capacity, Sweden, aerospace

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1. Introduction

The current global security environment has made defense expenditures a key concern in many countries. The question is not only whether and how much to invest in defense, but also how defense expenditures can generate broader societal value beyond their primary military purpose. Defense procurement and military R&D have historically served as catalysts for technological innovation, generating knowledge and capabilities that extend beyond their original military purpose. Yet, in the wake of globalization, digitalization, and the rising importance of intangible assets, the structure of contemporary defense programs differs from the more hardware-centered programs of earlier eras. Military and defense R&D and production activities are increasingly characterized by embeddedness in global value chains and a growing reliance on intangible assets such as software-defined functionality, modular system architectures, and system integration. These changes influence the nature and magnitude of spillovers and raise the question of whether established frameworks for understanding and measuring defense-to-civilian spillovers remain adequate. This paper analyzes that question using the SAAB Gripen fighter aircraft program (Gripen E) in Sweden as a case. We develop and probe a conceptual framework that distinguishes product spillovers from competence spillovers and spin-in, and examine how digitalization, global value chains, and the rising importance of intangible assets have altered the nature, magnitude, and frequency of defense-to-civilian spillovers.

1.1 Background and motivation

The relevance of defense-to-civilian spillovers.

In many OECD countries, government expenditures on defense R&D represent the single largest category of public R&D. While the main motivation rests on building defense capabilities, it is established that such investments also give rise to spillovers that benefit technological development and innovation in the wider economy (Eliasson 2017).[5] The R&D spillover literature shows that the social returns to R&D exceed the private returns (Griliches 1992, 1998), and Braunerhjelm, Andersson, and Deiaco (2025) document substantial positive effects from public defense R&D, identifying knowledge diffusion from advanced defense manufacturing as a key channel.[6] Spillovers between defense and civilian sectors also constitute a

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[5] Estimates of the ratio of social to private returns to R&D consistently range around four to one (Lucking, Bloom, and Van Reenen, 2019), and this ratio appears to have remained rather steady in the twenty-first century.

[6] Government-funded defense R&D also appears not to crowd out private research. Moretti, Steinwender, and Van Reenen (2021) find that a 10% increase in government-financed R&D generates an additional 5–6% increase in privately funded R&D in the same industry and firm.

longstanding stated policy objective for countries involved in defense procurement and military R&D (Wang 2025).

Aerospace and aircraft manufacturing constitutes an industry related to defense procurement and military R&D that is often associated with significant spillovers. Military aviation programs have historically functioned as incubators for technologies and organizational competencies that subsequently diffused into commercial markets. Using SAAB as a case, Eliasson (1996) demonstrated that advanced defense firms often operate as 'technical universities,' generating organizational and industrial knowledge spillovers that extend well beyond the originating firm. Kotha (2010) traced post-World War II knowledge spillovers during the early development of commercial aviation, showing how defense-originated knowledge enabled strategic entrepreneurship and ultimately Boeing's ascendancy in the commercial aviation market.[7]

Changing conditions for spillovers.

Several developments over recent decades have altered both the magnitude and the character of defense-to-civilian spillovers. First, the expansion of global value chains has reduced the reliance of defense programs on domestic suppliers; international sourcing and modular production architectures imply that production activities and supplier networks are distributed across multiple countries (Baldwin 2012), and analyses of the aircraft industry document that outsourcing by prime contractors in North America and Western Europe has transferred technological capabilities to emerging economies (Niosi and Zhegu 2010). As import contents in defense programs rise, the multiplier and spillover effects retained within the procuring country may be influenced. There is also evidence that the distribution of value capture along the value chain has changed in favor of upstream service providers. Liu and Saam (2022) demonstrate that upstream knowledge-intensive services contribute substantially to productivity gains along value chains, often more so than final assembly activities.

Second, digitalization and structural change have implied a growing importance of intangible capital (Andersson et al 2023, 2021). An increasing number of studies analyze whether intangibles generate spillovers in a similar way as traditional R&D.[8] An overall finding is that intangible capital — broadly

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[7] Studies of military expenditure and economic growth, such as Yildirim and Öcal (2016), find positive effects on growth with significant spatial dependence across countries, suggesting that defense investments propagate demand- and supply-side externalities through regional and national economies.

[8] Corrado, Hulten, and Sichel (2009) establish a framework for measuring intangible investment and demonstrate that the contribution of intangible capital to U.S. labor productivity growth is roughly similar to that of tangible capital. Subsequent work on European economies finds that intangible capital deepening accounts for a substantial share of labor productivity growth (Roth and Mitra 2025; Niebel, O'Mahony, and Saam 2017).

defined to include R&D, software, organizational capital, training, design, and brand value — generates significant spillovers (Corrado, Haskel, and Jona-Lasinio 2017; Bontempi and Mairesse 2015; Roth 2025). A key question is whether spillover effects are primarily associated with the R&D component of intangibles, or whether other types of intangibles (such as software and databases, human capital, design) also generate spillovers.[9] The available evidence points to non-R&D intangibles also generating significant spillovers (Goodridge, Haskel, and Wallis 2017; Nonnis, Bounfour, and Kim 2023; Deiaco and Lappi 2025). Roth and Rammer (2025) find that software and databases (S&D) and firm-specific human capital are main drivers of productivity (particularly in services), and conclude that non-R&D intangibles give rise to spillovers but likely through different mechanisms than R&D.[10] The rising importance of intangible capital does not necessarily mean fewer spillovers, but suggests that relevant spillovers may take different forms.

These issues bear directly on defense-related R&D and innovation. Such activities are often government-funded, and their spillover potential is a key concern for policy. They are also subject to rising integration in global value chains and a growing role of intangible capital (Eliasson 2017). In military aircraft development and production, there is an evident shift from discrete hardware components to intangible capital in the form of software-defined capabilities, modular system architectures, and integration know-how (Braunerhjelm, Andersson and Deiaco 2025). These changes are likely to influence defense-to-civilian spillover channels. Conventional approaches to measuring such spillovers — input-output multipliers, patent counts, or identifiable product spin-offs — may understate the societal returns of contemporary defense programs by failing to capture spillovers associated with intangible assets (cf. Goodridge, Haskel and Wallis 2017).[11] There is thus a need to understand both the magnitude and the type of spillovers generated by advanced defense programs under modern conditions of digital technologies, global value chains, and the growing role of intangible capital.[12]

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[9] There is some debate regarding differences in the spillover potential between intangible inputs (such as software and IT systems) and intangible capital (such as R&D, organizational know-how, human capital). De Ridder (2024) maintains that many intangible inputs are customized for a particular firm and are rarely patented, which reduces the prospects for spillovers even though they are characterized by non-rivalry in use (cf. Corrado, Haskel, Jona-Lasinio, and Iommi 2022; Crouzet, Eberly, Eisfeldt, and Papanikolaou 2022).

[10] From this perspective, they argue, there are reasons to support investments in non-R&D intangibles "as unintended spillovers to competitors may occur in a similar way as for R&D" (ibid., p. 30).

[11] Goodridge, Haskel, and Wallis (2017) demonstrate that spillovers from broader intangibles (not just R&D) are statistically significant but operate with lags and through inter-industry channels that input-output analysis does not capture.

[12] The need for knowledge of spillovers from defense R&D programs is also noted by Martí Sempere (2018), who identifies multiple barriers to spillovers including secrecy requirements, the specificity of defense technologies, and the organizational distance between defense and civilian innovation systems, and concludes that the uncertainty surrounding these effects makes it difficult to support informed policy decisions.

1.2 Contribution and empirical strategy

This paper tackles this question through an empirical analysis of the SAAB Gripen E program. Gripen E exemplifies the technological transformation described above: growing global value chain integration and increasing importance of intangible capital. The role of intangible capital materializes in a software-intensive system-of-systems with modular avionics architecture, model-based systems engineering, and a philosophy of continuous upgrading rather than a sequence of discrete hardware breakthroughs.[13] We argue that Gripen E is a relevant case for examining how global value chains, digitalization, and the growing importance of intangible capital influence both the magnitude and the character of defense-to-civilian spillovers.

We distinguish three forms of defense-to-civilian knowledge transfer: product spillovers (identifiable civilian products, services, markets, and revenue effects credibly traceable to defense program development); competence spillovers (diffusion of tacit systems integration know-how, organizational routines, safety-critical engineering practices, model-based development methods, and quality systems); and spin-in (civil-origin technologies, methods, or components integrated into defense systems).

Using a theory-probing single-case design, the paper combines two complementary sources of evidence. First, approximately 50 semi-structured interviews across the Gripen E ecosystem — including the focal firm, suppliers, public agencies, and related organizations — were conducted, transcribed, and synthesized to identify recurring mechanisms and perceived shifts in spillover form. These interviews also yielded engineering assessments from Saab Aeronautics used to characterize technology domains, development trajectories, and SoS integration intensity (Table 2). Second, three targeted surveys to distinct actor groups: suppliers to the Gripen program (n=22), researchers connected to relevant technical areas (n=6), and a comparison group of small and medium-sized enterprises without direct Gripen exposure (n=16). Survey items were harmonized into comparable indicators categorized as product spillover, competence spillover, and spin-in. The mixed-methods design allows us to assess both the form and the magnitude of defense-to-civilian knowledge transfer under conditions of digitalization, and to compare the experiences of network-proximate actors with those of firms outside the defense innovation network. A mixed-method approach is warranted given the lack of a systematic framework and methods to identify and measure spillovers associated with defense procurement and military R&D (Wang 2025).

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[13] https://www.saab.com/markets/india/gripen-for-india/technology/the-science-behind-gripen-es-innovative-avionics

1.3 Outline

The remainder of the paper is structured as follows. Section 2 develops the conceptual framework, drawing on the literatures on R&D spillovers and intangible capital, absorptive capacity, and complex products and systems-of-systems engineering (2.1), and introducing a typology distinguishing product spillover, competence spillovers, and spin-in (2.2). Section 3 describes the Gripen E program in the context of earlier Swedish fighter aircraft generations (3.1) and develops three propositions linking platform incrementalism, SoS architecture, and the institutional infrastructure for exploratory work to the form, magnitude, and diffusion of defense-to-civilian spillovers (3.2). Section 4 presents the research design as a theory-probing single-case study using pattern-matching logic (4.1) and details the data sources and mixed-methods design (4.2). Section 5 reports the empirical findings: survey evidence across the three forms of knowledge transfer (5.1), separate analyses of product spillovers (5.2), competence spillovers (5.3), and spin-in (5.4), organizational evidence for the delivery–exploration trade-off (5.5), and network effects (5.6). Section 6 discusses the main findings (6.1), implications for theory (6.2), policy conclusions (6.3), and limitations and directions for future research (6.4).

2. Conceptual framework: product spillovers, competence spillovers, and spin-in

2.1 Intangible capital, absorptive capacity, and systems-of-systems

To develop a conceptual framework for analyzing defense-to-civilian spillovers under conditions of digitalization, global value chains, and the growing importance of intangible capital, we draw on three bodies of literature. The first is the R&D spillover literature, which models knowledge externalities as flows that affect the productivity and innovation of firms other than the investing firm (Griliches 1992, 1998). This literature has established that social returns to R&D exceed private returns (Lucking, Bloom, and Van Reenen 2019). A recurrent theme is the difficulty of measuring spillovers: they are partly tacit, partly mediated by inter-firm networks, and often confounded by selection into R&D-intensive ecosystems. Recent extensions to intangible capital more broadly — encompassing software, organizational capital, training, and design — find that non-R&D intangibles also generate significant spillovers, though through different mechanisms than traditional R&D (Corrado, Haskel, and Jona-Lasinio 2017; Goodridge, Haskel, and Wallis 2017; Roth and Rammer 2025). This perspective is relevant for contemporary defense programs that increasingly generate knowledge embedded in software, systems architectures, integration methods, and organizational routines — forms of intangible capital that may not transfer as readily as discrete hardware artifacts (Eliasson 2017).

The second is the absorptive capacity framework introduced by Cohen and Levinthal (1990). They argue that a firm's ability to recognize, assimilate, and apply external knowledge depends on its prior related knowledge and on organizational investments in learning. The central implication is that spillovers are not automatic: they are conditional on the recipient's capability and embeddedness in relevant knowledge networks. In a defense context, this implies that firms without prior engagement in defense-related technologies or collaboration networks will have limited capacity to absorb the competencies generated by programs such as Gripen E, suggesting that spillovers from defense programs are selective and network-bounded rather than diffusing uniformly across an economy.

The third is the literature on complex products and systems (CoPS) and systems-of-systems (SoS) engineering. Davies and Hobday (2005) show that industries producing high-complexity capital goods — such as aerospace, telecommunications, and defense platforms — are organized around projects and systems integration rather than mass production of standardized components. Innovation in these industries depends on the capability to integrate multiple independently developed subsystems into a coherent whole, manage interfaces, and coordinate distributed design and production activities. Maier (1998) characterizes systems-of-systems as settings where multiple independently useful systems are integrated into a larger capability, typically with evolutionary development, distributed control, and emergent behavior. In such settings, knowledge is largely contextual: it resides in the methods, routines, and integration practices that coordinate complex technical systems, rather than in any single transferable component. This resonates with Carlsson and Stankiewicz's (1991) concept of 'technological systems' as dynamic networks of agents involved in the generation, diffusion, and utilization of technology under a particular institutional infrastructure, defined by knowledge and competence flows rather than flows of ordinary goods and services. These perspectives suggest that defense programs organized as systems-of-systems generate knowledge that is inherently difficult to extract, codify, and transfer as standalone products.

Taken together, these three literatures suggest that when defense innovation is software-intensive, organized through global value chains, and dependent on intangible capital in the form of systems integration capability, the dominant knowledge outputs are not discrete artifacts but organizational and engineering competencies embedded in people, routines, methods, and inter-firm networks.

2.2 Three forms of defense-to-civilian spillovers

We distinguish three forms of defense-to-civilian knowledge transfer that together constitute our analytical framework: product spillovers, competence spillovers, and spin-in. The distinction emphasizes competence spillovers as a conceptually distinct category aimed at capturing the dominant form of knowledge generated by contemporary defense programs.

Product spillovers

We define product spillovers as the emergence of identifiable civilian products, services, processes, standards, or business lines that are credibly traceable to defense program development and that manifest in observable market outcomes: new products introduced, new civilian markets entered, revenue spillovers to other product lines, or business model changes. Product spillovers correspond to the traditional conception of defense-to-civilian knowledge transfer — the classic 'spin-off' (cf. Alic et al. 1992) — and are the form most readily captured by conventional measurement approaches such as patent counts, product tracking, and input-output multiplier analysis. Historically, prominent examples include jet engines, satellite navigation, and the Internet (Ruttan 2006; Mowery 2010).

As defense programs become more software-intensive and organized around modular, continuously upgraded architectures, the frequency and visibility of product spillovers are expected to decline relative to other forms of knowledge transfer. This is consistent with Cowan and Foray's (1995) observation that the potential for dual use depends on where a technology sits in its life cycle and on the institutional conditions for cross-sector transfer, which in software-intensive domains are often constrained by classification, intellectual property regimes, and the tacit character of integration knowledge.

Competence spillovers

We define competence spillovers as the diffusion of engineering and organizational capabilities that are difficult to package as discrete products. These include competences related to safety-critical software practices, quality management systems, traceability and documentation routines, model-based development and simulation capabilities, systems integration know-how, and project governance methods. These capabilities correspond to what Eliasson (1996, 2017) characterized as the organizational and industrial knowledge that advanced defense firms generate and diffuse through 'competence blocks' — networks of firms, subcontractors, and specialists coordinating complex integrated production. The concept also aligns with the 'economic competence' of technological systems described by Carlsson and Stankiewicz (1991): the ability to develop and exploit new business opportunities, embodied in networks rather than individual firms.

Competence spillovers are mediated through collaboration, shared supplier relationships, labor mobility, boundary-spanning consultants, and communities of practice. They are shaped by absorptive capacity

(Cohen and Levinthal 1990): only firms with sufficient prior related knowledge and organizational investment can recognize and assimilate these capabilities. Competence spillovers are inherently selective and concentrated among actors embedded in the defense innovation network.

One implication of this diffusion logic is that competence spillovers in a digitalized, SoS-intensive environment require horizontal rather than vertical interaction to materialize. In earlier hardware-centered programs, spillovers could diffuse vertically and largely automatically: a component developed for a defense platform could be identified, extracted, and transferred to a civilian buyer through normal market mechanisms. Competence spillovers do not work this way. They require engineers, researchers, and potential civilian users from different sectors to meet, exchange experiences, and jointly identify civilian applications of defense-developed capabilities. This horizontal interaction — across organizational and sectoral boundaries — is the mechanism through which tacit, system-embedded knowledge becomes civilian value. It is precisely this interaction that the delivery–exploration trade-off erodes as programs mature, and that institutional arrangements such as testbeds, collaborative research programs, and structured mobility schemes must deliberately recreate.

Spin-in

We define spin-in as the inflow of civil-origin technologies, methods, or components that are integrated into defense systems. Spin-in becomes particularly salient when defense platforms depend on fast-moving civilian technology domains such as artificial intelligence, commercial software tooling, cloud computing, and digital communications architectures. As Mowery (2010) notes, the direction of technology transfer between defense and civilian sectors has shifted over time: whereas defense R&D was once the primary source of new general-purpose technologies, civilian innovation now frequently leads in domains critical to modern defense systems. Cowan and Foray (1995) anticipated this reversal, arguing that as civilian technology capabilities matured, the flow of knowledge would increasingly run from civilian to military applications. Spin-in complicates the measurement of defense-to-civilian spillovers because it blurs the boundary between defense-originated and civilian-originated knowledge: the growing prevalence of spin-in may reduce the observed frequency of ‘classic’ defense-to-civilian product spillovers while simultaneously increasing the integration of civilian capabilities into defense systems.

3. The Gripen E program: description and propositions

3.1 From Draken and Viggen to Gripen

The development of new fighter aircraft platforms has historically been a large and significant industrial undertaking in Sweden. In the Western hemisphere today, only three countries have the capacity to develop, design, and manufacture advanced fighter aircraft: the United States, France, and Sweden. These countries differ markedly in military spending, with the United States and France operating with defense budgets many times larger than Sweden's. Our focus is the Gripen E program, covering the period from around 2008 to the present day — a period spanning concept development and feasibility studies, detailed design and engineering, prototype development and ground testing, flight testing, certification, serial production, and export to Brazil.

This period coincides with substantial nationally and internationally turbulent developments. Swedish neutrality policy was phased out and replaced by NATO membership; the period was characterized by both significant public R&D cutbacks — the so-called *strategic time-out* in defense investments — and planned and substantial increases in defense spending. A major structural shift occurred in 2007 through the so-called materiel supply strategy, which resulted in a clear reduction of the Swedish defense innovation system. Before 2007, there was a clear division of roles in which the Armed Forces defined operational needs, FMV translated these into technical studies, and industry worked together with FOI in early development tracks. The strategy broke with this model, phasing out development in Sweden and replacing it with off-the-shelf procurement.

During the same period, very rapid technological development has influenced — and transformed — the development and diffusion of new technology from the Swedish aircraft industry. Gripen E was built to provide Sweden with a modern and future-proof air defense adapted to new military threats while preserving Swedish military and political freedom of action through national control over aircraft systems and upgrades. The investment was also intended to strengthen the Swedish defense industry and create export opportunities.

Gripen E is regarded as a technological leap relative to previous Gripen versions. The leap consists primarily of a new avionics architecture, advanced sensor integration, and software-based system development, rather than entirely new fundamental hardware systems — to which can be added a redesigned and partly reinforced airframe, a more powerful engine, and a more advanced radar. Gripen E is thus built as an incremental new platform. The Gripen system should be viewed as a complete system, including maintenance, weapons, simulators, and tactics — the entire operational solution delivered to the end user. It is built on a software-intensive SoS architecture and is often described almost as a single large flying computer, with a digital architecture in which flight-critical and non-flight-critical software are strictly separated in hardware. This allows the system to be updated incrementally and continuously, rather than only through 'mid-life updates.' Taken together, Gripen E is optimized for high performance, endurance, and future adaptability.

3.2 Spillover potential of the Gripen E program — three propositions

Three main conditions of the Gripen E program are likely to influence the nature and frequency of spillovers from the program.

Condition 1: Incremental platform development.

The classic spillovers associated with previous Swedish fighter aircraft programs — from the Lansen and Draken through the Viggen to early Gripen generations — emerged primarily from foundational, clean-sheet engineering. When a program starts from scratch, it must solve problems across the full technological stack: aerodynamics, materials, propulsion, avionics, weapons integration. The solutions to these problems are, by construction, new — and many are generic enough to have civilian applications. The development of the Viggen in the 1960s consumed ten percent of all Swedish R&D expenditure precisely because almost everything had to be invented or substantially reinvented.

Gripen E is categorically different. It is a further development of an existing aircraft platform. The basic airframe geometry, propulsion system, and fundamental flight systems of Gripen C/D are carried forward — they are solved problems. What remains to be developed is concentrated in the integration layer: how subsystems communicate, how software architectures manage the separation of flight-critical and non-flight-critical functions, how the system is verified as a coherent whole. This is complex, demanding engineering — but its knowledge output is inherently more contextual, system-specific, and harder to extract as a standalone civilian product than the foundational hardware innovations of earlier generations. An incremental platform structurally reduces the scope for generic technological breakthroughs that could be transferred to civilian markets. This gives rise to Proposition 1:

> *Proposition 1: The more a defense program builds on existing platform solutions, the lower the expected frequency and transferability of product spillovers, independent of organizational conditions.*

Condition 2: Digitalization and the shift to system-of-systems architecture.

Simultaneously with the decision to develop Gripen E as an incremental platform, the technological environment underwent a fundamental transformation. The shift from discrete hardware components to software-defined, modular, continuously upgraded system architectures — driven by the broader digitalization of the economy — changed both what was technologically possible and what defense programs needed to do. Gripen E was not just incrementally improving an existing aircraft; it was rebuilding the entire integration architecture around digital principles, a new avionics stack, and an SoS engineering philosophy.

This has significant effects on the preconditions for spillovers. In an SoS architecture, innovations reside in classified algorithms, proprietary integration methods, modular interfaces, and the organizational practices of model-based systems engineering. These cannot be extracted and commercialized as discrete civilian products because the knowledge is contextual by design. This gives rise to Proposition 2:

> *Proposition 2: The higher the SoS integration intensity of a defense program, the more dominant competence spillovers will be relative to product spillovers, and the more selective the diffusion of those competence spillovers will be.*

Condition 3: The strategic time-out and the delivery–exploration trade-off.

The third condition operates at the organizational rather than the technological level. In 2007, Sweden's materiel supply strategy dismantled the institutional architecture through which exploratory, early-stage defense R&D had historically been conducted. Before 2007, a clear division of roles ensured that the Armed Forces, FMV, FOI, and industry collaborated in early development tracks at low Technology Readiness Levels — precisely the organizational context from which the most significant spillovers of earlier Gripen generations had emerged. The strategy replaced this model with off-the-shelf procurement, effectively removing the institutional space for exploratory work from the Swedish defense innovation system when Gripen E development was beginning.

This institutional disruption triggered what may be labelled a *delivery–exploration trade-off* in the Gripen E program. The trade-off is a generalizable organizational dynamic: in any defense program that lacks protected exploratory capacity, delivery pressure systematically crowds out the exploratory work that generates and diffuses civilian spillovers. It operates through three channels — reduced time allocation to exploratory work, reduced boundary-spanning interaction with universities and civilian actors and reduced organizational tolerance for experimentation. Where exploratory institutional infrastructure is maintained, the trade-off operates gradually as production pressure accumulates over the lifecycle. In Gripen E, the institutional infrastructure was dismantled before the program began, activating the trade-off from the outset rather than allowing it to develop gradually. The subsequent production phase — with its permanent delivery requirements intrinsic to a continuously upgraded SoS platform — has sustained and reinforced it. This gives rise to Proposition 3:

> *Proposition 3: The absence of protected institutional infrastructure for exploratory work, whether through external disruption or gradual production-phase crowding-out, will systematically reduce the generation and diffusion of competence spillovers in mature defense programs.*

4. Research design

4.1 A theory-probing single-case study

This paper adopts a single-case study design (Yin 2018; Eisenhardt 1989) aimed at assessing the empirical relevance of the three propositions developed in Section 3. The design is best characterized as theory-probing rather than purely exploratory: the propositions linking platform incrementalism, system-of-systems architecture, and the institutional infrastructure for exploratory work to the form, magnitude, and diffusion of defense-to-civilian spillovers are specified ex ante, and the analysis examines whether the empirical patterns observed in the Gripen E program are consistent with these propositions and inconsistent with plausible alternatives (Eckstein 1975; Lijphart 1971; George and Bennett 2005).

A theory-probing case design is appropriate for two reasons. First, the propositions concern relationships and mechanisms that are insufficiently studied to support large-N hypothesis testing in the conventional sense. No established measurement instruments exist for the competence-spillover construct we develop in Section 2, and the joint operation of platform incrementalism, SoS digitalization, and an institutional time-out has not previously been examined in a single program. A case-based design is therefore well suited to assessing the plausibility and empirical traction of newly articulated propositions before they are subjected to broader comparative or quantitative tests (Eisenhardt and Graebner 2007; Levy 2008). The propositions also identify mechanisms that operate at the level of program organization, technology architecture, and institutional context — levels that are difficult to observe in aggregate data but that become visible in within-case process evidence (Bennett and Checkel 2015).

Second, the Gripen E program represents what Flyvbjerg (2006) terms an extreme case: a setting in which the phenomena of interest are present in particularly concentrated and observable form. Sweden's simultaneous experience of platform incrementalism, advanced SoS digitalization, and an unusually abrupt institutional disruption in 2007 makes Gripen E a theoretically productive case because the concentration of conditions makes the underlying mechanisms more legible than they would be in a more moderate setting. Extreme-case logic sharpens inferences in theory-probing designs: where the conditions identified in the propositions are present in concentrated form, the absence of the predicted patterns would constitute strong disconfirming evidence, whereas their presence provides correspondingly stronger support for the propositions than evidence drawn from a less pronounced setting (Gerring 2007).

4.2 Data sources and mixed-methods design

We follow a pattern-matching logic (Yin 2018) in which we confront expected patterns with evidence drawn from approximately 50 semi-structured interviews across the Gripen E ecosystem, including engineering assessments from Saab Aeronautics; three targeted surveys (suppliers, n=22; researchers, n=6; and a non-Gripen SME control group, n=16). The control group allows us to assess whether observed supplier-side patterns reflect Gripen-specific effects rather than general trends among comparable firms.

The interviews were conducted as semi-structured conversations, allowing respondents to elaborate on technological development, industrial collaboration, competence formation, and knowledge spillovers — including explicit comparisons between the Gripen E era and earlier program generations.

A key methodological strength is that the three conditions are corroborated across independent data sources: interview evidence, engineering assessments from Saab Aeronautics, survey data, and publicly available policy documents. Convergence across these independent sources strengthens the plausibility of the three-condition explanation beyond what any single source could support.

5. Empirical findings

This section presents empirical findings from interviews, surveys, and supporting contextual data on the nature and mechanisms of spillovers associated with the Gripen E program. The analysis is structured around three types of knowledge transfer — product spillovers, competence spillovers, and spin-in — followed by an examination of organizational evidence and network effects shaping their realization. The findings point to a clear shift in defense-to-civilian spillovers: from identifiable, product-based outcomes toward more diffuse and intangible forms of competence and system-level capabilities.

5.1 Survey results on spillovers

To assess the nature, magnitude, and distribution of spillovers, we administered structured surveys to three distinct actor groups: Gripen program suppliers (n=22), researchers affiliated with relevant technical areas at Swedish universities (n=6), and a control group of firms without direct Gripen program exposure (n=16).

Survey items were harmonized into comparable indicators categorized as product spillovers, competence spillovers, and spin-in. The control group design allows for a within-study comparison that partially addresses selection concerns: if the patterns observed among suppliers were driven by industry-wide trends rather than Gripen-specific effects, similar patterns should appear in the control group. The near-zero rates observed in the control group are inconsistent with this alternative explanation. Table 1 summarizes the results.

The survey evidence reveals a striking contrast between network-proximate actors and firms outside the Gripen ecosystem. Across all competence spillover indicators, suppliers report substantially higher rates of positive outcomes — technology development (77% vs. 7%), new technology developed (64% vs. 0%), quality improvements (59% vs. 0%) — with the control group reporting near-zero effects on virtually all dimensions. Within the supplier group, competence spillovers consistently outpace product spillovers: while 77% report technology development benefits, only 32% report entry into new civilian markets.

Among the six university-affiliated researchers, responses reflect the geographic and relational structure of the innovation ecosystem. Researchers based at Linköping University — physically proximate to Saab — report high or moderate research benefits (4 of 4), while researchers at Luleå University of Technology report no benefits (0 of 2). None of the six researchers report identifiable civilian products from Gripen-related work, while three report that civilian-origin technologies have been utilized in Gripen research — illustrating the spin-in dynamic.

Table 1. Share of respondents reporting positive spillover outcomes, by group and spillover type (%)

Indicator	**Suppliers (n=22)**	**Control group (n=16)**
COMPETENCE SPILLOVERS		
Technology development benefited from Gripen collaboration	77%	7%
Production capacity / working methods improved	59%	7%
New technology developed	64%	0%
Quality improvements or cost reductions	59%	0%
Competence build-up reported	50%	8%
Systems integration capability developed	23%	0%
PRODUCT SPILLOVERS		
Changed product portfolio	55%	7%
Entry into new markets	32%	0%
Revenue spillovers to other product lines	32%	7%
SPIN-IN (structural indicator)		
Civil-origin technology delivered to Gripen program	23%	0%

Source: Own survey data.

5.2 Product spillovers

Historically, aerospace and defense programs have generated a broad range of identifiable civilian product spillovers. Previous analyses of earlier Gripen generations (A–D) identified more than twenty distinct civilian applications, including components, materials, and technical subsystems that could be directly traced to defense R&D (Eliasson, forthcoming). These spillovers correspond to the classical ‘spin-off’ model, in which technologies developed for military purposes are subsequently commercialized in civilian markets.

In contrast, the empirical evidence from Gripen E suggests that such product-based spillovers are fewer and less visible. Interview respondents consistently emphasized the difficulty of identifying direct civilian products that can be clearly attributed to the program. Several respondents explicitly noted that ‘clear civilian spillovers are harder to identify than in previous generations’ and that ‘direct product spillovers are fewer compared to Gripen A–D.’

Some examples of product-related spillovers were nevertheless identified, including technologies related to advanced radar systems (e.g. AESA), gallium nitride (GaN)-based electronics, and specialized sensor technologies with applications in industrial measurement, telecommunications, and maritime monitoring. These cases illustrate that product spillovers still occur, but they tend to be more incremental, embedded in broader technological systems, and less easily separated from their original defense context.

A key explanation for this pattern lies in the changing technological architecture of the Gripen E system. Unlike earlier generations, where technological advances were often embodied in discrete hardware components, Gripen E is characterized by software-defined functionality, modular system architectures, and continuous upgrading processes. As a result, innovations are less frequently encapsulated in standalone products and more often embedded in complex systems and integration capabilities. While product spillovers have not disappeared, their relative importance has declined. Conventional approaches to measuring spillovers — focused on identifiable products, patents, or discrete technologies — may increasingly underestimate the societal impact of modern defense programs.

5.3 Competence spillovers

In contrast to the limited evidence of product spillovers, competence spillovers emerge as the dominant form of knowledge transfer associated with the Gripen E program. These spillovers consist of engineering capabilities, organizational routines, and system integration know-how that are difficult to codify and transfer as discrete products. Interview and survey evidence consistently highlight several dimensions.

First, the development of Gripen E has generated advanced capabilities in systems integration and SoS engineering — the ability to integrate multiple subsystems (sensors, communication systems, decision-support tools) into a coherent operational architecture. These capabilities are particularly relevant in contexts characterized by high complexity and interdependence, including autonomous systems, telecommunications infrastructure, and advanced industrial control systems. Within this dimension, the program has also driven the diffusion of new development methodologies and engineering practices, notably model-based systems engineering and digital twin technologies that enable simulation, testing, and validation in virtual environments. Agile development practices, adapted to safety-critical environments through certification, traceability, and safety-assurance requirements, have similarly contributed to new organizational routines and have been reported by respondents to transfer to engineers moving into automotive, mining, and advanced manufacturing.

Second, competence spillovers are evident in quality assurance and safety-critical engineering practices. The stringent requirements associated with defense systems — certification, verification, and documentation — have led to highly robust quality systems. These practices are transferable to civilian sectors where reliability and safety are critical, including aerospace, automotive, and medical technology.

Third, competence spillovers are mediated through human capital and labor mobility. Engineers and specialists trained within the Gripen ecosystem carry tacit knowledge, problem-solving skills, and system understanding into other organizations. This channel is particularly important given the tacit and context-dependent nature of the knowledge generated.

A concrete illustration is the collaboration between Saab and Ericsson in the development of advanced communication technologies, involving structured knowledge exchange in antenna design, signal processing, and system calibration. The result was mutual capability upgrading: defense-originated knowledge contributed to civilian innovation in telecommunications, while Saab benefited from exposure to scalable software architectures and production systems.

> *As one senior engineer at Saab Surveillance observed: 'It shortened their journey considerably — a bit of key competence at the right moment made all the difference' — a dynamic he identified as running in both directions, with Ericsson simultaneously providing Saab with practical solutions on cooling and antenna design that fed directly back into the Gripen program.*

The Saab–Ericsson collaboration illustrates a broader principle about how competence spillovers arise in a digitalized, SoS-intensive environment. Unlike product spillovers, which can diffuse through market transactions without sustained interaction between the parties, competence spillovers require deliberate horizontal engagement — engineers and specialists from different organizations working across sectoral boundaries on shared technical problems. It was not the existence of Gripen-developed knowledge per se that benefited Ericsson, but the structured opportunity to interact with engineers who held that knowledge and could apply it to a new context. This horizontal logic of diffusion has a direct implication for the delivery–exploration trade-off: as the program has moved into production and delivery pressure has increased, the organizational space for boundary-spanning, horizontal interaction has contracted. The competence exists within the ecosystem, but the conditions for diffusing it horizontally — across sectors and organizations — are simultaneously eroding.

Importantly, competence spillovers are inherently more difficult to observe and measure than product-based spillovers. They are not easily captured by traditional indicators such as patents or new product launches; they materialize through improved productivity, enhanced innovation capacity, and the ability to manage complex systems. They represent a form of intangible capital that diffuses through networks, collaboration, and human interaction rather than through markets alone.

5.4 Spin-in

In addition to outward spillovers from defense to civilian sectors, the findings highlight the increasing importance of spin-in — the inflow of civilian technologies, methods, and components into defense systems. Several respondents emphasized that modern defense systems, including Gripen E, rely heavily on technologies originating in civilian sectors, particularly in software development, data processing, telecommunications, and digital infrastructure. Civilian advances in software engineering, modular architectures, and cloud-based systems have influenced the design and development processes within the Gripen program.

The growing importance of spin-in reflects broader structural changes in the innovation landscape. Rapid technological progress in civilian sectors — especially in digital technologies — has shifted the frontier of innovation outside traditional defense domains. As civilian technologies become embedded within defense systems, the boundary between defense-originated and civilian-originated innovation becomes blurred. The observed decline in traditional product spillovers may therefore partly reflect the increasing role of spin-in rather than a reduction in knowledge flows per se.

The technology domains undergoing the most rapid expansion in Gripen E (Table 2) — avionics systems, airborne computer systems, tactical systems, and tactical autonomy — are precisely those where civilian innovation is advancing most rapidly and where spin-in is most prevalent. This is consistent with the incremental platform condition: when basic hardware is carried forward, the novel development effort concentrates in software-intensive domains where civilian technology is often ahead.

Table 2. Gripen E system-of-systems: technology domains, domestic industrial breadth, development trajectories, and SoS integration intensity

Technology domain	Technical change	Dom. research	Dom. supplier share	Industrial breadth (SE)	Dev. trajectory	SoS integration intensity
Aeronautical Engineering	Low	Yes	Low	Medium	Maturing	Low
Avionic Systems	**High**	**—**	**Medium**	**Few**	**Expanding**	**Very High**
Vehicle Systems	Low	Yes	Low	Few	Maturing	Low
Propulsion Systems	Medium	Yes	Low/Medium	Few	Maturing	Medium
Crew Station & Interaction	**High**	**Yes**	**Medium**	**Few**	**Expanding**	**High**
Simulators	High	Yes	High	Few/Medium	Maturing	High
Airborne Computer Systems	**High**	**Yes**	**High**	**Few**	**Expanding**	**Very High**
Tactical Systems	**High**	**Yes**	**High**	**Few**	**Expanding**	**Very High**
Core Autonomy	Low	Yes	N/A	Few	Maturing	Medium
Tactical Autonomy	**High**	**Yes**	**N/A**	**Few**	**Expanding**	**High**
OACD & System of Systems	Medium	Yes	N/A	Few	Maturing	Very High
Overall Air Vehicle	Medium	Yes	N/A	Few	Maturing	High
Air Mission Planning	Medium	Yes	High	Few	Expanding	High
Weapons	Medium	Yes	Medium	Few	Expanding	Medium
Maintenance Systems	Low	Yes	High	Medium	Maturing	Low
Training Systems	Medium	Yes	High	Few	Expanding	Medium
Flight Test & Verification	Low	Yes	High	Few	Expanding	Medium
Airframe	Medium	Yes	Low	Medium	Maturing	Low
Production Systems	Medium	Yes	Medium	Many	Expanding	Medium
Emerging Technologies	N/A	—	N/A	N/A	Expanding	High

Source: Based on assessments by Saab Aeronautics engineers (Andersson et al. 2026). Technical change: degree of change relative to previous Gripen versions. Industrial breadth: number of firms in Sweden excluding Saab. Highlighted rows indicate domains combining high technical change with few domestic actors and very high SoS integration intensity.

Table 2 also illuminates the global value chain dimension of the Gripen E program. Domains with low domestic supplier shares — aeronautical engineering, vehicle systems, and airframe — reflect established international sourcing patterns where Sweden retains systems integration capability but relies on global supply chains for components and subsystems. More consequential for spillover generation is the pattern in the rapidly expanding domains: avionics systems, airborne computer systems, and tactical systems combine high technical change with few domestic actors and very high SoS integration intensity. The limited domestic industrial breadth implies that competence spillovers are structurally constrained to a small network of actors, while the integration of civil-origin technologies through spin-in increasingly draws on international rather than domestic civilian innovation. This configuration — high SoS intensity, few domestic actors, and growing spin-in from global technology frontiers — illustrates how global value chain integration and digitalization jointly reshape the channels through which spillovers can occur: away from domestic product markets and toward a thin network of domestically embedded systems integrators whose competence is difficult to diffuse more broadly. The implication is that some spillover effects of contemporary defense programs may occur outside the domestic economy, reducing the effectiveness of traditional multiplier-based approaches in capturing their full impact.

5.5 Organizational evidence: the delivery–exploration trade-off in operation

A consistent theme across interviews with engineers and managers in the Gripen ecosystem is that the practical opportunity to pursue spillover-generating activities has narrowed as the program has moved from development into production and delivery phases. Engineers who in earlier program phases engaged in exploratory side projects, technology demonstrations, and informal cross-sector interactions are now concentrated on near-term operational requirements and delivery commitments.

> *A professor with two decades of experience at the intersection of LiU and the Saab ecosystem put the organizational logic bluntly: 'You have organized yourselves for a situation where the pressure from above is about value… You have organized to be as efficient as possible. Profit and loss is pushed down to the departmental level — that cannot be good for spillover.'*

The three channels specified in Section 3.2 are each visible in the interview evidence. Reduced time allocation to exploratory work is the most consistently reported: engineers describe a systematic shift in how working time is distributed, with exploratory and cross-sector activities progressively displaced by certification, documentation, and delivery preparation. Reduced boundary-spanning interaction is visible in the declining frequency of informal contacts with university researchers as the program has moved into production. Reduced experimentation is reflected in descriptions of a governance environment in which tolerance for failure has contracted.

> *A researcher who has followed the Gripen program across multiple generations described the production logic directly: 'A first flight is an incredible focal point in a company like this. Everyone works to be ready for first flight, and no one wants to be the one who causes a delay.' He noted that this organizational logic — entirely appropriate for its purpose — is precisely what crowds out the exploratory work that historically generated civilian spillovers.*

Respondents who have been involved with the Gripen program across multiple phases consistently describe a shift: the Gripen E era is characterized by substantially less organizational space for exploratory work than the development phases of earlier generations. This within-respondent, cross-temporal comparison is the strongest form of evidence available in a single-case design for the proposition that conditions have changed over the program lifecycle. The 2007 restructuring is identified by multiple respondents as the institutional break point — not merely a gradual trend.

> *A senior engineer involved in Ericsson's 5G development confirmed the asymmetry from the recipient side: 'It went much faster for us to get started thanks to Saab being there and us being able to, within certain limits, use the knowledge that existed.' He noted that while the collaboration enabled substantial acceleration in development, security constraints on defense-related knowledge ultimately limited how far it could be taken — an illustration of how the realization gap operates even when spillover-generating conditions exist.*

5.6 Network effects

The realization of spillovers — whether product-based or competence-based — is shaped by network effects within the broader innovation ecosystem. Spillovers are not automatic but depend on the structure and functioning of the surrounding network of firms, universities, and public organizations. The Gripen ecosystem, centered around Saab and linked to actors such as Linköping University and various suppliers, constitutes a 'competence block' in which knowledge is generated, shared, and recombined. Within this ecosystem, repeated interaction, trust, and long-term collaboration facilitate the diffusion of both codified and tacit knowledge. Firms closely connected to the Gripen program — as suppliers, research partners, or collaborators — are significantly more likely to benefit from spillovers, whereas firms outside the network face substantial barriers in accessing and utilizing the knowledge generated. This pattern supports the view that spillovers are mediated by prior knowledge, organizational capabilities, and network embeddedness. Several institutional and structural factors further constrain the realization of spillovers, including security classification, export controls, intellectual property regimes, and certification requirements. While such constraints are inherent to defense-related activities, they limit the extent to which knowledge can be transferred and commercialized in civilian markets.

Taken together, these findings point to a 'realization gap' between potential and actual spillovers. While the Gripen E program generates significant knowledge and capabilities, the extent to which these are translated into broader economic benefits depends on the functioning of the innovation ecosystem and the presence of institutions that enable knowledge diffusion.

6. Discussion and conclusions

This paper has examined how digitalization, integration in global value chains, and the rising importance of intangible capital change the nature, magnitude, and channels of defense-to-civilian spillovers. Using the SAAB Gripen E program as a theory-probing single case, we developed and confronted with evidence three propositions linking platform incrementalism, system-of-systems (SoS) architecture, and the institutional infrastructure for exploratory work to the form, magnitude, and diffusion of spillovers. This section synthesizes the main findings (6.1), draws out their implications for theory (6.2) and policy (6.3), and discusses the limitations of the analysis and the comparative research it motivates (6.4).

6.1 Main findings

First, the dominant form of defense-to-civilian spillover from the Gripen E program is competence-based rather than product-based. Across the supplier sample, 77% report that technology development benefited from Gripen collaboration, 64% report new technology developed, and 59% report quality and process improvements. Identifiable product spillovers — entry into new civilian markets (32%), revenue effects on other product lines (32%) — are present but considerably less common. The within-firm gap between competence and product outcomes, combined with the within-program contrast to earlier Gripen generations (A–D) where more than twenty discrete product spin-offs were documented, supports Proposition 1: incremental platform development on an established airframe substantially reduces the scope for transferable hardware-based product spillovers.

Second, competence spillovers diffuse selectively. The control group of comparable SMEs without direct Gripen exposure reports near-zero rates on virtually every indicator (0–8%), and even within the population of network-proximate actors, deeper systems-integration capability is reported by a smaller share (23%) than the more general technology-development benefit (77%). The researcher subsample reinforces this pattern: respondents at Linköping University, geographically and relationally proximate to Saab, report substantial research benefits, while respondents at Luleå report none. This is consistent with Proposition 2: the higher the SoS integration intensity, the more dominant competence spillovers become relative to product spillovers, and the more selective their diffusion. The absorptive-capacity prerequisite for assimilating systems-level knowledge (Cohen and Levinthal 1990) appears to bind tightly when that knowledge is contextual, classified, and embedded in organizational routines.

Third, the organizational conditions that would convert generated competence into broader civilian value have contracted over the program's lifetime. Interview evidence consistently identifies the 2007 dismantling of Sweden's early-stage development infrastructure — the collaborative tracks linking the Armed Forces, FMV, FOI, industry, and universities — as a discrete break point rather than a gradual erosion. The resulting delivery–exploration trade-off was activated from the program's outset and has been sustained by the continuous-upgrade demands of the SoS platform. This is consistent with Proposition 3: where protected institutional infrastructure for exploratory work is absent, the generation and diffusion of competence spillovers is systematically reduced. Spin-in, in turn, has become more prominent: 23% of suppliers and half of the surveyed Gripen-related researchers report that civil-origin technologies have been integrated into Gripen-related work, indicating that the dominant direction of knowledge flows in some technology domains has reversed relative to earlier eras.

Taken together, the evidence supports the central claim of the paper: under conditions of platform incrementalism, SoS digitalization, and a constrained institutional infrastructure for exploratory work, the Gripen E program functions primarily as a competence generator rather than a product generator. The societal value it produces is real and economically significant, but it is intangible, network-mediated, and substantially harder to observe with conventional spillover measures than the visible hardware spin-offs of earlier defense generations.

6.2 Implications for theory

The analysis contributes to three connected literatures. First, it contributes to the literature on R&D and intangible-capital spillovers by providing operational content to the competence-spillover construct and by illustrating why product-centric measurement approaches systematically understate the societal returns of contemporary defense programs. Goodridge, Haskel, and Wallis (2017) and Roth and Rammer (2025) document that non-R&D intangibles generate spillovers through different mechanisms than R&D but operate at an aggregate level. The Gripen E case adds a micro-level account of *how* such spillovers are generated and diffused: through systems integration know-how, model-based engineering practices, safety-critical engineering routines, and the labor mobility and supplier interactions that carry them.

Second, the analysis contributes to the complex products and systems (CoPS) and SoS engineering literatures by linking systems-integration capability to the form that spillovers take. When defense platforms are simultaneously incremental and SoS-organized, the knowledge they generate is doubly constrained: there is less novel hardware to generate, and what is novel is non-transferable by design — residing in classified algorithms, proprietary integration methods, modular interfaces, and the organizational practices that operate them.

Third, the analysis contributes to the defense innovation policy literature by making the institutional preconditions for spillover generation analytically explicit. The three-condition framework moves beyond single-mechanism explanations toward a historically grounded account of how structural, architectural, and institutional conditions jointly determine the form and generative capacity of spillovers. The structural and architectural conditions — incremental platform, SoS digitalization — account for the shift in spillover form. The institutional condition — the 2007 disruption — accounts for why the organizational capacity to generate and diffuse competence spillovers contracted from the program's outset rather than gradually over its lifecycle.

6.3 Policy conclusions

The findings imply a substantive reorientation of the policy framework for capturing societal returns from advanced defense programs. The implicit model behind most existing instruments — that spillovers emerge automatically from R&D investment and become visible as identifiable civilian products — describes a world that no longer corresponds to how contemporary defense programs operate. One conclusion is that there is a need to actively design institutions that enable the realization of spillovers. Vertical transfer — from defense program to civilian market through identifiable products — was the dominant logic of earlier spillover generations and remains the implicit model behind most conventional measurement approaches. In a digitalized, SoS-intensive world, this logic no longer describes the dominant channel. Competence spillovers require horizontal interaction: engineers moving between sectors, collaborative research structures that bridge defense and civilian innovation communities, and testbeds where defense-developed integration capabilities can be explored in new civilian contexts.

More generally, the findings suggest that the societal returns to strategic R&D investments depend critically on the alignment between technological characteristics and institutional arrangements. Where innovation is increasingly driven by systems integration and intangible capabilities, policy frameworks must evolve accordingly — from counting products to enabling capability translation.

6.4 Limitations and future research

The findings should be interpreted considering three sets of limitations, each of which motivates a specific direction for future research. The first set concerns the inferential limits of a single-case theory-probing design. The analysis can establish that the observed spillover patterns are consistent with the propositions developed in Section 3 and inconsistent with several plausible alternative accounts. It cannot establish the relative causal weight of the three conditions — incremental platform, SoS architecture, and institutional time-out — nor can it determine whether the mechanisms identified would operate in the same way in defense programs without Sweden's particular institutional disruption of 2007. Three alternative explanations deserve explicit consideration. One is selection into the defense network: firms reporting high competence spillovers may have been more capable than the control group before Gripen E began, with the program mobilizing rather than generating capability. The control-group design partially addresses this — if pre-existing capability were the explanation, comparable patterns would be expected in the control group, which is not what is observed — but does not eliminate it, because selection into the supplier network is itself plausibly endogenous to prior capability. A second alternative is industry-wide trends unrelated to the program. The within-program comparison to earlier Gripen generations is the most direct response: the same firm and broadly the same institutional environment produced very different spillover patterns under the A–D versus E architectures, suggesting that program-specific conditions do real work beyond general industry dynamics. A third alternative is that the delivery–exploration trade-off would have emerged through normal program maturation regardless of the 2007 disruption. Adjudicating among these alternatives requires comparative research designs examining defense programs that share some, but not all, of the conditions identified here — for instance, programs with SoS architectures but without comparable institutional disruptions, or programs operating in countries with intact early-stage development infrastructure.

The second set of limitations concerns measurement. The survey samples are modest (n=22 suppliers, n=6 researchers, n=16 control firms), and the researcher subsample in particular is too small to support inferences beyond illustration of the geographic and relational structure of the innovation ecosystem. The survey indicators capture self-reported outcomes rather than externally validated capability changes, and the binary framing of 'positive spillover outcomes' obscures variation in magnitude. Combining interviews, engineering assessments, and survey data partly compensates, but only partly. A natural next step is to operationalize and validate richer spillover indicators — particularly register-based labor-mobility data linking the defense innovation network to the wider economy, and matched-firm designs that compare suppliers with non-suppliers on observable capability trajectories over time.

The third set of limitations concerns scope. The Gripen E program is one program in one country at one moment in its lifecycle. The propositions developed here may travel well to other software-intensive, modular, continuously upgraded complex products and systems — civil aerospace, naval systems, advanced telecommunications, parts of the energy and biopharma industries — but the mapping is not automatic. The defense context is distinguished by the intensity of classification, export-control, and procurement frictions that moderate the conversion of competence spillovers into civilian product outcomes; in less constrained sectors, competence spillovers may translate more readily into product spillovers, and the visibility shift documented here may be correspondingly less pronounced. Future work that extends the framework to other CoPS sectors, and that examines whether the delivery–exploration trade-off operates in functionally equivalent ways outside defense, would help identify which elements of the account are general and which are defense-specific.

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