

**From Dual-Use Challenges to Omni-Use Opportunities:
Venture Capital, Governance, and the Future of Omni-Use
Technologies**

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Vollständiger Abdruck der von der Fakultät für Wirtschafts- und Organisationswissenschaften der Universität der Bundeswehr München zur Erlangung des akademischen Grades eines Doktors Dr. rer. pol. angenommenen Dissertation.

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Die Dissertation wurde am 10.10.2025 bei der Universität der Bundeswehr München eingereicht und durch die Fakultät für Wirtschafts- und Organisationswissenschaften am 07.01.2026 angenommen. Die mündliche Prüfung fand am 05.02.2026 statt.

Acknowledgements

My first and deepest thanks go to Univ.-Prof.‘in Dr. Elisabeth Müller and Prof.‘in Dr. Rafaela Kraus, my doctoral supervisors. From our earliest conversations to the final manuscript, you combined exacting standards with unfailing generosity. You challenged me to sharpen questions, justify choices with evidence, and write with precision. You safeguarded the project’s academic independence while opening doors to interview partners, data, and institutional resources at Universität der Bundeswehr München. Your timely and meticulous feedback, your guidance on method, theory, and research ethics, and your patience in the face of tightening deadlines were decisive for this dissertation. In moments of doubt, you offered calm direction, when I was ambitious you urged me to go further. Thank you for your time, trust, and steady encouragement, and for modelling the intellectual rigour and integrity to which I aspire.

Parts of this dissertation draw on the insights of 32 experts from venture capital, industry, government, the military, and academia who generously gave their time for interviews. Your openness, challenges, and candour sharpened my thinking and grounded this work in reality. I am equally grateful to the mentors and peers who read drafts, offered pointed comments, and pushed me to be clearer, and more rigorous.

Lastly, I owe an immeasurable debt to my family and friends. Over these years you have accepted that my weekends were often spent at a desk, and you have met my countless refusals with patience rather than frustration. Your willingness to rearrange plans, forgive absences, and keep cheering from the sidelines gave me the quiet space and confidence to pursue this ambitious project to the end. Thank you for understanding why I had to say no so often, for believing that the sacrifice would be worthwhile, and for making home a place where this work could take shape.

Abstract

This cumulative dissertation, “*From Dual-Use Challenges to Omni-Use Opportunities: Venture Capital, Governance, and the Future of Omni-Use Technologies*”, examines how Europe can understand, evaluate, and govern technologies that straddle civilian, military, and hybrid domains while aligning innovation, investment, and security objectives. Building on the insight that the conventional dual-use label obscures convergent realities in contemporary general-purpose technologies, this dissertation proposes an omni-use continuum perspective embedded in European policy and market conditions (European Commission, 2020; Fiott, 2014; Vaynman & Volpe, 2023).

Study I conducts a systematic review of sixty-one peer-reviewed studies on European venture capital to delineate the boundary conditions within which omni-use innovation must be financed and scaled. It distinguishes stable drivers (for example, legal frameworks, governance, taxation, and culture) from dynamic drivers (for example, macroeconomic cycles and capital-market conditions), and shows how Europe’s fragmentation, smaller fund sizes, reliance on public-private co-investment, and a persistent scale-up equity gap constrain evaluation and scaling (Alperovych et al., 2020; European Commission, 2024b; Wright & Robbie, 1998). The review adopts evidence-synthesis standards consistent with Denyer and Tranfield and PRISMA (Denyer & Tranfield, 2009; Moher et al., 2009).

Study II investigates the boundaries and conditions of the dual-use technology classification through thirty-two semi-structured expert interviews with participants from the fields of investment, entrepreneurship, policymaking, defence and academia. The evidence reveals a reinforcing pool of constraints, e.g. of resource, structural, and perceptual nature. Essentially, the dual-use concept creates a host of constraints without offering any substantive value in return. Germany serves as a critical case, highlighting the visibility of these frictions

in practice. The central outcome is that the dual-use classification is not fit for purpose in a world filled with omni-use technologies.

Study III operationalises a reframing of dual-use by introducing the Omni-Use Technology Continuum Taxonomy, a decision-making instrument constructed from academic and management literature, and semi-structured interview data and refined through expert validation. The taxonomy encodes ten criteria to evaluate technologies as well as businesses and thereby rendering evaluative assumptions transparent and decision rules auditable (Wecking et al., 2020). It is designed to improve cross-stakeholder comparability in European settings and to relieve some of the constraints identified in study II, the funding constraints in particular.

Together, the three studies contribute towards a conceptual shift from dual-use to omni-use. They provide empirical evidence on European bottlenecks that co-produce the funding gap, and a practicable taxonomy that aligns with Europe's industrial-policy trajectory and venture-ecosystem realities to support proportionate, transparent, and investment-relevant governance.

Zusammenfassung

Diese kumulative Dissertation mit dem Titel „From Dual-Use Challenges to Omni-Use Opportunities: Venture Capital, Governance, and the Future of Omni-Use Technologies“ untersucht, wie Europa Technologien verstehen, bewerten und regulieren kann, die zivile, militärische und hybride Anwendungsbereiche überbrücken, während zugleich Innovations-, Investitions- und Sicherheitsziele aufeinander abgestimmt werden. Aufbauend auf der Erkenntnis, dass das konventionelle Dual-Use-Label konvergente Realitäten zeitgenössischer General-Purpose-Technologien verschleiert, schlägt diese Dissertation eine Omni-Use-

Kontinuumperspektive vor, die in europäische Politik- und Marktbedingungen eingebettet ist (European Commission, 2020; Fiott, 2014; Vaynman & Volpe, 2023).

Studie I führt ein systematisches Review von einundsechzig peer-reviewten Studien zu europäischem Venture Capital durch, um die Rahmenbedingungen abzugrenzen, innerhalb derer Omni-Use-Innovation finanziert und skaliert werden muss. Sie unterscheidet zwischen stabilen Treibern (zum Beispiel rechtliche Rahmenbedingungen, Governance, Besteuerung und Kultur) und dynamischen Treibern (zum Beispiel makroökonomische Zyklen und Kapitalmarktbedingungen) und zeigt, wie Europas Fragmentierung, kleinere Fondsgrößen, die Abhängigkeit von öffentlich-privaten Ko-Investitionen und eine persistente Eigenkapitallücke in der Scale-up-Phase Bewertung und Skalierung einschränken (Alperovych et al., 2020; European Commission, 2024b; Wright & Robbie, 1998). Das Review orientiert sich an Evidenzsynthesestandards, die mit Denyer und Tranfield sowie PRISMA im Einklang stehen (Denyer & Tranfield, 2009; Moher et al., 2009).

Studie II untersucht die Grenzen und Bedingungen der Dual-Use-Technologieklassifikation anhand von 32 halbstrukturierten Experteninterviews mit Teilnehmenden aus den Bereichen Investment, Unternehmertum, Politikgestaltung, Verteidigung und Wissenschaft. Die Evidenz zeigt einen sich gegenseitig verstärkenden Pool von Restriktionen, z.B. ressourcenbezogener, struktureller und wahrnehmungsbezogener Natur. Im Kern erzeugt das Dual-Use-Konzept eine Vielzahl von Restriktionen, ohne im Gegenzug einen substanziellen Wert zu bieten. Deutschland dient dabei als kritischer Fall und verdeutlicht die Sichtbarkeit dieser Friktionen in der Praxis. Das zentrale Ergebnis ist, dass die Dual-Use-Klassifikation in einer Welt voller Omni-Use-Technologien nicht zweckmäßig ist.

Studie III operationalisiert eine Neuinterpretation von Dual-Use durch die Einführung der Omni-Use Technology Continuum Taxonomy, eines Entscheidungsinstruments, das auf

wissenschaftlicher und managementbezogener Literatur sowie auf halbstrukturierten Interviewdaten basiert und durch Expertenvalidierung weiter verfeinert wurde. Die Taxonomie kodiert zehn Kriterien zur Bewertung von Technologien sowie Unternehmen und macht dadurch Bewertungsannahmen transparent und Entscheidungsregeln auditierbar (Weking et al., 2020). Sie ist darauf ausgelegt, die Vergleichbarkeit zwischen verschiedenen Stakeholdern in europäischen Kontexten zu verbessern und einige der in Studie II identifizierten Restriktionen zu verringern, insbesondere die Finanzierungsrestriktionen.

Zusammen tragen die drei Studien zu einem konzeptionellen Wandel von Dual-Use zu Omni-Use bei. Sie liefern empirische Evidenz zu europäischen Engpässen, die die Finanzierungslücke mitverursachen, sowie eine praktikable Taxonomie, die mit Europas industriepolitischer Entwicklung und den Realitäten des Venture-Ökosystems im Einklang steht, um eine verhältnismäßige, transparente und investitionsrelevante Governance zu unterstützen.

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List of Abbreviations and Acronyms

AI	Artificial Intelligence
BVC	Bank-affiliated Venture Capitalist
CVC	Corporate Venture Capitalist
DD	Due Diligence
DRC	Dual-Use Research of Concern
EIB	European Investment Bank
ESG	Environmental, Social, and Governance
EU	European Union
GVC	Governmental Venture Capitalist
ICT	Information and Communication Technology
IPO	Initial Public Offering
IRR	Internal Rate of Return
IVC	Independent Venture Capitalist
MOD	Ministry of Defence
NATO DIANA	NATO Defence Innovation Accelerator for the North Atlantic
NTBF	New Technology-Based Firm
OSINT	Open-Source Intelligence
PE	Private Equity
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
R&D	Research and Development
SLR	Systematic Literature Review
SME	Small and Medium-sized Enterprise
TLC	Telecommunications
TMT	Top Management Team
TRL	Technology Readiness Level
VC	Venture Capital / Venture Capitalist
VHB-JOURQUAL3	Verband der Hochschullehrer für Betriebswirtschaft Journal Quality Rating (third version)

From Dual-Use Challenges to Omni-Use Opportunities: Venture Capital, Governance, and the Future of Omni-Use Technologies

1. Introduction and Motivation

Under conditions of accelerating technological convergence and renewed geopolitical rivalry, Europe's ability to finance and govern dual-use innovation has become a first-order strategic concern. Artificial intelligence, autonomy, advanced materials, and space systems routinely straddle civilian and military domains, yet the labels used to classify them remain blunt instruments. The consequence is friction at precisely those junctures where clarity is most valuable: capital allocation by investors, eligibility decisions in public programmes, and procurement choices by state actors. In this setting, the European innovation-finance architecture, characterised by smaller average fund sizes, a comparatively thin growth market, and pervasive public-private interdependence, struggles to translate technological potential into deployable capability at pace (Alperovych et al., 2020; Bertoni et al., 2010, 2019). Policy ambitions articulated at European level, including the drive for technological sovereignty and a more resilient industrial base, heighten the salience of these coordination problems (European Commission, 2020).

A central driver of delay is classificatory ambiguity. The “dual-use” label collapses heterogeneous artefacts, use-cases, and governance contexts into a binary designation that travels poorly across evaluator arenas. In venture finance, such ambiguity inflates diligence costs, complicates compliance assessments, and introduces reputational uncertainty, thereby widening the cost of capital for affected firms. In public programmes, heterogeneous and sometimes inconsistent definitions determine eligibility thresholds, export control triggers, and reporting obligations, creating a patchwork that founders and investors must navigate without stable expectations. In ethics and security discourses, the dual-use dilemma is long

recognised, namely, that the same knowledge and artefacts can be marshalled for public benefit or harm (Atlas & Dando, 2006; Clarke, 2013). Recent work further shows that categorisation choices influence innovation trajectories and the diffusion of emerging technologies across sectors, challenging stylised civil-military boundaries (Carrozza et al., 2022; Caviggioli et al., 2023). When these classificatory practices meet Europe's fragmented capital markets, the result is protracted decision-making at a time when capability gaps have become politically undeniable.

The analytical starting point of this dissertation is therefore not a normative claim about more or less defence spending, but a structural observation: uncertainty about what technologies are, and how they are governed, systematically impairs investment and collaboration in European dual-use innovation. This observation is consistent with ecosystem perspectives in strategy, which emphasise interdependent roles, complementarities, and failure points across actors rather than firm-centric optimisation (Adner, 2006). In the European case, complementarities between public mission, private risk capital, and incumbent industrial capabilities are particularly tight. Where complementarities are tight and definitions are noisy, coordination failures multiply. Entrepreneurs face moving goalposts; investors face diligence dead-ends; public agencies face accountability risks. Classification is not the only friction, but it is a tractable and high-leverage one.

Since 2020 I have worked at the intersection of the gun industry, entrepreneurship, and strategy consulting, with projects spanning defence primes, private equity and venture funds, and state agencies, alongside study and work stints in the United States, China, and across Europe. The view from that mix was disquieting. I kept encountering signals that the 2020s would not be a decade of less conflict: tightening constraints in critical raw materials, widening social polarisation, and hardening geopolitical competition. When I looked at Europe's defence and dual-use ecosystem through that lens, I saw an industrial base that had

been financially starved, a venture market uneasy with anything touching “defence”, and a start-up scene that lacked both scale and confidence.

The full-scale Russian invasion of Ukraine in 2022 turned unease into obligation. I spent months searching for a university that would allow me to research these questions without running into civil-clause prohibitions; only the Universität der Bundeswehr München opened the door. That institutional choice mattered: it enabled access to practitioners while preserving academic independence. The more founders, investors, and officials I interviewed, the clearer the pattern became. Decisions stalled not because the technologies were inherently “bad risks”, but because the label “dual use” masked material differences in purpose, context, and governance, and because European finance plumbing struggled to price that ambiguity. Those observations are why this dissertation exists.

The dissertation’s purpose is to explain how Europe’s investment and classification regimes jointly shape the financing of dual-use innovation and to propose a practicable remedy. It proceeds in three steps that build on one another. First, it maps Europe’s coupled public-private finance architecture for defence and dual-use ventures and identifies where decision bottlenecks arise for entrepreneurs attempting to cross the valley of death. Secondly, it shows how prevailing classification practices, especially the shorthand “dual use”, propagate through investment memos, eligibility criteria, and procurement logics, thereby affecting time-to-decision and the cost of capital. Thirdly, it develops a Technology Continuum Taxonomy that replaces that label with a governance-anchored continuum designed to be used directly in diligence, programme design, and procurement workflows. The contributions are correspondingly empirical (a structured account of Europe’s finance architecture), conceptual (a reframing from “dual use” to an omni-use continuum), and practical (an implementable taxonomy intended to reduce uncertainty premia and align incentives). The aim is modest yet consequential: to lower avoidable transaction costs

without diluting substantive safeguards by making classification explicit, consistent, and operational (Adner, 2006; European Commission, 2020).

2. Conceptual background

2.1 European venture capital and governance architecture

European venture capital provides the meso-level conditions under which security-relevant innovation is screened, funded, and scaled. Fragmentation across member states, comparatively small fund sizes, and thin later-stage markets constrain cheque sizes and shorten investment horizons (Gompers & Lerner, 2002; Mason & Harrison, 1996; Quas et al., 2022). These structural features shape due diligence, syndication, and preferred exit routes, and they condition how investors interpret risk and value in security relevant sectors.

Public and quasi-public capital plays an influential role in this setting. Instruments associated with European and national innovation policy crowd in private investment and stabilise fundraising across cycles, yet they also introduce programme logics and compliance demands that influence sectoral focus and portfolio construction. Deal formation and exits reflect these conditions, early-stage rounds rely on dense, trust-based networks that are often national or regional in scope, while cross-border syndication concentrates in a few hubs (Gompers & Lerner, 2002; Mason & Harrison, 1996).

These financing and governance conditions explain why evaluation in Europe requires a precise conceptual framework for classifying technologies and ventures, so that risk and value can be assessed consistently across contexts where civil and military uses overlap and shift.

2.2 *Core construction and classification logic*

This dissertation treats the evaluation task as a classification problem for omni-use technologies, whose properties and applications span on a fluid civilian-military continuum. The central implication is that categorical shortcuts are ill-suited to contemporary technological convergence and should be replaced by assessment frameworks that are adaptive, transparent, and decision-useful for finance and policy alike (Stilgoe et al., 2013; Ulnicane et al., 2023).

The unit of analysis is a technology situated in its application and user context. Governance, developmental intent, and use environments interact to shape both risk and value, which is why the framework foregrounds context rather than inferring alignment from artefacts in isolation. In keeping with the dissertation's papers, the analysis acknowledges blurred boundaries and the inherently multifaceted character of modern innovation ecosystems (Burmaoglu & Saritas, 2017; Vaynman & Volpe, 2023).

Operationally, the classification architecture is continuum-based and hybrid. Ten criteria spanning technical, strategic, and market dimensions are assessed through a structured mix of qualitative judgement and quantitative indicators, ensuring that context-dependent features are not forced into spurious precision while measurable attributes remain comparable across cases (Nickerson et al., 2013; Tran & Daim, 2008). Technologies are evaluated from TRL 5 upwards to focus on cases with sufficiently defined application potential for investment-relevant appraisal.

To enhance proportionality, the scoring logic combines empirically derived criterion weights with a prudential threshold that prevents high-salience risks from being averaged away. In particular, if any two criteria reach the maximum score, the placement is elevated to the military-aligned end of the continuum, this preserves sensitivity to outsized security implications while maintaining comparability across evaluations.

The decision interface is a graded position on the civil-hybrid-military continuum accompanied by an auditable rationale. Designed to travel across evaluator arenas, the output supports investors in de-risking decisions, assists policymakers in prioritising support, and helps operators navigate governance requirements without collapsing heterogeneous evidence into a single over-general tag (European Commission, 2014, 2023; European Investment Bank, 2024). In venture contexts, generic investment heuristics privilege salience and size, which can amplify the distortion introduced by coarse labels when evidence is partial and contested (Gompers & Lerner, 2002; Mason & Harrison, 1996).

These observations delimit the conceptual gap addressed in the dissertation. Evaluators need a common vocabulary and an approach that connect technical facts to application, user, and governance context in a way that complements technology measures and compliance proofs and that can be applied consistently across the European settings described earlier.

3. Research Approach

3.1 Research Question

European decision makers are confronted with technologies whose applications move fluidly across civil, military, and hybrid contexts. Venture investors must evaluate regulation-intensive development with comparatively small funds and thin exit markets, while public authorities balance openness, resilience, and security across diverse national regimes (European Commission, 2020, 2024a; Fiott, 2014; Gompers & Lerner, 2002; Kanetake, 2018; Mason & Harrison, 1996; Quas et al., 2022). Judgements are often formed under uncertainty and time pressure, with limited ability to observe long-run outcomes before capital or policy commitments are made.

A central difficulty is conceptual. The dual-use label compresses heterogeneous users and applications into a single-label, oversimplified concept, failing to perform between evaluator diverse arenas and creating vagueness. Research on categorisation shows that coarse labels can misguide evaluation under uncertainty, while responsible innovation work argues that governance should surface purposes, actors, and settings rather than treat technologies as fixed carriers of harm or benefit (Nickerson et al., 2013; Stilgoe et al., 2013).

These conceptual limits become operational within Europe's financing and governance architecture. Fragmentation across member states, reliance on public and quasi-public limited partners, and a persistent scale-up finance gap shape screening horizons and syndication practices. Identical technologies and ventures can therefore be judged differently across committees, agencies, and member states, even when underlying technical facts are constant (European Commission, 2020, 2024a; Fiott, 2014; Gompers & Lerner, 2002; Kanetake, 2018; Mason & Harrison, 1996; Quas et al., 2022).

Against this backdrop, the dissertation asks:

“How can emerging omni-use technologies be systematically understood and evaluated, so that investment, innovation, and security objectives are aligned in Europe?”

The scope of this dissertation is European, especially because security- and defence-economy related academic work has been neglected or even blocked due to civil clauses and underfunding within almost every university over the last two decades. Security-relevant technology denotes technologies or ventures whose misuse, or misconduct, would create material risks for public safety, national or European security. The unit of analysis is the technology in its application and user context rather than in isolation. This framing reflects the way European instruments bind technologies through end use and end-user provisions as

much as through intrinsic properties, and it recognises that governance and market structure vary within the union (European Commission, 2020, 2024b; Mazzucato, 2018; Ulnicane et al., 2023).

The cumulative design of the dissertation resolves the question through three interlocking sub-questions that move from system to concept to instrument.

RQ1: What are the drivers shaping VC investments in Europe? How do these drivers influence investment strategies and syndicate formation? What impact do these investments have on investee companies throughout the investment cycle and, at its conclusion, the exit?

RQ2: What challenges does the dual-use classification create for modern technologies, and how do these challenges shape regulatory and financial frameworks across civilian, military, and hybrid applications in Europe?

RQ3: How can an omni-use technology continuum taxonomy be designed and validated to provide a transparent and practicable framework for evaluating and classifying such technologies and businesses, supporting consistent judgement by various stakeholders?

This sequence specifies the system in which omni-use ventures operate, clarifies why current classifications hinder effective evaluation, and motivates the construction of an operational approach that connects technical facts to application, user, and governance context using the resources already present in Europe's innovation system.

3.2 *Structure*

The dissertation follows a cumulative design that moves from system, to problem, to instrument. Figure 1 visualises this logic. Paper 1 establishes the market and dynamics in which innovative firms in Europe are financed and scaled. Paper 2 investigates how the dual-use classification is enacted within that setting and why it produces financial, structural, and perceptual barriers. Paper 3 provides an operational response by developing a continuum-

oriented omni-use evaluation framework for technologies whose applications can shift between civilian, hybrid, and military contexts.

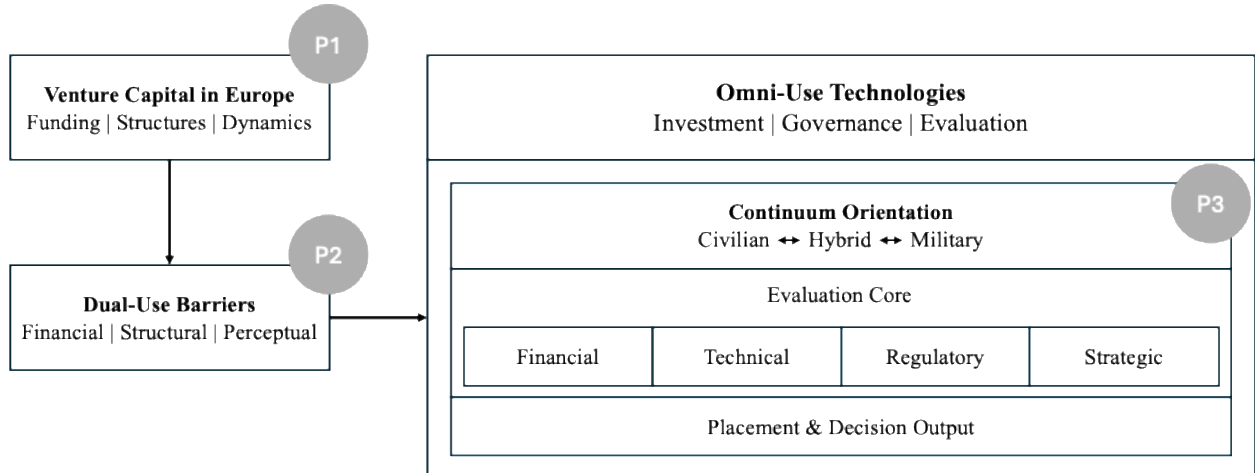


Figure 1: Overarching thesis and publication structure

Paper 1 serves as the meso-level foundation. It synthesises funding sources, structures, and dynamics in European venture capital and derives their implications for screening horizons, syndication practices, and exit pathways (Gompers & Lerner, 2002; Mason & Harrison, 1996; Quas et al., 2022). The paper is intentionally general rather than defence-specific. Its function in the cumulative argument is to characterise the boundary conditions under which any security-relevant venture must raise, validate, and scale.

Paper 2 connects these boundary conditions to the conceptual core of the thesis. It examines how investors, founders, and public authorities interpret and apply the dual-use label in practice and shows why this concept misrepresents heterogeneous technologies, users, and applications into a single class that travels poorly between evaluator arenas and nowadays does merely bring challenges and barriers rather than value and benefits. The analysis draws on research in categorisation and responsible innovation to argue for context-sensitive evaluation that surfaces technology, application, user, and governance setting rather than treating it as fixed carriers of harm or benefit (Nickerson et al., 2013; Stilgoe et al., 2013).

Paper 3 develops a response to the identified challenges in paper 2. It specifies an evaluation methodology and tool that integrates financial, technical, regulatory, and strategic dimensions, by utilising ten evaluation criteria and produces a placement along a civil-hybrid-military continuum and generates a decision output that can be used by various stakeholders. The purpose of the framework is to offer a practical solution. Within Europe's mission-oriented innovation agenda, it offers a transparent basis for comparative judgement that can travel across evaluator contexts while remaining sensitive to national security logics (Mazzucato, 2018; Ulnicane et al., 2023).

Table 1 summarises the three embedded papers and anchors each to its research question and target outlet. It makes the division of labour transparent: Paper 1 answers RQ1 on European venture capital drivers, decision-making, syndication, and firm-level effects; Paper 2 answers RQ2 on the challenges created by the dual-use category across civilian and military applications; Paper 3 answers RQ3 by designing and validating the continuum taxonomy that operationalises the reframing. The table also reports authorship and status, clarifying contribution across studies.

Table 1: Overview of embedded publications

No.	Title	Authors	Outlet	Addressed RQ
P1	The European Venture Capital Ecosystem: Towards a Research Agenda	Singer, Müller	Management Review Quarterly, Revise and resubmit, revision in progress	RQ1
P2	Dual-Use or Omni-Use? Rethinking Technology in a Borderless World	Singer, Müller, Kraus	Research Policy, Revise and resubmit, revision in progress	RQ2

P3	The Omni-Use Technology Continuum Taxonomy: Towards Systematic Evaluation	Singer, Kraus, Müller	Technological Forecasting & Social Change, Under review RR1	RQ3
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The written thesis mirrors this architecture. The initial part introduces the motivation and establishes the conceptual background. The present chapter states the research question, explains the structure using Figure 1 and Table 1, and then sets out the research approach. A synthesis chapter next integrates results across papers and develops implications for investors, founders, and public authorities. Each embedded paper follows in full and is preceded by a concise fact sheet that reports title, outlet and status, and author contributions.

3.3 *Research Approach*

This dissertation adopts a cumulative design that aligns method with question and keeps the unit of analysis constant: technologies situated in their application, user, and governance context within Europe. Three complementary strategies are combined. A systematic literature review maps the European venture capital setting in which innovations are financed and scaled, providing the boundary conditions for evaluation. An interpretive study based on semi-structured expert interviews examines how the dual-use technology classification is creating challenges and boundaries rather than common ground and value. A design-oriented study then develops and proposes a continuum-based evaluation framework.

3.3.1 Data sources and analysis transparency

Table 2 summarises methodologies and data sources across the three studies. Paper 1 analyses sixty-one peer-reviewed articles on European venture capital. Paper 2 is based on 32 semi-structured expert interviews, analysed thematically with an added quantitative

weighting step. Paper 3 combines policy and industry reports, academic literature, and semi-structured expert interview data to support taxonomy construction, scoring, and validation. The European scope is constant throughout, which ensures that constructs and criteria are calibrated to the governance and market arrangements described in the conceptual background.

3.3.2 Quality, validity, and ethics

Quality assurance is built into each stage. The review protocol in Paper 1 documents databases, keywords, screening rules, and coding templates so that search and synthesis are reproducible. Paper 2 employs interview guides, double-coding of transcripts, and a trail from first-order quotations to aggregate dimensions, participants provided informed consent and transcripts were pseudonymised in line with data-protection obligations. Paper 3 reports construct definitions, scoring rubrics, and validation procedures, and uses expert feedback rounds to refine criteria, criteria weight and decision rules. Across the dissertation, triangulation between literature, interviews, and framework testing mitigates single-method bias, while the European focus clarifies boundary conditions for transferability (Mazzucato, 2018; Ulnicane et al., 2023).

Table 2: Overview of applied research methodologies

No.	Title	Qualitative Methodology	Quantitative Methodology	Data Source
P1	The European Venture Capital Ecosystem: Towards a Research Agenda	Systematic literature review, PRISMA, narrative/thematic synthesis		61 peer-reviewed journal articles on European venture capital

P2	Dual-Use or Omni-Use? Rethinking Technology in a Borderless World	Semi-structured expert interviews, theoretical sampling; Gioia- style thematic analysis	Weighted impact score from transcripts	32 semi- structured expert interview data
P3	The Omni-Use Technology Continuum Taxonomy: Towards Systematic Evaluation	Integrative synthesis of industry/policy reports, academic literature, and expert interviews, iterative expert validation	Hybrid evaluation with multi-criteria scoring	Policy and industry reports, academic literature, and semi-structured expert interview data

4. Synthesis and Implications

4.1 Findings

Across the three embedded studies, the dissertation advances a shift from the dual-use categorisation to an omni-use technology continuum. Study I delineates the European venture capital context that conditions technology funding and scaling, Study II shows how those conditions materialise as resource, structural, and perceptual constraints for dual-use technologies and ventures; Study III operationalises these insights into a omni-use technology taxonomy that renders evaluative assumptions transparent.

4.1.1 Study I: European venture capital as boundary condition for dual- and omni-use innovation

The systematic review of sixty-one peer-reviewed articles maps the European venture capital ecosystem into interlocking layers of stable drivers (for example, legal frameworks, corporate governance, taxation, culture, and global value chains) and dynamic drivers (for example, macroeconomic cycles and capital-market conditions). These drivers interact with investment decision processes and syndication practices to shape screening horizons, risk allocation, and the latitude for post-investment value creation (Wright & Robbie, 1998). The synthesis highlights fragmentation, smaller average fund sizes than for example in the USA, reliance on public-private co-investment, regional imbalances, and a persistent scale-up equity gap, features that together circumscribe how omni-use ventures access growth finance and navigate cross-border scale. In the analysis in Study I, market drivers, venture-capital activities, and investee effects form a tightly coupled system, implying that evaluative tools proposed downstream must be compatible with Europe's capital structure and policy regime rather than with idealised or US-centric venture assumptions (Alperovych et al., 2020; European Commission, 2024b).

4.1.2 Study II: Constraints due to the dual-use technology classification in practice

Thirty-two semi-structured interviews with investors, founders, policymakers, military users, and academics render Study I's challenge analysis visible. Using Gioia-style coding, first-order statements were condensed into second-order themes and then into three aggregate dimensions, resource constraints, structural barriers, and perceptual complexity, creating an auditable chain from quotations to constructs (Gioia et al., 2013). Resource constraints integrate investment challenges (for example, ESG-filtered capital, reputational risk aversion) with market access barriers (for example, slow or opaque public procurement). Structural barriers combine regulatory and governance issues with ethical and moral concerns

that condition organisational behaviour to operate. Perceptual complexity captures stigma, category ambiguity, and narrative conflicts that distort evaluations even when technical quality is high.

To prioritise where frictions bind in real decisions, the qualitative analysis was complemented with a weighted impact based on three indicators, frequency of mention, perceived pressingness, and sentiment, computed from the interview data. As the key takeaways, market access barriers emerged as highly pressing (4.9) yet positive (sentiment = 0.95) and frequent, whereas frequency was dominated by regulatory and governance issues (143); investment challenges, though less frequent, carried the most negative sentiment (-1.85), consistent with bottlenecks at the funding and scaling outcomes within study I.

4.1.3 Study III: Operationalising omni-use through a technology continuum taxonomy

Building directly on Studies I–II, Study III develops and introduces the Omni-Use Technology Continuum Taxonomy, an evaluative instrument that encodes the evidenced drivers and frictions into ten operational criteria namely destructive potential, lethality, critical infrastructure impact, funding sources, potential for military use, regulatory compliance, technology impact scope, competitive landscape, team composition and business model and strategy.

The assessment instrument developed in this study enables end-users to appraise ventures and technologies along the omni-use continuum by assigning scores to ten criteria on a five-point ordinal scale, where 1 denotes clear civil orientation and 5 denotes clear military orientation. To ensure consistent application, each scale point is accompanied by precise operational descriptors. The criteria are organised into two clusters. The first comprises quantitatively observable indicators, the second comprises qualitatively judged indicators that are evaluated by users with the aid of structured guidance distilled from expert elicitation.

Prioritised weights were developed through a structured consultation with domain experts and are embedded in the tool. When a user enters criterion-level scores, the system computes a weighted composite index of civil-military proximity. To preserve prudence in ambiguous cases, a knock-out rule is incorporated. If at least two criteria receive the maximum score of 5, the tool automatically flags the case as “military-close” on the continuum, irrespective of the aggregate score.

The tool was stress-tested with worked examples and subsequently challenged in expert sessions to probe face validity and practical usability. The resulting framework affords stakeholders a rigorous, transparent, and replicable means to evaluate omni-use technologies and ventures, balancing quantitative indicators with structured qualitative judgement while maintaining conservative safeguards in high-risk constellations.

4.2 Discussion

This dissertation reframes “dual-use” from a categorical label to an omni-use continuum whose position is shaped by governance, finance, and market perception rather than by any vague technology classification. The cumulative logic begins with Study I’s overview of European venture capital structures and incentives, proceeds to Study II’s mechanism-level account of frictions due to the dual-use classification, and culminates in Study III’s operational taxonomy that enables diverse stakeholders to position omni-use technology on a civil to military continuum.

4.2.1 Study I as the scaffold: why European context changes the weights

Study I synthesises and systematises a fragmented literature into a coherent European venture-capital ecosystem, shows how stable drivers (legal frameworks, taxation, governance, policy instruments, and governmental venture capital) interlock with dynamic drivers (macroeconomic cycles and capital-market liquidity) to shape investment decisions,

syndication logics, and exit pathways. By foregrounding investor heterogeneity, independent, corporate, bank-affiliated, and governmental funds, the review explains cross-actor complementarities and crowding-in mechanisms, clarifies the geography of proximity and trust in cross-border deals, and surfaces the scale-up finance gap that constrains the translation from venture formation to growth and liquidity events. The resulting conceptual framework offers an auditable map of causal pathways rather than a list of factors, thereby furnishing policy and practice with levers that travel across jurisdictions and stages of the investment cycle.

Theoretically, the study advances an integrative lens that joins institutional and financial-economics perspectives with networked views of syndication, showing how Europe's structural specificities, market fragmentation, smaller fund sizes, differing legal systems, and linguistic-cultural heterogeneity, co-produce screening horizons and exit preferences (Denyer & Tranfield, 2009; Moher et al., 2009; Tranfield et al., 2003).

Substantively, the identification of an equity/scale-up gap places Europe's under-supply of later-stage capital at the centre of the research agenda, linking capital-architecture constraints to observed outcomes in firm growth and listing geography (Quas et al., 2022). Within the cumulative dissertation, this structural account provides the backdrop for Study II's analysis of governance frictions and categorical stigma and motivates the decision-tooling in Study III by specifying where evaluative noise originates and how proportionate interventions might be targeted.

4.2.2 Demonstrating the challenges of a dual-use classification

Study II shows that the dual-use label functions as an ill-fitting binary that collapses heterogeneous technologies and evaluator logics, thereby distorting decision-making in European finance and policy arenas. Drawing on categorisation theory, ambiguous and tainted categories predictably suppress positive evaluations even when technical quality is

high (Nickerson et al., 2013). In practice, regulatory uncertainty and politicised risk amplify investor caution, creating a structural-financial feedback loop that constrains early growth and weakens translation from laboratory to market, a governance problem that resonates with responsible innovation debates about anticipatory, proportionate oversight (Stilgoe et al., 2013).

The analysis identifies bottlenecks at the interface of markets and the state: misaligned procurement rules and prime-contractor gatekeeping reduce contestability and slow diffusion, while university civil clauses and ESG-screened mandates generate a stigma-barrier cycle that suppresses spin-offs despite evident capability. These perceptual and institutional frictions, consistent with categorisation effects, help explain why alleged neutral classifications yield systematically different resource and legitimacy outcomes across European evaluator arenas (Nickerson et al., 2013; Stilgoe et al., 2013).

Methodologically, the interpretive-analytic design links first-order accounts to aggregate dimensions through Gioia-style coding, then weights frequency, pressingness, and sentiment to prioritise decision-relevant frictions (Gioia et al., 2013; Miles et al., 2014). Substantively, the demonstrated misfit of the dual-use classification motivates an omni-use continuum that renders adaptation costs, pathway dependencies, and evaluator context explicit, thereby supplying the conceptual and empirical rationale for the taxonomy advanced in Study III.

4.2.3 Reframing dual-use through an omni-use continuum

Study III replaces a brittle categorical label with an auditable continuum, operationalised through ten criteria and explicit weighting, thereby aligning classification with established taxonomy-development practice and reducing evaluation noise under uncertainty (Nickerson et al., 2013). By foregrounding “Business Model and Strategy” alongside security-relevant dimensions, the framework integrates strategic management with

defence innovation logics, addressing pathway dependence and evaluator heterogeneity rather than forcing heterogeneous artefacts into a single vague and undefined category (Porter, 1998; Stilgoe et al., 2013). Anchoring the window at TRL 5+ focuses assessment on technologies with demonstrated relevance, improving external validity for investment and procurement decisions (Mankins, 1995).

A conservative design combines a weighted composite with a “two 5s” safeguard so that high-impact risks cannot be averaged away, reflecting responsible-innovation principles of anticipation and proportionality in practical decision rules (Stilgoe et al., 2013). The worked cases illustrate how non-kinetic technologies can trigger reclassification via infrastructural reach, while platform characteristics and commercial orientation shift hardware-intensive systems along the continuum without invoking lethality. Because the instrument externalises assessor heuristics as transparent scales, it creates a shared vocabulary across startups, investors, and procurers, enabling proportionate oversight and more consistent resource allocation than the dual-use label could support (European Commission, 2024a; Nickerson et al., 2013).

4.3 Contributions and Implications

For investors, the omni-use continuum provides a decision architecture that reduces category ambiguity, addresses ESG-driven exclusion, and renders due-diligence reasoning auditable across investment committees. By replacing the brittle dual-use label with a scored, weighted, and threshold-guarded taxonomy, the framework converts reputationally sensitive judgements into transparent criteria, thereby dampening the stigma-barrier cycle that amplifies perceived risk and deters capital (Nickerson et al., 2013; Stilgoe et al., 2013). In particular, a continuum model helps funds distinguish civilian-leaning, military-proximate, and genuinely omni-use propositions, enabling proportionate screening and portfolio

construction rather than blanket exclusions under generic ESG clauses (Quas et al., 2022). This is salient in Europe's structurally constrained VC environment, where smaller fund sizes, public-private co-investment, and a persistent scale-up gap already circumscribe risk appetite: tools that sharpen screening horizons and make risk allocation explicit are therefore complementary to existing governance and LP mandates (Wright & Robbie, 1998). Concretely, the taxonomy's hybrid of weighted composites and a conservative "two 5s" safeguard prevents high-impact security risks from being averaged away while still crediting commercial traction, regulatory readiness, and business-model orientation; this supports traceable IC memos, LP side-letter compliance, and nuanced ESG reporting without collapsing heterogeneous cases into an overly simplified ban (Mankins, 1995; Stilgoe et al., 2013). In doing so, the continuum reduces investor hesitancy documented in our interviews, where ESG screens and reputational concerns systematically excluded otherwise promising ventures, and offers a practical pathway to de-risked participation through proportionate classification, TRL-aligned focus, and shared vocabulary between funds, founders, and procurers.

Public-private consortia and regional innovation hubs should take particular note of the findings. These intermediary actors, such as the German Fraunhofer Institutes, the British Catapult Centres, or various defence incubators and accelerators, are uniquely positioned to bridge early-stage research and commercial deployment. Yet many lack evaluative tools for sufficient assessment of technologies and ventures at hand. The taxonomy developed in this dissertation offers a platform to structure cohort selection, impact reporting, and strategic guidance. This is particularly relevant given the growing number of publicly funded innovation programmes targeting cross-sectoral resilience, including those administered under the European Defence Fund or Horizon Europe (European Commission, 2023).

For accelerators and incubators, the taxonomy can also facilitate founder education. By integrating omni-use principles into curriculum design or mentorship frameworks, these organisations can raise awareness about procurement pathways, ethical positioning, and regulatory anticipation. Equally, they can help startups navigate the reputational minefields often associated with defence innovation, by contextualising omni-use relevance in socially responsible framing.

An important, and often underappreciated, second-order effect is that shared evaluative language and predictable decision rules can lower entry barriers and thereby facilitate the onboarding of new market participants into security-relevant markets. By making criteria and thresholds explicit, the taxonomy provides early-stage firms with a navigational aid to align product roadmaps, compliance preparation, and partner selection with defence-specific expectations, which reduces search, due diligence, and translation costs on both sides of the market. Intermediaries and primes can employ the tool as a pre-competitive interface for readiness checks and as a common reference in accelerator curricula, which together shortens time-to-first pilot and broadens the pipeline of credible entrants (Adner, 2006; European Commission, 2023; European Investment Bank, 2024).

Another often overlooked implication pertains to intra-organisational governance. Strategic innovation units within large corporates and public-sector organisations must increasingly navigate fragmented policy regimes, shifting public attitudes, and unclear ethical mandates. The taxonomy not only guides external investment or partnership decisions but can also structure internal portfolio reviews, scenario planning, and compliance audits. In this sense, the omni-use continuum supports reflexive governance practices within mission-oriented innovation environments.

Additionally, managerial practice in procurement agencies, both civilian and military, may benefit from the adoption of the omni-use continuum. The empirical findings underscore

that existing procurement systems are often ill-suited to the fluid innovation profiles of omni-use technologies, leading to either exclusion from consideration or improper categorisation. Procurement decision-makers, who must often operate under legalistic and risk-averse frameworks, would benefit from the taxonomy's ability to produce structured, multi-criteria assessments that can be used to justify novel acquisitions or pilot programmes. Interviewees noted that procurement flexibility varies substantially across NATO member states, with some adopting decentralised models of innovation intake (Military 3), which aligns well with taxonomy-enabled filtering and evaluation.

Lastly, the findings emphasise the importance of knowledge standardisation and policy alignment. National and supranational efforts should coordinate the uptake of omni-use tools and language across stakeholder ecosystems. The absence of shared frameworks contributes to duplicative assessments, inconsistent funding decisions, and unnecessary transaction costs. Initiatives such as the European Innovation Council, NATO DIANA, and the EIB's Strategic Roadmap (European Investment Bank, 2024) could act as integrators by embedding omni-use evaluation into strategic priority-setting and reporting standards.

The managerial implications of this dissertation reach beyond any single actor group. They speak to the transformation of entire institutional logics underpinning technology evaluation, investment, and governance. By mainstreaming the taxonomy and the concept of omni-use technologies, Europe can begin to dismantle the silos that currently fragment its innovation landscape and move towards a more integrated, strategic, and anticipatory approach to high-impact technology development.

4.4 Limitations

The dissertation is deliberately European in scope. Concepts, evidence, and the evaluation framework are calibrated to European financing and governance arrangements,

including export-control, security screening, and mission-oriented innovation policies (European Commission, 2020, 2024; Mazzucato, 2018). The qualitative component is anchored in Germany as an extreme case within the European Union, which sharpens the visibility of structural frictions but constrains external validity to member-state contexts that share similar legal and policy architectures (Fiott, 2014; Kanetake, 2018). Readers should therefore treat generalisation beyond the European setting with care, especially where capital markets and procurement regimes diverge from those described.

Study I privileges peer-reviewed scholarship to synthesise the European venture context. This choice strengthens rigour but introduces publication lag and under-coverage of grey literature and fast-moving market intelligence. As a result, the review maps drivers, decision rules, and exit dynamics rather than providing high-frequency tracking of capital-market shifts. Where the thesis discusses fund size distributions, syndication practices, or exit options, the evidentiary base therefore reflects established findings rather than real-time data (Gompers & Lerner, 2002; Mason & Harrison, 1996; Quas et al., 2022).

Data and sampling introduce additional limits. Study II rests on 32 semi-structured expert interviews across investors, founders, policymakers, defence users, and academia. Although theoretical sampling increased perspective diversity, the Germany-heavy distribution and finite interview count restrict saturation on cross-sector and cross-national sub-questions. Most interviews were conducted in German and translated for analysis; despite a consistent protocol, translation can attenuate nuances in legal terminology and policy practice that matter in export-control and procurement decisions (European Commission, 2020, 2024).

Design choices in Study III embed normative judgements. The omni-use taxonomy specifies ten criteria with explicit weights and decision rules. Expert-informed pairwise comparisons improved face validity, yet different communities of practice may set alternative

weights or emphasise additional criteria, which creates scope for inter-rater variation in operational use. The threshold rule that elevates cases with concentrated, high-impact risks improves precision where destructive potential or critical-infrastructure exposure is evident, but errors remain possible when contextual information is incomplete (Héder, 2017; Mankins, 1995; Mazzucato, 2018; Ulnicane et al., 2023).

A further limitation follows from the maturity boundary adopted in Study III. By focusing on technologies at TRL 5 and above, the framework targets application-proximate innovation that is relevant to investors and procurers, yet it excludes earlier scientific modalities where omni-use trajectories remain indeterminate. Upstream path dependencies in research agendas or standards formation may therefore be under-detected, even though maturity itself is not a proxy for acceptability in sensitive domains.

Validation remains pre-operational. Study III employs iterative expert feedback, multi-criteria scoring, and illustrative applications. It does not report prospective decision outcomes, such as procurement selections or portfolio reallocations, that would permit causal inference about downstream effects in live settings. Field trials integrated into investment, accelerator, and public-procurement processes are needed to establish predictive validity under the constraints described for European innovation policy.

Finally, the object of study is dynamic. Investment doctrines, export-control lists, security screening, and procurement law continue to evolve across the European Union and at national level (European Commission, 2024a; Fiott, 2014). A taxonomy calibrated to present conditions will require periodic re-weighting and criterion revision as new threat surfaces and civil applications emerge, and as governance practice shifts with policy reform and case law (European Commission, 2020; Kanetake, 2018).

4.5 *Further Research Opportunities*

This dissertation has laid the groundwork for understanding, classifying, and governing omni-use technologies, but it also opens a range of questions that merit sustained, theory-informed inquiry. The small but growing literature has tended to underutilise theory; yet suitable lenses can be highly practical in structuring research designs and deriving decision-useful insights. Responsible Research and Innovation provides one such scaffold for interrogating anticipation, reflexivity, inclusion, and responsiveness in omni-use settings, while mission-oriented innovation clarifies how public purpose shapes instrument choice and evaluative criteria (Mazzucato, 2018; Stilgoe et al., 2013). Building on these, future work can combine theory-testing with design-oriented contributions to strengthen external validity and usability in European decision context.

One clear opportunity lies in the further empirical application and refinement of the Omni-Use Technology Continuum Taxonomy. The framework now requires prospective tests inside real decision processes, investment committees, accelerator cohort selection, and public procurement pipelines, to examine whether taxonomy-guided deliberation changes risk assessment, time-to-pilot, and adoption outcomes. Ecosystem strategy offers a tractable lens for these studies: positioning and complementarity arguments suggest that changes in procurement legibility or screening exposure should shift partner formation and investment syndication (Adner, 2006; Wright & Robbie, 1998). Embedding field experiments or stepped-wedge pilots in agencies operating under the EU's critical-technology guidance would enable causal assessment under realistic constraints.

Quantitative extensions could combine the taxonomy with data-science approaches to scale assessment. A priority is to move beyond maturity proxies by integrating governance-exposure and market-structure signals alongside TRLs, consistent with the critique that maturity and suitability must remain analytically distinct (Héder, 2017; Mankins, 1995).

Business-model pattern taxonomies can supply structured features that correlate with civil-military addressability and route-to-contract (Weking et al., 2020). Using text analytics on investment memos, patent abstracts, and EU grant proposals, paired with out-of-sample validation on procurement outcomes, would create the foundation for predictive placement models and longitudinal benchmarking.

Conceptually, the boundaries of “omni-use” invite comparative research. Cross-jurisdictional studies could leverage differences in policy instruments and strategic doctrines across the EU, the United States, and China to test how institutional architectures shape classification and adoption. Within this dissertation, work on China’s policy trajectory and EU industrial strategy already foregrounds these contrasts, adding comparative case studies would deepen explanatory leverage (European Commission, 2020; Meng & Wang, 2023). International relations analyses of dual-use signalling and deception also provide propositions about how governance contexts mediate cooperation and control, which could be examined in firm- and programme-level data (Vaynman & Volpe, 2023).

The role of ethics, legitimacy, and law in omni-use innovation remains underexplored and would benefit from theory-led designs. Responsible Research and Innovation offers constructs for operationalising stakeholder inclusion and responsiveness, legal analyses of export control and screening regimes specify boundary conditions for acceptable deployments, and security-policy work identifies mechanisms linking narrative frames to adoption trajectories (Fiott, 2014; Kanetake, 2018; Stilgoe et al., 2013). Future studies might test whether explicit “ethics-by-design” routines and provenance controls reduce perceived screening risk and accelerate pilot approvals in sensitive domains such as autonomous systems or synthetic biology (Douglas & Savulescu, 2010; Penney et al., 2018).

Universities’ internal governance, civil clauses, partnership vetting, and reputational-risk procedures, conditions early path formation for omni-use ventures. Responsible Research

and Innovation again offers theory-backed evaluative criteria, while ethics-of-knowledge debates highlight how disclosure, openness, and dual-use concerns are co-managed in laboratories (Douglas & Savulescu, 2010; Stilgoe et al., 2013). Comparative organisational studies across consortia could test which advisory and classification mechanisms improve clarity without foreclosing beneficial applications.

Finally, connecting the omni-use agenda to the European venture-capital literature would facilitate cumulative progress. Theory-informed studies can examine how taxonomy-visible criteria (for example, procurement legibility or screening exposure) interact with known drivers of European investment decisions and syndication patterns, thereby explaining risk-taking and time-horizon differences observed in smaller, public-private funds (Alperovych et al., 2020; Mason & Harrison, 1996; Wright & Robbie, 1998). Mixed-methods designs that integrate field experiments with archival VC and procurement data would produce tractable, policy-relevant findings for investors, regulators, and procurers operating under EU mandates.

4.6 Author's Declaration

In addition to the acknowledgements and the specific declarations contained in the embedded publications, I hereby disclose the use of generative AI and AI-assisted technologies in the writing process. I employed Grammarly and ChatGPT to refine the language and improve the readability of the thesis, and I used DeepL for translation purposes. All outputs from these tools were subsequently reviewed and revised by me, and I accept full responsibility for the final content. I also confirm that I received no financial support for the research, authorship, or publication of this thesis or the embedded articles.

5. The European Venture Capital Ecosystem: Towards a Research Agenda (Study I)

Title	The European Venture Capital Ecosystem: Towards a Research Agenda
Authors	Jonas Singer, Univ.-Prof. 'in Dr. Elisabeth Müller University of the Bundeswehr Munich
Publication	Management Review Quarterly
Status	Revise and resubmit, revision in progress

5.1 Abstract

This paper examines the literature on venture capital (VC) investments in Europe, focussing on the unique dynamics and structural characteristics that differentiate the European VC market from its global counterparts. The paper sets the stage for developing a comprehensive research agenda aimed at identifying the strategic opportunities and challenges faced by investors and entrepreneurs alike within this VC ecosystem. At the heart of this agenda lie three fundamental questions: What are the drivers shaping VC investments in Europe? How do these drivers influence investment strategies and syndicate formation? What impact do these investments have on investee companies throughout the investment cycle and, at its conclusion, the exit? Through a systematic literature review of 61 studies published up to 2023 in internationally reputed journals, this paper aims to provide a comprehensive understanding of the European VC ecosystem, thereby informing scholars and other stakeholders ranging from policymakers to start-ups. In doing so, we hope to guide

new research to substantially advance knowledge about the European VC ecosystem and its critical role in fostering innovation and the sustained growth of innovative young firms.

5.2 *Introduction*

Venture capital (VC) serves as a pivotal force in the evolving environment of Europe's innovative young enterprises. This financial instrument is crucial; its importance goes far beyond simple monetary contributions, and it translates expertise and strategic direction into robust growth (Murray, 1996; Serrasqueiro et al., 2016; Haeussler et al., 2019). VC funds operate as financial intermediaries specialising in investments in privately held companies. They are actively involved in monitoring and advising these companies, with the ultimate objective of maximising revenue for their funds. Based on Joseph Schumpeter's notion of innovation as the essential force in robust economies, this paper considers VC investments as agents of 'creative destruction', promoting a cycle of continuous innovation and growth (Pradhan et al., 2019; Schumpeter, 1934).

This study investigates the intricate mechanisms of VC investments (which are a subset of private equity investments) within Europe, unravelling their essential role in nurturing and economically empowering start-ups. The study is structured to address three primary research questions within the European VC environment: What are the drivers shaping VC investments? How do these drivers influence investment strategies and syndicate formation? What impact do these investments have on investee companies throughout the investment cycle and at its conclusion, the exit? To answer these questions, we conduct a systematic literature review (SLR). In accordance with contemporary literature review standards, we follow the five-step process of Denyer and Tranfield (2009) while also adhering to the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) guidelines commonly used for SLRs (Moher et al., 2009).

This systematic approach contributes to research on the European VC ecosystem in two key ways. First, we provide a state-of-the-art overview based on theoretical and empirical research up to 2023. We identify and classify the drivers of the European VC

ecosystem into stable factors (e.g., legal framework, social and cultural environment) and dynamic factors (e.g., economic conditions, capital markets). This classification helps assess their importance in shaping the VC landscape. We also analyse the literature on VC activities, focussing on investment decisions and syndicate formation to understand VC strategies in Europe. In the final step, we review the literature on post-investment performance, highlighting the impact of different types of venture capitalists, their activism, and the strategic and structural considerations of VC funds. This overview aims to not only enhance the academic discourse on VC investments in Europe but also to offer insights for policymakers, investors, and entrepreneurs, contributing to a deeper understanding of these financial markets.

A nuanced understanding of the European VC ecosystem can also provide a helpful basis for further research endeavours, which leads to our second contribution. Specifically, on the basis of our review, we identify the current research gaps and develop an agenda for further research on VC investments in Europe. This study lays the groundwork for understanding the complex interplay between the various determinants affecting investment behaviours and outcomes. We hope this study will serve to guide new research in a manner that will substantially advance knowledge about the European VC ecosystem and its role in fostering innovation and the sustained growth of innovative young firms.

5.3 Background: The VC investment process and its key stakeholders

5.3.1 The VC investment process

VC investments face unique challenges such as agency problems and information asymmetry, particularly with start-ups as investment targets (Cumming et al., 2010; Hartmann-Wendels et al., 2011; Metrick & Yasuda, 2011). Entrepreneurs often struggle to accurately convey the true potential and risks of their ventures, creating an information gap

between them and investors. To secure funding, they might overstate their prospects, and investors have to evaluate these claims critically (Imad'Eddine & Schwienbacher, 2013; Metrick & Yasuda, 2011; Serrasqueiro et al., 2016). To overcome these challenges, VC firms follow a systematic approach ('The VC process', Figure 2), from establishing a VC fund to exiting the business (Tyebjee & Bruno, 1984; Gompers & Lerner, 2002; Isaksson, 2006; Fried & Hisrich, 1994; Wright & Robbie, 1998; Payne et al., 2009).

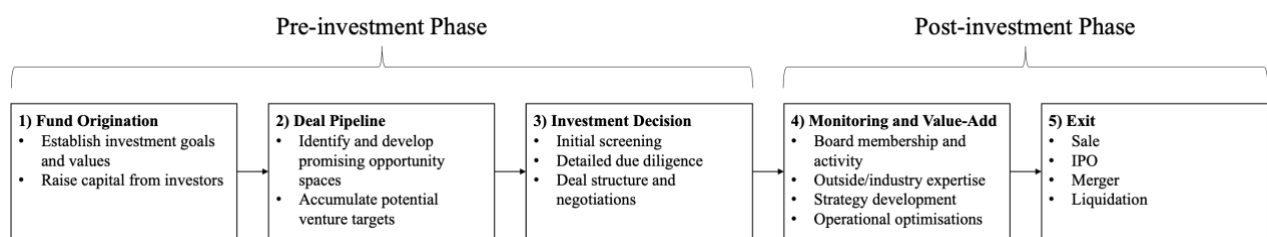


Figure 2: The VC process (Gompers & Lerner, 2002; Isaksson, 2006)

The initial phase, fund origination, involves the establishment of investment objectives aligned with the venture capitalists' ethos, accompanied by the critical task of capital aggregation from a cohort of investors (limited partners) (Tyebjee & Bruno, 1984). The subsequent phase, the deal pipeline, is characterised by the strategic identification of opportunity spaces and the aggregation of ventures that could be targeted for investment within the fund's specific focus. This meticulous process ensures a diversified and rich portfolio of investment candidates (Isaksson, 2006). In the investment decision stage, a multi-tiered screening approach is adopted, which entails an initial filter followed by an intensive due diligence (DD) practice. This stage is crucial for assessing risk, aligning investor and venture objectives, and laying the groundwork for deal structuring and negotiation dynamics, which ultimately dictate investors' influence and control over the company (Fried & Hisrich, 1994; Payne et al., 2009; Tyebjee & Bruno, 1984). As ventures mature within the portfolio, the monitoring and value-adding stage becomes instrumental. Here, the venture capitalist assumes a more hands-on approach than in the early stages, often participating in board

activities, providing strategic and operational guidance, and leveraging external expertise to steer ventures towards sustainable growth trajectories (Gompers & Lerner, 2002). Ultimately, the exit stage is where the venture capitalist seeks to realise the investment's value. This phase can involve various channels, such as strategic sales, initial public offerings (IPOs), mergers, or, in some cases, liquidation. Each exit strategy is selected based on its ability to maximise returns and is reflective of the overarching investment strategy used by the VC firm (Mason & Harrison, 1996).

5.3.2 Key stakeholders

Besides the continuously increasing complexity of the capital and funds environment, the diversity of investors has often been ignored in the past (Manac et al., 2022). Independent venture capitalists (IVCs) and private venture capitalists (PVCs) are mainly driven by the overarching aim of optimising financial returns. In contrast, diverse categories of investors may prioritise objectives beyond the maximisation of economic returns on their investments. Such objectives may span a wide spectrum, ranging from social considerations, as observed in governmental venture capitalist (GVC) initiatives, to strategic imperatives, as evidenced by corporate venture capitalist (CVC) and bank-affiliated venture capitalist (BVC) entities. Investigations in this domain have commonly treated investors as a homogeneous entity, thereby inadvertently overlooking the nuanced effects arising from the diverse profiles of these investors (Croce et al., 2015). The investment target, which in the current literature is often overlooked or not considered, also plays a central role within the stakeholder ecosystem (Figure 3) because the target is the major 'flywheel', which not only serves as the fund's selection focus but also operationalises the return on investment for investors and therefore dictates their uplift.

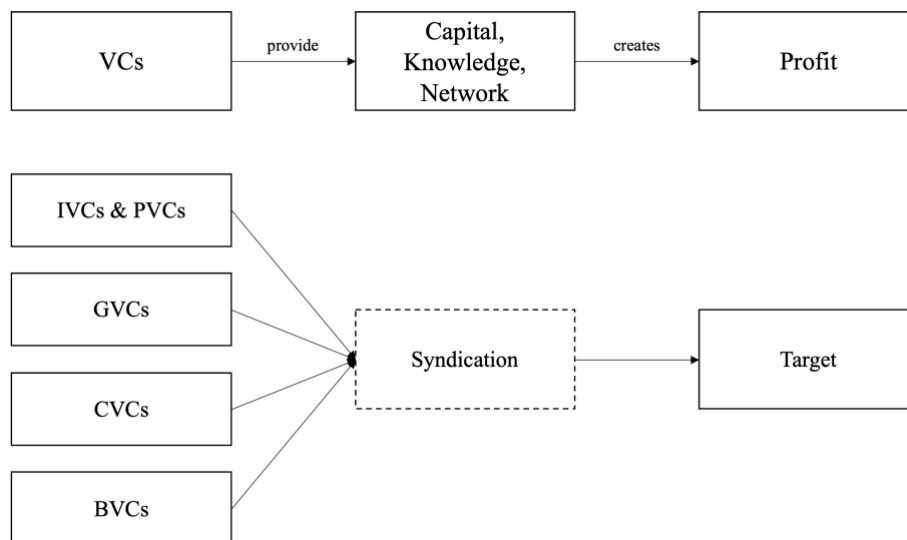


Figure 3: Stakeholders in the VC ecosystem

A closer look at the different types of VC investors reveals that IVCs and PVCs have distinctive investment preferences that set them apart from other investors. Within Europe, they demonstrate a higher appetite for investments in internet and telecommunications (TLC) services than in R&D and engineering services. Moreover, IVCs and PVCs tend to avoid the riskiest investments typically associated with very early-stage start-ups during their seed phase, instead focussing on more mature companies (Bertoni et al., 2015). In terms of regional preferences, IVCs and PVCs demonstrate an inclination to invest in companies some distance away from their own location, mainly in the 50 km to 300 km range (Bertoni et al., 2015).

GVCs exhibit the most distinctive investment pattern among the investor types in Europe. They steer away from TLC services and instead focus on industries such as R&D, engineering services, biotechnology, pharmaceuticals, and other high-tech manufacturing. Notably, they specialise in early-stage start-ups at the seed stage, showing a strong inclination for companies less than a year old. Furthermore, GVC investors heavily favour local investments, displaying a positive and significant tendency to favour companies within 10 km

of their premises and also exhibiting a pronounced inclination towards domestic investments (Bertoni et al., 2015, 2019).

In contrast, CVCs demonstrate a stronger inclination towards investing in TLC services than in biotech and pharmaceuticals. Interestingly, CVC investors do not display a specific preference based on factors such as company age, stage, or size. However, they distinctly favour investments in companies located at a considerable distance from their premises. Additionally, CVC investors are remarkably more open to cross-border investments than are other investors (Bertoni et al., 2015).

BVCs lack a specific industry specialisation pattern. However, they favour low-risk investments, as evidenced by their clear aversion to newly established companies and those with fewer than 10 employees. Instead, they focus on established companies that have been operating for over 5 years and have 50 or more employees. Furthermore, BVC investors exhibit a notable preference for local investments, particularly favouring companies within a 10 to 50 km radius of their location (Bertoni et al., 2015).

5.4 Methodology

The continuous advancement of knowledge in recent years has fuelled exponential growth in the volume of academic literature, leading to a vast array of studies, theories, and methodologies. Amidst this abundance of information, SLRs have emerged as an essential means of synthesising and critically analysing the body of research (Tranfield et al., 2003). Towards this end, we conducted a comprehensive SLR on VC investments in innovative young companies in Europe, offering an in-depth understanding of the key drivers, impacts, and gaps within the domain. We followed the five-step process of Denyer and Tranfield (2009) while also complying with the PRISMA guidelines, which are commonly used for SLRs (Moher et al., 2009).

5.4.1 Step 1: Formulating the research question

The investigation is driven by three key research questions, each probing a different aspect of VC investments and their impact on innovative young firms. The first question explores the drivers influencing these investments. The second question focuses on the factors that influence funds to start-up investment decision-making and syndicate formation, a critical aspect of Europe's diverse economic environment where smaller fund sizes often make cross-border collaborations essential (Murray & Marriott, 1998). The third question explores the effect on investee companies throughout the investment cycle and at its conclusion, the exit. This paper aims to synthesise the academic literature on these questions to provide a comprehensive understanding of the VC landscape in Europe, offering insights for policymakers, investors, and innovative young firms.

5.4.2 Step 2: Identifying relevant studies

To ensure a thorough review of the relevant literature, we utilised two distinct search methodologies (Harari et al., 2020). First, we conducted a keyword search of the EBSCO Business Source Premier database, which covers a broad array of academic journals (Hiebl, 2023). To pinpoint the necessary keywords, we performed an analysis of the keywords used in research on private equity and VC as a subset of private equity in Europe. We then expanded these findings with related concepts, leading to the creation of the following search string for our study: *Europe* AND (TI ('growth funding' or 'growth financing' or 'growth capital') OR TI ('high-growth companies' or 'high-growth firms' or 'high-growth startups') OR TI ('venture capital' or 'vc') OR TI 'private equity' OR TI ('scale-ups' or 'scaleups') OR AB ('growth funding' or 'growth financing' or 'growth capital') OR AB ('high-growth companies' or 'high-growth firms' or 'high-growth startups') OR AB ('venture capital' or 'vc') OR AB 'private equity' OR AB ('scale-ups' or 'scaleups'))*. Only sources that had the

above keywords in their title or abstract were included. This primary search string resulted in 9,368 records. Next, we applied the inclusion criteria outlined in Step 3 to this search string. Second, we conducted a manual search to ensure comprehensiveness, looking beyond the algorithmic search. This manual approach, which involved citation tracking and hand-searching relevant top journals, brought to light an additional five journal papers that met our inclusion criteria but had not been identified through the previous methods (Harari et al., 2020). By structuring our search for the most relevant studies in this manner, we ensured comprehensive coverage of all the relevant academic literature on the subject of VC investments in Europe (Hiebl, 2023).

5.4.3 Step 3: Selecting relevant studies

Studies were included in our literature review if they met the following selection criteria:

- A. *Publication Type*: The studies for review were selected from peer-reviewed scholarly journals, ensuring a high standard of research quality, rigorous empirical analysis, and practical implications (Miller, 2006).
- B. *Language*: We included studies written in English to align with the global academic community's communication language, ensuring relevance and accessibility within international academic circles (Hamel, 2007).
- C. *Year of Publication*: We included papers until July 2023 to capture a broad spectrum of scholarly work and to analyse how recent publications build on earlier research.
- D. *Journal Quality*: We included academic journals with a VHB-JOURQUAL3 rating of A+, A, or B. This rating is published by the German Academic Association for Business Research (Hennig-Thurau & Sattler, 2015). More specifically, we included journals from the following VHB subcategories: (1) general business administration, (2) finance, (3) strategic management, (4) entrepreneurship, (5) technology,

innovation, entrepreneurship, and (6) international management. The high correlation between this rating and established benchmarks such as the Academic Journal Quality Guide (0.66) and the SCImago Journal Rank (0.70) validates its effectiveness in assessing the quality of journals (Hennig-Thurau & Sattler, 2015).

E. *Scope*: Only studies relevant to the research questions and geographical focus (Europe) of the paper were included, ensuring a precise and targeted review.

Irrelevant studies were excluded to maintain the integrity and relevance of the research.

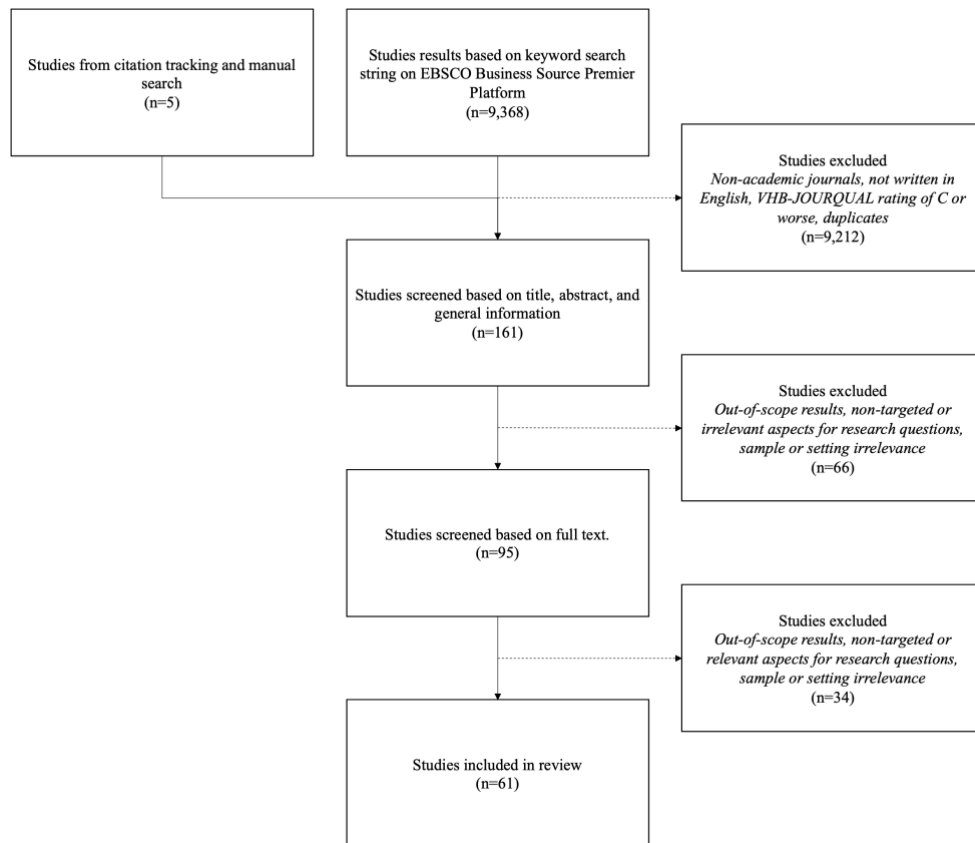


Figure 4: Review process chart

This rigorous selection process (Figure 4) culminated in a dataset comprising 61 relevant academic papers that aligned with the established criteria and formed the basis of our research. Further information on these papers and their key findings are given in Appendix 1.

5.4.4 Step 4: Analysing and synthesising the papers

We reviewed the selected studies and categorised them based on their relevance to our research questions as follows. To address the first research question, we systematically reviewed the literature focussing on the multifaceted drivers of VC investments in Europe. Our analysis centred on identifying key factors clustered in stable and dynamic drivers and overarching macroeconomic conditions that collectively influence investment decisions. By synthesising these findings, we aimed to construct a nuanced understanding of the relevant investment drivers within the European VC ecosystem.

The second research question required a targeted examination of VC activities, including the dynamics underpinning fund allocations to start-ups and strategic syndicate formation. Given the criticality of cross-border collaborations within Europe's heterogeneous economic environment, our review emphasised factors that facilitate or impede these investment decisions. The identification of these factors involved a detailed exploration of both the internal fund mechanisms and external environmental variables that guide the formation of investment syndicates.

For the third research question, our focus shifted to the effects of VC fund investments on companies during the holding period and at the point of exit. This analysis sought to uncover the tangible impacts of such investments on the operational, financial, and strategic dimensions of the investee companies. Through a careful review of related studies, we aimed to interpret the transformative potential of VC funding across different stages of company development and during the critical phase of investment exit.

5.4.5 Step 5: Reporting the results

To gain a clear understanding of VC investment research, we started by outlining the fundamental structure of the VC ecosystem that emerged as a key result of our analysis. We then used our insights to explain what drivers propel the VC market, how VC activities are

conducted, and the performance metrics of VC investments. We concluded by identifying key areas for further study, highlighting their importance for continued academic inquiry.

5.5 The VC ecosystem

Figure 5 shows the main result of our SLR: a conceptual framework that delineates the ecosystem of VC investments. This ecosystem is anchored in the interplay between market drivers, VC activities, and targeted companies.

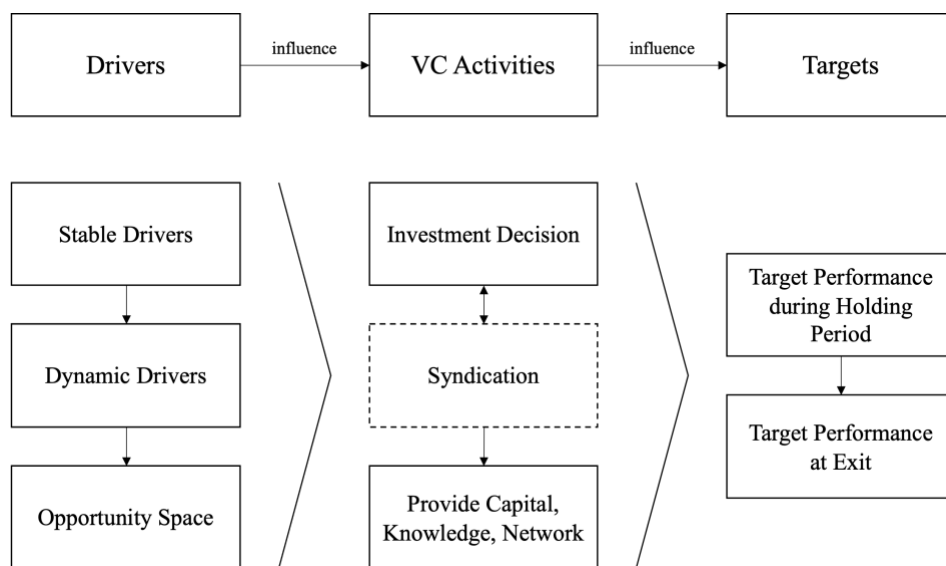


Figure 5: Overall ecosystem of VC investments

We categorised the market drivers into two distinct groups: those that evolve at a gradual pace (stable drivers) and those that exhibit rapid and frequent fluctuations (dynamic drivers). Stable drivers encompass elements such as the legal framework, corporate governance, the social and cultural environment, taxation and public policies, and GVCs, whereas dynamic drivers capture volatile elements such as economic and capital market conditions. These drivers, in combination with the VC activities, modulate the spectrum of opportunity space for entrepreneurial activities that arise within a given environment.

Investment decisions are central to VC activities and are influenced by all categories of drivers. The syndication of investments, a nuanced strategy within VC practices, is

identified as a pivotal activity. Syndication enables the pooling of resources, sharing of risks, and integration of diverse expertise. Syndicates often emerge as a response to complex market dynamics, providing a structured platform for collaborative investment and risk reduction for individual investors. Venture capitalists contribute more than just financial investment; they offer a wealth of knowledge and expansive networks, thereby enhancing the value of the investee companies. This multifaceted support is instrumental in steering the venture from inception through various growth stages.

The targets of VC activities are encapsulated in the performance of portfolio companies both during the holding period and at the point of exit. Performance during the holding period reflects the venture capitalist's active involvement, whereas performance at the point of exit reflects the venture's market viability and the realisation of the venture capitalist's strategic objectives.

This ecosystem provides a comprehensive overview of the interdependencies between market conditions, VC activities, and the performance outcomes of the investee companies. In the following sections, we discuss and synthesise the results of the existing research that led us to develop this ecosystem framework.

5.6 Drivers of VC investments in Europe

The interplay between stable and dynamic drivers has a profound impact on the vibrancy of the VC market, influencing the availability of investment opportunities, the flow of capital, and the success of entrepreneurial endeavours. To understand the dynamics of this part of the ecosystem, we explore the findings on each of the drivers displayed in Figure 6 in detail and assess their role in shaping the European VC landscape.

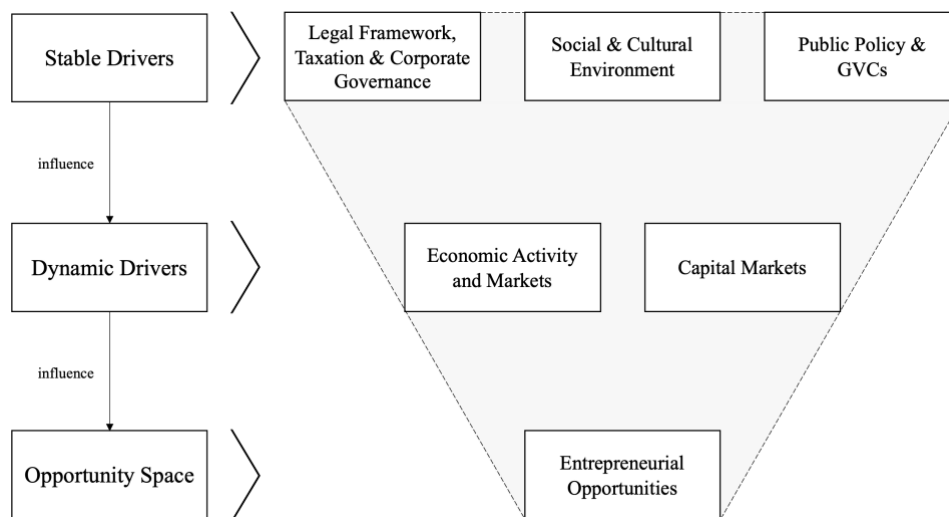


Figure 6: Drivers of VC investments in Europe

5.6.1 Stable drivers

5.6.1.1 *Legal framework, taxation, and corporate governance*

Groh et al. (2010) find that legal frameworks, which encompass property rights protection and enforcement, significantly influence the attractiveness of VC markets by affecting the size of capital markets and the capacity of local firms to obtain external financing. They also demonstrated that political factors are influential in establishing corporate governance norms, highlighting the need for strong minority shareholder protection to ensure the vitality of capital markets. In addition, Cumming et al. (2006) suggest that the quality of a country's legal system may exert a more important influence on the facilitation of VC-backed exits than the size of its domestic stock market. The diversity of legal environments across nations, such as variations in legal origins and accounting standards, substantially influences governance structures within the VC sector. Robust legal frameworks are crucial for fostering cross-border syndication activities, as evidenced by Meuleman et al. (2017). Supporting this, Cumming et al. (2010) and Leleux and Surlemont (2003) find that stronger legal infrastructures, reflected in higher legality indices that take into account judicial efficiency, the rule of law, the prevalence of corruption, expropriation risks, the

probabilities of contract repudiation, and the safeguarding of shareholder rights, are instrumental in augmenting the likelihood of VC investment activities.

In relation to taxation, Groh et al. (2010) note that taxes, particularly on capital gains and corporate earnings, directly influence VC investment by shaping entrepreneurial decisions, such as whether to start or close a business, and can make self-employment more appealing by offering financial advantages over corporate employment. Henrekson and Sanandaji (2018) add that lower taxes on stock options increase the attractiveness of investing in innovative entrepreneurial firms, leading to a shift in financial capital and talent towards this sector. While acknowledging other systemic differences in economic models, the study suggests that European countries could foster entrepreneurial finance by adopting more favourable tax policies for stock options.

5.6.1.2 The social and cultural environment

Numerous studies have demonstrated that the distinct national cultures of countries influence both individual inclinations and contextual factors, ultimately resulting in varying levels of entrepreneurial activity (Tyebjee & Vickery, 1988; Huber Ooghe et al., 1991). Notably, Groh et al. (2010) show that the cultivation of a research-oriented culture is crucial for nurturing the growth of a robust risk capital industry. They also demonstrate that some countries exhibit a greater propensity for embracing risk than others, an effect that is closely entangled with culture. This inclination is expected to have consequences for the profitability of industries, because sectors inclined towards risk are projected to yield higher average returns than those that are less prone to risk.

In addition, trust emerges as a pivotal driver, exerting a dual influence on investment decisions and exit performance. Bottazzi et al. (2016) show that the importance of trust in investments is most pronounced in the early stages, when it is essential for establishing successful partnerships. Early-stage investments particularly require trust due to the inherent

uncertainties associated with them. Despite increasing investment likelihood, high levels of trust show a negative correlation with exit success. Additionally, language commonality is positively correlated with investment likelihood and trust, but the linguistic diversity in Europe poses challenges to establishing these trust-based relationships.

5.6.1.3 Public policy and GVCs

Revest and Sapio (2012) and Grilli (2014) point to the influence of policy measures on the development of new technology-based firms (NTBFs) in Europe. Revest and Sapio (2012) present evidence of the pivotal roles of certification and signalling by European and national policies, and the enduring positive effects of preferential R&D tax incentives, findings that are consistent across different financial systems. Grilli (2014) complements this by proposing a heuristic framework that delineates three strategic areas for policy intervention aimed at fostering the growth of NTBFs. The framework advocates for policies that mitigate the socio-regulatory consequences of entrepreneurial failures, recognise the local idiosyncrasies of the VC market for targeted territorial marketing, and utilise public financial support to enhance NTBFs' access to private funding through 'halo and certification' effects.

In line with these findings, the collective insights from Bertoni et al. (2019) and Buzzacchi et al. (2013) emphasise that GVCs can catalyse investments from PVC firms into younger and smaller companies in less competitive regions, illustrating a productive interplay between public and private funds. This finding is complemented by Grilli and Murtinu (2014) and Alperovych et al. (2020), who question the direct governmental role in VC markets but acknowledge the benefits of environments that support PVC initiatives. Similarly, Tavares-Gärtner et al. (2023) demonstrate through a real options model that public-private co-investments effectively lower investment thresholds more than independent ventures do, advocating for the strategic use of equity premiums to align the interests of PVCs. Together,

these studies highlight the nuanced but important systemic impact of GVCs, particularly in activating PVC investment and addressing market failures in financing innovative start-ups.

5.6.2 Dynamic drivers

5.6.2.1 *Economic activity and markets*

The economic condition of a nation is dynamic and is anticipated to have an important influence on VC activity as well as on entrepreneurial and innovation activities, which are closely related and have long been recognised as such (Alhorr et al., 2008; Groh et al., 2010; Schumpeter, 1934). The magnitude of the economy serves as a distinguishable marker, reflecting the abundance of corporate entities and opportunities for deal-making, and economic expansion serves as a catalyst, fostering an augmented demand for financial resources (Groh et al., 2010). At the same time, economic affluence and developmental progress play instrumental roles in nurturing the entrepreneurial spirit, primarily through the amplification of available capital for investment endeavours. This environment enhances the feasibility of launching new ventures, due to not only the accessibility of start-up funding but also the rise in disposable income levels within the domestic market (Wilken, 1979, as cited in Groh et al., 2010).

The findings of Alhorr et al. (2008) and Tyebjee and Vickery (1988) present contrasting perspectives on the importance of European economic integration for the European VC market. Alhorr et al. (2008) observe that economic integration, such as common markets and currencies, tends to increase the likelihood of cross-border VC investments, which can spread technology and enhance regional networks. This suggests a scenario where the European Union (EU), with its integrated economy, could be well positioned to promote international investments. However, Tyebjee and Vickery (1988) highlight the small and fragmented nature of European markets as a challenge for new ventures, implying that despite the potential for international investment, start-ups may

struggle due to the need to secure substantial domestic market share or expand internationally, which can be particularly daunting tasks.

5.6.2.2 Capital markets

A well-established capital market plays a pivotal role in facilitating the exit strategies of venture capitalists, contributing significantly to the vibrancy of the VC market, particularly with regard to IPO exits. Empirical evidence highlights that risk capital thrives in nations with deep and liquid stock markets, where liquidity exerts a substantial and positive influence on early-stage VC investments (Groh et al., 2010; Imad'Eddine & Schwienbacher, 2013; Manigart et al., 2000; Meuleman & Wright, 2011; Tyebjee & Vickery, 1988).

International capital flows into Europe have been steadily increasing in past decades. In 2022, Europe received considerable investments from abroad, with 24.5% of all private equity funds raised from North America and 22% from Australia and Asia (Invest Europe, 2023). The data presented by Groh et al. (2010) suggest a robust supply of VC funds in Europe, with the volume of funds raised often surpassing the amount invested within a year. This indicates a favourable supply landscape for venture investments. In contrast, Quas et al. (2022) show that the EU faces a concerning challenge in nurturing innovative start-ups into high-growth companies, a stark contrast to the success of the United States and China in fostering unicorns. Failure to address this scale-up financing challenge could have detrimental consequences for Europe, such as the relocation of technologies, knowledge, and jobs elsewhere, which could ultimately jeopardise the EU's standing in the global tech market. Calls for the creation of substantial sovereign mega-funds (of about €100 billion) have been issued, but experts caution that their size could distort the VC market and potentially crowd out private investors (Quas et al., 2022). Although research findings on the crowding-in or crowding-out effects of governmental investments are mixed, Bertoni et al. (2019) endorse the idea that GVC investments facilitate a crowding-in effect. They find that

PVC investors are more likely to direct their investments towards businesses – typically young, small, and positioned in less competitive areas – that they usually bypass when GVCs do not have a major presence. The prevailing consensus is that public funding should be paired with private capital, alongside efforts to improve the risk-return profile for private investors.

Lahr and Mina (2014) highlight the influence of liquidity crises and technological opportunities on the staging of VC investments, suggesting that market conditions critically impact investment stages and particularly noting resilience in early- and late-stage investments during financial crises. This is complemented by the studies of Revest and Sapio (2012) and Colombo et al. (2019), who point out that although VC growth in Europe has been considerable, it has been predominantly concentrated in the United Kingdom, with much of the rest of Europe experiencing stagnation. The apparent disparity in regional growth within Europe suggests that the issue with VC distribution is not merely one of volume but also of geographical and developmental imbalances, possibly reflecting differentiated market dynamics and investment climates across European regions. Bertoni et al. (2016) add to the debate on VC distribution and emphasise that VC investments have a greater impact on portfolio ventures in less developed VC markets, particularly in continental Europe. They also highlight the role of high entry costs for young high-tech companies in thin VC markets and suggest that reducing these entry barriers, potentially through policy measures such as start-up competitions and contests, can benefit social welfare.

5.7 VC activities

5.7.1 Investment decision-making of VC firms

Social and geographic networks are the primary influence on investment decisions. For example, Wuebker et al. (2015) highlight the important impact of social networks on VC

investment decisions. In uncertain markets such as emerging industries, personal connections and referrals are more influential than co-investors' reputations. They find that venture capitalists are guided by, but not entirely dependent on, their peer networks. Inexperienced investors rely more on personal ties than experienced investors, a dependency that decreases with experience but later increases again.

The uneven distribution of VC investments across geographies has been extensively studied and predominantly attributed to supply-side factors (Colombo et al., 2019). It is widely held that entrepreneurial ecosystems and close proximity between investors and their investment targets play a crucial role in promoting entrepreneurship, particularly in nurturing a greater proportion of high-growth firms that are of particular interest to venture capitalists (Bertoni et al., 2015). Recent research by Coad and Srhoj (2021) shows that the demand for VC investments is higher when venture capitalists and ventures are in close proximity to each other. This effect vanishes when national borders need to be crossed, except for countries with very similar cultures and institutional frameworks. Colombo et al. (2019), Bottazzi et al. (2016), and Bertoni et al. (2015) report similar findings, but they also observe that the type of fund markedly influences the observed effects.

In addition, the investment decisions of VC firms are influenced by factors that are associated with both the VC firm and the target firm. VC decision-making evolves with a fund's lifecycle and diversification, as Petty and Gruber (2011), Karsai et al. (1998), and Wuebker et al. (2015) find. Early rejection factors differ from those that come into play later, with the portfolio's composition becoming increasingly important over time. Product and service criteria are key to deal assessment, outweighing management team factors. Nonetheless, traditional investment criteria such as product strategy, market dynamics, financial outlook, and VC-specific considerations such as fund focus and deal structure remain important. A thorough internal DD by VC fund managers is also correlated with

improved investee post-investment performance (Cumming & Zambelli, 2017). However, DD by external parties such as accountants or consultants has minimal impact. This underlines the critical role of internal DD in predicting the success of VC investments.

Additionally, the top management of the VC fund influences decisions. According to Patzelt et al. (2009), the educational and professional backgrounds of VC firms' top management teams (TMTs) significantly shape their investment strategies. Firms with TMTs rich in science or engineering education and entrepreneurial experience tend to favour early-stage ventures, whereas those with extensive management education typically diversify across industries. Moreover, firms with internationally experienced TMTs are more likely to have a broader geographic investment reach than those without such TMTs, highlighting the pivotal role of TMT characteristics in guiding VC investment approaches.

5.7.2 Syndication

Our analysis shows that the importance of syndication varies depending on contextual factors, such as region, industry, and legal environment, as well as the size of the VC firm. Studies by Manigart et al. (2006) and Verwaal et al. (2010) show how VC firms use syndication strategically, the strategies varying with firm size and region. Small VC firms engage in syndication to access resources, whereas large firms use it for reciprocal deals. In Europe, venture capitalists syndicate primarily to manage portfolio risks, such as sharing financial risks and accessing larger deals, rather than to improve deal management. This approach also varies by investment stage, with early-stage investors focussing on adding value. These practices highlight differences from US venture capitalists and demonstrate the strategic use of syndication to foster innovation and support entrepreneurial ventures. Evidence also points to syndication gaining importance as an industry matures, reflecting the need for shared expertise and risk management in established markets (Huber Ooghe et al., 1991). In addition, Cumming et al. (2010) and Reid et al. (1997) reveal that a strong legal

framework significantly encourages syndication in VC, particularly for early-stage investments in developed markets. This suggests that better laws reduce agency issues, enhancing the value of syndication. Syndication is also more commonly adopted by young VC firms than by mature firms, likely due to the benefits of risk sharing, diversification, and information sharing. Capital inflows positively influence both syndication and co-investments, with syndication providing a network that promises future deal flow.

Other research has also demonstrated the role of relational variables in syndication. For example, venture capitalists are more inclined to involve syndication partners in deals characterised by low levels of trust when trust is lacking, especially in cross-border investments, than when trust is present (Bottazzi et al., 2016). However, data on the increase in international syndicated deals as markets mature are inconclusive, suggesting that although syndication is a preferred strategy domestically, the complexities of cross-border deals may present challenges that affect its prevalence (Huber Ooghe et al., 1991). Meuleman et al. (2017) show that although relational embeddedness undeniably drives future partnerships, structural embeddedness and trust-boosting institutions such as robust legal frameworks and industry associations emerge as catalysts for cross-border syndicate formation. These factors substantially reduce the dependence on existing relational ties when selecting cross-border partners. They also demonstrate the positive main effect of both direct and indirect ties between current syndicates and prospective partners in the initiation of new connections.

5.8 Performance of VC investments and their impact on the target firm

The empirical literature offers mixed findings on the performance of VC investments during the holding period and at the point of exit (Metrick & Yasuda, 2011). However, we posit that most such comparisons are inherently fraught with complexity due to the variability of the timeframes used in the analyses, which can profoundly influence outcomes.

Additionally, the distinct characteristics and scale of individual funds invariably yield a spectrum of unique results, which we discuss in more detail in this section.

5.8.1 Impact and performance during the holding period

5.8.1.1 *Investor activity*

The findings of Bottazzi et al. (2008), Inderst and Mueller (2009), and Croce et al. (2013) collectively advance the discourse on the profound influence of proactive investor engagement in the VC landscape. These studies articulate the benefits of investor activism – from strategic recruitment to fundraising – as determinants of sustained firm growth during the holding period and successful exit outcomes.

Adding to this discourse, Manzaneque et al. (2016) uncover the nuanced governance dynamics within the Spanish corporate sector, revealing that directors appointed by pressure-resistant institutional shareholders can significantly mitigate the risks of business failure. This finding speaks to the active governance role these shareholders play, especially in protecting firms from financial distress, thereby reinforcing the ‘convergence of interest hypothesis’: the alignment of directorship with shareholder interests.

5.8.1.2 *Investor type*

Regarding the impact of investor type, Grilli and Murtinu (2014) and Guerini and Quas (2016) offer complementary perspectives on the role of GVCs in Europe. Although Grilli and Murtinu (2014) establish the pronounced positive impact of IVCs on the growth of high-tech entrepreneurial firms, they also note that GVCs do not markedly affect firm growth unless they serve as non-leading partners in VC syndicates. Conversely, Guerini and Quas (2016) find that GVC investment significantly increases the likelihood of obtaining private venture capital, serving as a crucial endorsement for high-tech entrepreneurial firms. This certification effect can play a vital role in mitigating information asymmetries and attracting PVCs.

Bertoni et al. (2010) investigate the impact of VC type on investment sensitivity to cash flow in Italian tech-based firms, noting that IVC funding reduces these firms' dependence on internal cash, easing financial constraints. In contrast, CVC funding does not show the same effect, suggesting different efficacies in alleviating financial barriers for firm growth.

In comparing the impact of domestic and international investors, Devigne et al. (2013) reveal that companies initially supported by domestic investors experience more rapid growth in the short term, whereas those backed by cross-border investors show greater growth in the medium term. The highest growth is observed in companies funded by a syndicate of both domestic and cross-border investors. This research highlights the distinct contributions of different types of investors throughout a company's growth stages. Domestic investors, familiar with the local context, effectively support early growth stages by mitigating information asymmetries and providing relevant resources. Cross-border investors, with their knowledge of international markets, become more important as companies mature.

5.8.2 Impact and performance at the point of exit

5.8.2.1 *Investor influence and the paradox of trust*

In synthesising the insights from Gompers et al. (2008), Kräussl and Krause (2014a), and Murray (1996), we find notable differences in the performance of the US and European VC markets. The better performance of the seasoned VC market in the United States starkly contrasts with Europe's emerging VC landscape. This performance difference is especially pronounced in early-stage European ventures, which struggle to match the growth trajectory of their American counterparts, hindered in part by a less vigorous entrepreneurial environment. Murray (1996) further illuminates the role of venture capitalists, who function not just as financiers but also as strategic advisers, offering managerial guidance while sparingly involving themselves in the technical details of innovation. This multifaceted

influence is contested by Bottazzi et al. (2016), who emphasise the complex relationship between trust and investment success, proposing that higher trust might not always be conducive to achieving desired outcomes such as IPOs, thus challenging the traditional endorsement of trust as a positive asset in VC dynamics.

Falconieri et al. (2019) show that IPO firms receiving support from large heterogeneous VC syndicates exhibit a distinct underperformance trajectory, spanning both the short-term and long-term post-IPO periods. This phenomenon can be attributed to the intensification of agency conflicts and the multiplication of coordination challenges. The degree of underperformance is notably associated with the increasing size and diversity of VC syndicates.

5.8.2.2 Strategic and structural factors

Analysing the cost and performance data provided by Murray and Marriott (1998), a clear recommendation for the success of VC investors emerges: a specialised, early-stage VC fund with a minimum size of about €28 million. Funds managing less than €21 million face uncertainty in obtaining investment rewards commensurate with the substantial levels of risk and illiquidity involved. We assume that because this research is more than 25 years old, the volumes today would be considerably higher due to inflation. In contrast, Manac et al. (2022) find that once a viable minimum fund size such as that described by Murray and Marriott (1998) is reached, larger fund size correlates negatively with fund performance, a trend that persists across various fund types. However, venture and expansion/late-stage funds in particular show lower performance, with the former facing high inherent risks and the latter struggling with debt, hindering operational efficiencies. They attribute this lower performance to factors such as agency problems, with general partners pursuing larger funds for personal gain, optimism leading to riskier investments, and the unpredictable growth of the fund ecosystem.

The studies by Cumming (2008) and Cumming et al. (2017) collectively highlight the influence of VC firms' control rights on the success of exits. Cumming (2008) finds that strong VC control rights significantly increase the likelihood of acquisitions, whereas weaker VC rights are correlated with more IPOs and business write-offs. Cumming et al. (2017) further find that IVCs are often associated with more successful exits than GVCs are.

Diller and Kaserer (2009b) emphasise the important role of fund inflows, influenced by unique characteristics such as illiquidity and segmentation. They confirm the 'money chasing deals' hypothesis, highlighting that fund inflows, together with general partners' skills and the stand-alone investment risk, are key factors affecting fund returns. The research also reveals a notable persistence in fund returns, suggesting a correlation between past and future performances.

In an empirical analysis of the exit mechanisms of UK VC firms, Espenlaub et al. (2015) show a distinct preference for mergers and acquisitions (M&As) over IPOs in domestic exits, a trend that diverges from international exit strategies. This pattern is attributed to a confluence of factors: the VC firm's experience, the maturity and scale of the VC fund, prevailing market conditions, and the legal framework in the origin country of the portfolio company.

5.9 Future research directions

Building on a nuanced examination of research on VC investments in Europe, this study lays the groundwork for understanding the complex interplay between various determinants affecting investment behaviours and outcomes. The following section outlines potential avenues for future research, with a particular focus on areas that have not been sufficiently explored.

5.9.1 Research avenue 1: The role of policy, GVCs, and culture as stable drivers in the European VC market

Our analysis offers nuanced insights into the role of policy and particularly GVCs as stable drivers of the European VC market. The body of research by Revest and Sapio (2012), Grilli (2014), Bertoni et al. (2019), Buzzacchi et al. (2013), Alperovych et al. (2020), and Grilli and Murtinu (2014) presents a comprehensive understanding of the pivotal role of policy instruments, such as certification, signalling, and R&D tax incentives, in shaping the VC landscape, with the consensus that GVCs can activate PVC investment in sectors and regions that may otherwise be overlooked. Nevertheless, we lack knowledge about the nuanced effects of regulatory changes on VC activities. Hence, future research should examine the influences of tax laws, investment regulations, and cross-border agreements on investments, and how the signalling effect of GVCs influences the decision-making process of IVCs, particularly in the high-risk early stages. It will be crucial to assess both the supply-side and demand-side effects of government involvement, understanding how policy can either stimulate or inhibit private investment.

In addition, Grilli and Murtinu (2014) and Guerini and Quas (2016) highlight the distinct roles of GVCs in Europe, where they enhance firm growth mainly as non-leading syndicate partners and significantly bolster the chances of securing private VC through a certification effect. Bertoni et al. (2015, 2019) further confirm the crowding-in effect of governmental VC on private investments, indicating the strategic importance of GVC in attracting additional funding for ventures. Exploring effective synergies among different investor types (IVCs and PVCs, BVCs, CVCs, GVCs) to enhance start-ups' growth strategies is an untapped area. Research should focus on how these investors can form syndicates that match start-ups' goals and market niches. It should also probe the complexity of creating international syndicates in Europe's diverse market, considering cultural, legal, and economic

differences to foster successful investments. The aim should be to craft guidelines for forming cross-border investment syndicates that optimise the unique capabilities of diverse investor groups.

Research has also emphasised the influence of cultural dynamics on VC investments. As shown by Groh et al. (2010), Wuebker et al. (2015), and Tyebjee and Vickery (1988), cultural attitudes towards risk and innovation play a critical role in shaping VC, with national cultures influencing the propensity for entrepreneurship and, consequently, the success of the risk capital sector. Therefore, an in-depth exploration of how Europe's cultural diversity affects entrepreneurial initiatives and VC patterns would be valuable for understanding how to overcome potential cultural boundaries and improve entrepreneurial activities and VC investment activities.

5.9.2 Research avenue 2: The equity gap and sector-specific trends in the European VC market

Our analysis points to the equity gap in Europe and draws attention to its impact on venture growth stages. Groh et al. (2010) uncover a paradox in the European private equity sector, where funds available surpass investment amounts, yet a critical equity gap hinders the progression of start-ups into high-growth firms. Quas et al. (2022) emphasise the dangers of this gap, such as the risk of losing technology and talent to the United States as European unicorns relocate or list on US exchanges, potentially diminishing the EU's global tech influence. Their findings, which are in line with those of Balboa et al. (2017), also highlight the lack of focus on the scale-up phase, which is key for company growth and is significantly hampered by the equity gap. Given the importance of the equity gap for the scaling up of ventures, a more detailed scientific investigation of this phenomenon, its causes, and its solutions is also essential.

In addition to a lack of research on the equity gap, we note that the complexity of the European market has led to overgeneralisation in study outcomes (Huber Ooghe et al., 1991). It has been established that capital inflows have a positive impact on syndication and co-investments, which are essential for sustained deal flow and shared risk management as individual industries mature (Huber Ooghe et al., 1991). In addition, sectors with a higher inclination towards risk tend to offer higher returns (Groh et al., 2010; Tyebjee & Vickery, 1988; Henrekson & Sanandaji, 2018). To address the generalisation issue, future research should focus on detailed sector-specific analyses within distinct European regions. This approach will uncover the unique challenges and opportunities of different sectors and how they attract VC investments. Further, the importance of syndication and its role in attracting co-investments as industries evolve warrants a closer examination.

5.9.3 Research avenue 3: The role of international investors in the European VC market

Our analysis of the research on international investors in Europe emphasises that capital inflows from global investors into Europe have been on the rise, with considerable private equity funds sourced from North America and the Asia-Pacific region, as reported by Invest Europe (2023) and supported by earlier studies (Imad'Eddine & Schwienbacher, 2013; Manigart et al., 2000; Meuleman & Wright, 2011). However, research by Devigne et al. (2016), for example, also underscores the distinct behaviours of domestic and international VC investors in Europe. Domestic venture capitalists are more prone to escalating commitment to underperforming investments than their international counterparts, who seem less influenced by social or emotional ties to the portfolio firms. Future studies should further elaborate on these distinct behaviours and their consequences for the success of the investment targets. They should also focus on the impact of non-European investors on the European VC market and the geopolitical nuances that shape these cross-border investments. Understanding how international capital contributes to the European investment ecosystem

will be vital, as will exploring strategies for optimising international investments within Europe, such as ways to transcend national borders more effectively.

5.9.4 Research avenue 4: The role of time, location, and effective DD in investment decision-making

Our analysis, in particular that of the contributions of Petty and Gruber (2011), Karsai et al. (1998), and Wuebker et al. (2015), indicates a need for further research to unravel the evolution of decision-making processes across the lifecycle of investment funds and probe the changing decision dynamics over time that precipitate such changes. This exploration will need to dissect the heterogeneity of decision-making across different investor types. In addition to the important role of time in investment decision-making, research by Colombo et al. (2019), Bottazzi et al. (2016), and Bertoni et al. (2015) underscores the importance of location, or proximity, highlighting a decrease in the influence of distance on VC investment decisions for certain investor types. Future research should therefore examine the evolving dynamics of the relationship between proximity and investment decisions in the post-COVID-19 era, where remote interactions have become more prevalent.

Additionally, a pressing area of research focuses on the effectiveness – or the lack thereof – of DD procedures conducted by external agents in contrast to those conducted by fund managers, as shown by Cumming and Zambelli (2017). Further research should seek to understand the difference in outcomes between DDs performed by externally providers and those performed internally and develop methodologies to enhance the effectiveness of these evaluations. These research outcomes will have important implications not only for fund management but also for the consulting and banking sectors.

5.9.5 Research avenue 5: Investment target performance and exit strategies in the European VC market

Our analysis of studies on target performance during the holding period and at the point of exit highlights the need for more research on exit strategies in the European VC market. Although studies such as those by Falconieri et al. (2019) and Espenlaub et al. (2015) offer initial insights into exit strategies and their outcomes in the European VC market by pointing to the profound effects of syndicate composition and regional market characteristics on post-IPO performance and exit preferences, they also suggest that exit strategies are complex. In particular, future research should explore how VC firms' value addition strategies during the holding phase, such as strategic guidance and operational improvements, affect the growth and scalability of investee companies. Research should also examine the balance between investor involvement and target company autonomy that optimises performance while preserving entrepreneurial independence.

In addition, Falconieri et al. (2019) observe that firms backed by large and diverse VC syndicates tend to underperform after an IPO. Espenlaub et al. (2015) reveal a marked preference for M&As over IPOs for domestic exits within the United Kingdom, influenced by the experience of the VC firm, the maturity and size of the fund, and market and legal conditions. Therefore, further research is needed to explore exit strategy trends across Europe and how they compare with global practices. Investigating the factors that contribute to successful exits in different European countries and sectors could provide valuable insights for VC firms and entrepreneurs alike.

5.10 Conclusion

Our research into the VC ecosystem in Europe addressed three primary research questions, offering insights into the complex dynamics that define the sector. First, we

investigated the principal drivers behind VC investments in Europe. Our SLR revealed that VC investments are influenced by a constellation of factors, prominently including the regulatory environment, economic conditions, and the foundational role of trust and social networks. Studies by Groh et al. (2010) and Bottazzi et al. (2016) underscore the complex interplay between these factors, highlighting how legal frameworks and market conditions serve not only as barriers but also as catalysts for VC flows. This multifaceted landscape requires venture capitalists to adopt a nuanced approach that balances risk and opportunity in their investment decisions.

Second, we examined the determinants influencing investment strategies and syndicate formation. The identified drivers significantly shape investment strategies and the propensity for syndicate formation. The collective expertise and risk sharing facilitated by syndicates are deemed essential for navigating the complexities of the VC market. The literature, for example, Cumming et al. (2010), has elucidated the strategic rationale for syndication, emphasising its role in mitigating the uncertainties inherent in VC investments. This collaborative investment approach is indicative of a broader trend towards leveraging collective wisdom and resources to mitigate the inherent risks of early-stage financing.

Third, we analysed the impact of these investments on companies throughout the investment cycle, leading up to the exit phase. VC investments exert a transformative impact on investee companies, guiding them through growth trajectories that culminate in successful exits. Research, exemplified by Falconieri et al. (2019) and Espenlaub et al. (2015), has articulated the pivotal influence of VC in enhancing the operational, financial, and strategic facets of investee companies. The strategic guidance and network access provided by venture capitalists are instrumental in realising the market potential of the investee companies, underscoring the critical role of VC in steering companies towards lucrative exit strategies.

By addressing these research questions, this paper contributes to the scholarly discourse on VC, providing a comprehensive overview of the factors influencing VC activities in Europe and their implications for investee companies. The findings underscore the complexity of the VC ecosystem, highlighting the nuanced interplay between regulatory environments, market dynamics, and the strategic conduct of venture capitalists. Future research should explore the mechanisms through which regulatory changes and international investment dynamics influence the European venture capital ecosystem, particularly focussing on the integration and effectiveness of cross-border syndication and the evolving impact of digital transformation on investment decision-making processes, and addressing the scale-up gap that hinders the growth of high-potential start-ups into globally competitive firms.

6. Dual-Use or Omni-Use? Rethinking Technology in a Borderless World

(Study II)

Title	Dual-Use or Omni-Use? Rethinking Technology in a Borderless World
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Publication	Research Policy
Status	Revise and resubmit, revision in progress

6.1 Abstract

As technology advances, the traditional dual-use classification, originally designed to distinguish between civilian and military applications, presents substantial challenges for stakeholders navigating modern, versatile innovations. This paper examines the obstacles inherent in the dual-use concept within today’s rapidly evolving landscape of ‘omni-use’ technologies, which seamlessly span across sectors with minimal adaptation. By analysing resource constraints, structural barriers, and perceptual complexity, this study highlights the limitations of current governance structures for dual-use technologies. Drawing on 32 semi-structured interviews with venture capitalists, government representatives, military officials, academics, and entrepreneurs, we examine how these barriers hinder technology transfer, complicate public–private partnerships, and stifle investment in dual-use startups. The findings indicate that the rigid dual-use classification not only restricts innovation but also creates ethical and security dilemmas across diverse sectors. Set within the European context, this study places particular emphasis on Germany, positioning it as a critical case study in

navigating dual-use challenges. This paper advocates for adaptive governance models that accommodate the cross-sectoral and dynamic nature of omni-use technologies, offering a roadmap to effectively manage these technologies in an increasingly interconnected world.

6.2 *Introduction*

Technological innovation increasingly transcends traditional boundaries, with many advancements covering both civilian and military domains. Historically framed within the concept of ‘dual-use’, technologies serving both civilian and military applications have recently become central to governance debates (Malik, 2018a; Molas-Gallart & Sinclair, 1999). However, the rapid convergence of sectors driven by artificial intelligence (AI), biotechnology, and advanced materials highlights the limitations of this classification. These innovations often exhibit ‘omni-use’ characteristics, transitioning seamlessly across applications with minimal adaptation (Vaynman & Volpe, 2023). This transformation indicates the need for governance frameworks that can accommodate technologies resisting narrow categorisation.

The dual-use concept, while fundamental in shaping technology governance, now struggles to accommodate modern complexities. Evolving technologies blur traditional boundaries, necessitating adaptive governance to address ethical and regulatory challenges. Rigid frameworks designed to control sensitive technologies have inadvertently stifled innovation and complicated market access (Chen et al., 2021). Regulatory inconsistencies, coupled with ethical dilemmas, further challenge stakeholders, including policymakers, venture capitalists, and entrepreneurs, who must navigate fragmented and often contradictory systems (Quas et al., 2022; Ulnicane et al., 2023). The ethical dimensions of dual-use technology development require a balanced approach that safeguards societal interests while fostering innovation (Stilgoe et al., 2013; Ulnicane et al., 2023).

Investment challenges further compound these problems. Dual-use startups often encounter a ‘valley of death’, struggling to secure early-stage and scale-up funding amid regulatory uncertainty and ethical scrutiny (Alperovych et al., 2020; Quas et al., 2022). Venture capitalists hesitate to invest because of long development cycles, high compliance costs, and reputational risks (Adner, 2006; Leleux & Surlemont, 2003). These dynamics disproportionately affect small firms, which lack resources to navigate complex governance landscapes or attract large-scale investment (Grilli & Murtinu, 2014).

This study focuses on Europe, with Germany serving as a key example of the challenges and opportunities associated with dual-use technologies. It examines the limitations of the dual-use framework and advocates for a transition towards ‘omni-use’ governance models. Specifically, this study addresses the following research question: *What challenges does the dual-use classification pose for modern omni-use technologies, and how do these barriers affect ethical, regulatory, and financial frameworks in civilian and military applications?*

Drawing on insights from 32 semi-structured interviews with stakeholders and integrating findings from the key literature, this study provides a roadmap for managing the dynamic and cross-sectoral nature of omni-use technologies.

By reframing dual-use technologies within the broader context of omni-use, this paper contributes to the growing discourse on responsible innovation, adaptive governance, and cross-sector collaboration (Ulnicane et al., 2023). It highlights the urgency of bridging regulatory, financial, and ethical gaps to unlock the transformative potential of emerging technologies in a globally interconnected landscape.

6.3 *Theoretical Context*

This section provides a comprehensive overview of the dual-use concept and the challenges within this concept and ecosystem, highlighting the multi-faceted nature of dual-use technologies and their implications for investment and regulation. The literature on dual-use technologies often lacks depth, primarily focusing on technical aspects such as military-to-civilian knowledge spillovers (Caviggioli et al., 2023) while overlooking policy and economic dimensions. This narrow scope results in an incomplete understanding. However, more recent approaches, such as the Responsible Research and Innovation framework by Ulnicane et al. (2023), offer a broader perspective by integrating ethical and societal considerations into dual-use research.

6.3.1 Definition of Dual-use

The absence of a universally accepted definition of ‘dual-use technologies’ presents significant challenges. The term ‘dual-use’ is ambiguous, lacks precision, and fails to capture the complexities of interactions between commercial and defence sectors (Fiott, 2014). At a low technology readiness level¹, the future applications of research are often uncertain, making it difficult to determine whether a technology is primarily civilian or defence-oriented from the outset (European Commission, 2024b). This uncertainty complicates early-stage regulatory efforts and risk assessments because the dual-use potential of a technology may not yet be evident. Simultaneously, the rapid pace of technological advancements necessitates continuous revisions to definitions and regulatory frameworks to keep up with new dual-use applications (Ramses, 2022).

¹ The Technology Readiness Level (TRL) is a systematic scale developed by NASA to evaluate the maturity of a technology, ranging from conceptual research (TRL 1) to proven operational use (TRL 9) (Yfanti & Sakkas, 2024).

The expansion of dual-use technologies has accelerated, particularly with advancements in biotechnology, information technology, AI, and advanced materials. The democratisation of science, through open access and decentralised technological development, has raised concerns regarding the potential misuse of these technologies by non-state actors and DIY biology communities (Douglas & Savulescu, 2010).

As the global landscape for dual-use technology evolves, traditional governance frameworks struggle to keep pace with the increasing complexity and scope of emerging risks. The fluid nature of technological development necessitates definitions that account for the rapid transition of technologies between civilian and military applications, further complicating regulatory and monitoring efforts (Vaynman & Volpe, 2023). Vaynman & Volpe (2023) assert that ‘almost all technology is dual-use to some degree: it has both civilian and military applications’ (p. 1).

6.3.2 The Dual-Use Dilemma

The dual-use dilemma involves balancing technological innovation with security concerns, given the potential for technologies to be repurposed for harmful applications (Kanetake, 2018; Kuhlau et al., 2013). It is fundamentally an ethical issue. For instance, the development of highly virulent pathogens in civilian research settings presents a substantial biosecurity risk (Atlas & Dando, 2006; Carrozza et al., 2022; Harris et al., 2016).

Recent findings suggest that emerging dual-use technologies may not hinder but facilitate access to weapons of mass destruction or even weapons of total destruction (Zimmer et al., 2024). As modern technologies continue to advance, the risks associated with their misuse grow substantially, making the ethical and security concerns surrounding dual-use technologies even more pressing.

6.3.3 The Dual-Use Investment Ecosystem

The investment landscape for dual-use technologies is fraught with complexities, particularly in mobilising resources for applications that balance military and civilian needs (Malik, 2018a; Meng & Wang, 2023). The European Union (EU) faces significant challenges in mobilising resources (Calcara et al., 2020; European Commission, 2024b). At the European level, funding decisions must carefully weigh scientific importance against associated risks, a process complicated by differing national priorities and security concerns (Imperiale & Casadevall, 2018). Private investors are often hesitant to commit capital to ventures with high regulatory burdens and long development cycles, particularly when government involvement may slow the commercialisation of these technologies (Adner, 2006; Harris et al., 2016). Investment in dual-use technologies is particularly impacted by geopolitical instability, which often deters venture capital due to the unpredictable nature of returns (Kraemer-Eis et al., 2024). Public venture capital plays a critical role in de-risking investments for high-risk and dual-use startups, acting as a catalyst for private investment through syndication and co-investment models (Alperovych et al., 2020; Grilli & Murtinu, 2014). The European Investment Bank indicates the importance of using public resources to attract private funding for disruptive technologies, particularly in industries where high initial costs and regulatory complexities create significant barriers. This ‘seeding effect’, as described by Leleux & Surlemont (2003) demonstrates how public funding bodies taking the lead can stimulate private sector involvement, bridging capital gaps and fostering innovation.

The lack of early public-sector adopters delays commercialisation, leaving the EU behind other regions in capitalising on these technologies (European Commission, 2024b). Without committed customers, particularly government entities, market uptake of dual-use technologies remains slow, discouraging development, deployment, and investment. This

results in underfunding, high loan rates, and short-term financing, especially for high-tech projects with long payback periods (Kundu et al., 2020).

Large firms with significant military sales are better positioned to invest in dual-use technologies due to their greater access to resources and capital (Acosta et al., 2018). This disparity highlights the need for targeted support to enable smaller entities to participate in dual-use technology development. The European Commission (2014) emphasises the importance of clear strategies and guidance to help SMEs and regional authorities navigate funding opportunities effectively. Its roadmap addresses existing capital gaps, particularly for SMEs and startups, by extending initiatives such as the European Tech Champions Initiative to bridge these gaps and strengthen support for dual-use technologies (European Investment Bank, 2024).

6.3.4 The Regulatory Environment

International cooperation is essential for regulating dual-use technologies but remains inherently challenging due to conflicting national interests and security concerns. Effective regulation of dual-use technologies requires coordinated international efforts and adherence to multilateral agreements, which can be challenging to achieve (Kanetake, 2018; Kundu et al., 2020). The challenge lies in balancing stringent export controls with the need to support legitimate commercial and scientific activities (European Commission, 2024b). Geopolitical tensions, such as the ongoing war with Russia, further weaken the effectiveness of multilateral arms control agreements (European Commission, 2024a). The deep integration of dual-use technologies in civilian and military sectors increases the cost and complexity of monitoring and compliance (Casadevall et al., 2014; Vaynman & Volpe, 2023). Effective governance must not only prevent misuse of technologies but also foster scientific progress. This requires a shift from secrecy to openness, from restriction to enablement, and from

segregation to the integration of public discourse (Drew & Mueller-Doblies, 2017; Dubov, 2014).

6.4 Methods

6.4.1 Research Context

This study used a qualitative research design to investigate the complexities and challenges associated with dual-use technologies in Europe. A qualitative approach is well-suited for this type of exploratory research because it enables an in-depth understanding of complex, contextual, and dynamic phenomena (Flick, 2022). This study explored how various stakeholders, including venture capitalists, government bodies, military, industry experts, startups, and scholars, perceive and navigate these challenges.

6.4.2 Data Collection and Sample

Primary data were collected through semi-structured interviews with a diverse group of stakeholders. This method is effective for gathering rich, detailed insights from participants while allowing flexibility to explore emerging themes (Kvale & Brinkmann, 2009).

The interview guideline was developed following a comprehensive review of the literature on dual-use technologies, regulatory frameworks, and investment challenges. In addition, insights from unstructured interviews were incorporated to ensure that the questions addressed the most pressing issues in the field. The guideline consists of 32 questions divided into six thematic sections: (1) background information (e.g. expert's role and experience); (2) understanding dual-use technologies, focusing on the dual-use dilemma and its impact; (3) challenges in dual-use technologies, such as issues related to classification and ethical considerations; (4) regulatory and policy Issues, addressing both current regulations and future needs; (5) funding and investment, exploring opportunities and barriers for dual-use

startups; and (6) future trends and opportunities, examining the evolution and categorisation of dual-use technologies.

The final sample comprised 32 semi-structured interviews with participants from Germany (27), France (1), Belgium (1), Italy (1), the United Kingdom (1), and the Netherlands (1). The sample included the following stakeholders:

Prime Defence Contractors (n = 4, 12.5%): These participants provided insights into the practical challenges and strategic considerations specific to dual-use technologies within the defence industry.

Venture Capitalists (n = 5, 15.6%): Their perspectives helped in understanding the investment climate, risk assessment, and funding challenges associated with dual-use technologies.

Politicians (n = 6, 18.8%): Key policymakers provided insights into how political priorities and legislative efforts influence the regulation and promotion of dual-use technologies, particularly concerning national security and economic development.

Military Officials (n = 5, 15.6%): Personnel with military backgrounds provided perspectives on security concerns, strategic priorities, and the role of defence procurement in fostering dual-use technologies.

Dual-Use Entrepreneurs (n = 7, 21.9%): Innovators and business leaders engaged in dual-use technology development shared practical insights into market challenges, regulatory compliance, and innovation strategies.

Academic Experts (n = 5, 15.6%): Scholars with expertise in dual-use technologies, ethical considerations, and regulatory frameworks contributed theoretical and contextual knowledge.

The sample was selected using theoretical sampling, ensuring that participants provided diverse perspectives in key areas of dual-use technology application (Corbin &

Strauss, 2008). Each interview lasted between 40 and 90 minutes, allowing for an in-depth exploration of participants' experiences and viewpoints. The majority of interviews were conducted in German. To ensure the accuracy of translations into English, a systematic approach was employed, involving the use of professional translation software, verification of key terminology by native speakers, and iterative cross-referencing to preserve the semantic integrity of original responses.

In qualitative research methodologies, this study employed the concept of an 'extreme case', which is particularly valuable for determining the fundamental nature of challenges in a given context (Miles et al., 2014). Germany represents an extreme case within the EU due to its pronounced deficiencies in early and scale-up stage funding for dual-use technologies. These challenges include an underdeveloped venture capital ecosystem, bureaucratic delays in public funding, and the restrictive application of environmental, social, and governance (ESG) clauses, which systematically exclude defence-related innovations from major funding streams. In addition, Germany faces significant deficits in defence-related technology innovation and operates within highly rigid procurement processes. These limitations position Germany at the far end of the spectrum, contrasting sharply with other EU member states, which adopt varied approaches to these issues.

Examining an extreme case such as Germany provides various methodological advantages. Investigating a context where challenges are most pronounced provides deeper insights into their essence and underlying dynamics. Extreme cases serve as a lens through which structural and systemic obstacles become more visible, enabling the identification of broader themes that may be less apparent in moderate contexts (Miles et al., 2014). Focusing on Germany allows this study to reveal critical barriers in dual-use ecosystems, particularly at the intersection of regulatory, cultural, and financial constraints, offering a nuanced understanding of multifaceted challenges that hinder innovation and investment.

6.4.3 Additional Data Sources

In addition to the semi-structured interviews, unstructured interviews were conducted in the early stages of the study to explore initial assumptions and refine the study's focus. Unstructured interviews offer an open-ended, flexible approach that facilitates the discovery of new insights and helps identify key issues that may not have been initially anticipated (Bryman, 2016). Discussions with key stakeholders from the defence, technology, and regulatory sectors provided both depth and breadth, informing the development of the semi-structured interview guide. This approach aligns with the recommendation of Kvale & Brinkmann (2009) that unstructured interviews are particularly valuable for refining research instruments and ensuring that primary data collection addresses both relevant and emerging issues.

6.4.4 Data Analysis

The interview data were analysed using a thematic analysis approach, which enables the identification of themes across qualitative data (Miles et al., 2014). Thematic analysis was chosen for its flexibility and ability to uncover nuanced insights from the diverse perspectives of stakeholders involved in dual-use technologies. This method enabled a structured but adaptable analysis of complex issues, including regulatory challenges, ethical considerations, and investment hurdles, which are central to the study.

6.4.4.1 *Coding and Categorisation*

The analysis followed a structured process, beginning with open coding of all interview transcripts. This involved line-by-line coding of relevant text segments, focusing on key themes such as 'classification issues', 'regulatory barriers', 'funding challenges', and 'ethical concerns'. During this phase, codes were assigned based on both predefined themes drawn from the literature review and emergent themes identified within the data. Following

the recommendations of Corbin & Strauss (2024), this initial coding ensured that the analysis remained open to new insights while remaining grounded in theoretical foundations.

The Gioia diagram presented below provides a structured visualisation of the findings derived from this thematic analysis, illustrating the progression from first-order concepts to second-order themes and ultimately to aggregate dimensions. This framework captures the multi-layered challenges inherent in the dual-use technology ecosystem, elucidating the nuanced connections between the concerns of specific stakeholders and overarching dimensions of complexity (Gioia et al., 2013).

The thematic analysis adhered to a structured condensation logic, wherein first-order concepts, representing specific stakeholder concerns and observations, were systematically grouped into second-order themes. For instance, first-order concepts such as public funding delays, short-term investment focus, and ESG exclusion policies were consolidated under the second-order theme of investment challenges. Similarly, fragmented regulatory landscapes, inconsistent export regulations, and slow policy updates were aggregated into the second-order theme of regulatory and governance issues.

These second-order themes were subsequently condensed into aggregate dimensions, representing the highest level of abstraction. For example, the second-order themes investment challenges and market access barriers were grouped under the aggregate dimension of resource constraints. Likewise, regulatory and governance issues and ethical and moral concerns were integrated into the aggregate dimension of structural barriers. This hierarchical structuring not only clarified the relationships between specific concerns and broader themes but also provided a comprehensive framework for understanding the complexities of dual-use technology ecosystems.

The interconnectedness of the themes is evident in the manner by which second-order themes are linked within the same aggregate dimension. For instance, within the aggregate

dimension of resource constraints, the second-order theme of investment challenges is closely intertwined with market access barriers. This relationship highlights how financial constraints and limited market access collectively shape the dual-use technology ecosystem. Similarly, within the aggregate dimension of structural barriers, the second-order theme regulatory and governance issues is interconnected with ethical and moral concerns, illustrating how regulatory complexity and ethical dilemmas jointly influence governance challenges.

By mapping these relationships, the diagram not only traces the progression from specific concerns to broader themes but also indicates the interconnectedness of financial, regulatory, ethical, and cultural barriers. This comprehensive view provides valuable insights into factors shaping dual-use innovation and governance, offering a robust foundation for further analysis and policy development.

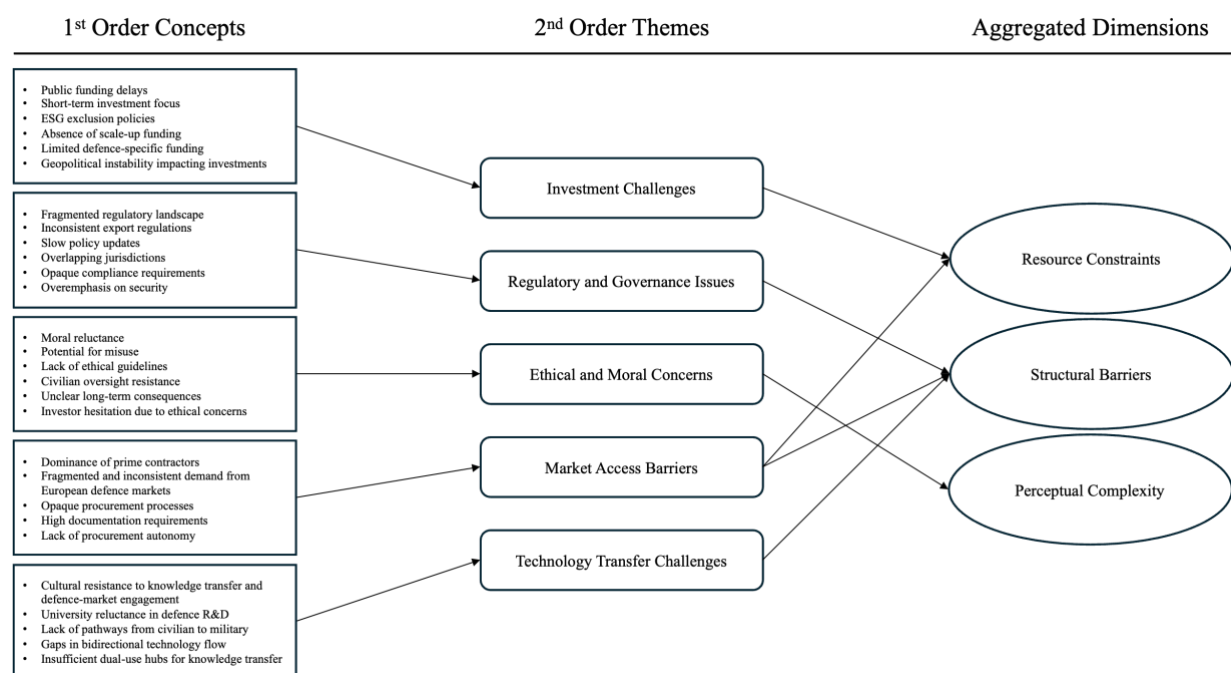


Figure 7: Gioia Diagram for Dual-Use Challenges (Gioia et al., 2013)

6.4.4.2 Quantitative Assessment of Dual-Use Challenge Severity

Building on the thematic development outlined in the previous section, this study performed a quantitative assessment to systematically evaluate the severity and impact of the identified challenges. This approach enabled a structured comparison of the most pressing

issues at the second-order theme level within the dual-use technology ecosystem, complementing the qualitative findings with numerical insights. The analysis was based on three key dimensions: frequency, pressingness, and sentiment intensity. Frequency indicates how often a particular challenge was raised across stakeholder interviews, whereas pressingness captures the perceived urgency of the challenge, assessed on a Likert scale ranging from one (low urgency) to five (high urgency). Sentiment intensity quantifies the emotional valence associated with each challenge, ranging from -2 (strongly negative) to $+2$ (strongly positive), distinguishing between issues perceived as barriers and those framed as opportunities.

To ensure methodological rigour, the overall weighted impact score for each challenge was computed by multiplying the three variables (frequency $\times$ pressingness $\times$ sentiment intensity). This calculation enabled the prioritisation of challenges based on their overall significance and the extent to which they influence stakeholder decision-making. By employing this structured approach, the study translated qualitative insights into measurable constructs, facilitating a more robust assessment of the dual-use landscape.

To enhance transparency, the assignment of pressingness and sentiment intensity scores was conducted using software-based text analysis tools, ensuring an objective and replicable evaluation process. These assessments were derived from a detailed computational analysis of 32 semi-structured interviews, using natural language processing techniques to extract and quantify sentiment, urgency, and frequency. The evaluation of pressingness was based on explicit indicators of urgency within textual data, identifying whether stakeholders framed a given issue as an immediate obstacle, a growing concern, or a long-term challenge. Sentiment intensity was assigned algorithmically, categorising discourse as predominantly negative, neutral, or positive based on predefined linguistic parameters. These codings were validated through automated cross-referencing and consistency checks, minimising subjective

bias and ensuring methodological robustness. This framework systematically transforms subjective narratives into structured and comparable measures.

6.4.4.3 Validation

To enhance the robustness of the findings, this study conducted triangulation by cross-referencing interview data with secondary sources, including policy papers and the academic literature on dual-use technologies (Flick, 2022). In addition, the findings were validated through expert feedback, where preliminary themes and conclusions were presented to five domain experts from the semi-structured interviews for their insights and critiques. This validation process helped refine the themes and ensured that the analysis remained accurate and relevant to current industry and policy debates.

6.4.4.4 Data Management and Software Tools

All interview transcripts were managed using MAXQDA qualitative analysis software, which facilitated the organisation and retrieval of coded data. MAXQDA was effective in managing the large volume of qualitative data and maintaining a clear audit trail throughout the analysis.

6.5 Findings

This section explores the key themes, structured alongside the aggregated dimensions and second-order themes, that emerged from interviews with all stakeholders. It highlights the investment challenges, market access barriers, regulatory and governance issues, technology transfer challenges, and ethical and moral concerns that shape the dual-use landscape. To provide further context and support for these findings, Table 7 in the Appendix presents a selection of interviewee quotes, illustrating how their perspectives align with the identified second-order themes and aggregate dimensions. These quotes serve as direct evidence, reinforcing the analysis and adding depth to the discussion.

6.5.1 Resource Constraints

Resource constraints include both investment challenges and market access barriers because these themes highlight the financial and structural limitations that hinder funding access and restrict procurement opportunities for emerging dual-use technologies.

6.5.1.1 *Investment Challenges*

As a core element of Resource Constraints, these financial barriers highlight the challenges in securing stable investment streams for dual-use technologies. The sector's heavy reliance on public funding mechanisms, driven by the lack of private capital, further underscores the structural funding gap that restricts growth and innovation.

Investment Fatigue: A major barrier to the commercialisation of dual-use technologies is investor reluctance, affecting both governmental venture capitalists and private venture capitalists. This hesitance is driven by ethical concerns, compliance complexities, reputational risks, uncertain commercial outcomes (due to dependence on geopolitical shifts), and perceived long-term risks. ESG clauses, which restrict investment in military-related industries, further deter funding for dual-use technologies, leading to their systematic exclusion from many investment portfolios. One interviewee highlighted this challenge, stating 'Due to ESG regulations, most generalist funds are not able to invest in dual-use technologies. This can also not be changed easily' (VC 5). Another interviewee noted that the dual-use classification itself is sometimes used as a pretext to slow decision-making and justify inaction because investors avoid associations with military-related products or services to mitigate brand and reputational risks (VC 2). Thus, despite their societal and economic potential, dual-use technologies are excluded from large pools of venture capital.

Dependence on Public Funding: Given the aforementioned constraints in private investment, startups often turn to public funding sources such as the European Innovation

Council. Public funds are generally more receptive to dual-use technologies, recognising their national security benefits. However, accessing these funds requires startups to meet stringent criteria, including clear distinctions between civilian and military applications. This reliance on public funding imposes additional compliance burdens and tends to prioritise early-stage development, leaving a financing gap at later stages when companies need to scale. Several dual-use founders (Startup 1, Startup 3, Startup 4) have criticised the extended timelines associated with public funding, noting that these delays present significant challenges. The lengthy process, often spanning months or even years from initial application to disbursement, creates substantial difficulties for startups that depend on timely financial support to sustain momentum and maintain a competitive edge.

Funding Gaps and Regulatory Barriers: The complex regulatory environment further exacerbates the funding gap, particularly during the transition from seed funding to later-stage investments (e.g. Series A or B). This ‘valley of death’ leaves many dual-use startups vulnerable. While some specialised venture capital firms focus on defence technologies, they remain limited in number and capital volume. This creates a challenging landscape for startups because one dual-use startup founder mentioned that a young company needs to raise massive amounts of money to grow to a considerable size first, before even being in the position to be seriously considered by primes or governmental entities for collaboration. However, this also creates massive financial pressure within the young company (Startup 2).

Ethical Concerns and Discrimination: Ethical concerns, particularly regarding potential military applications, deter many investors from engaging with dual-use startups. In addition, discriminatory conditions in terms and valuations are frequently imposed by both venture capital firms and banks, further restricting access to capital. One founder highlighted these challenges, stating ‘We realised two extremes fairly quickly when speaking about the

dual-use potential for our technology. “Old” established institutions like banks still massively devalue your ideas the moment you mention dual-use potential, placing you in the same risk category as prostitution and gambling. Essentially, they don’t want to work with you’ (Startup 7).

6.5.1.2 Market Access Barriers

Market access barriers fall under resource constraints because funding access and procurement opportunities remain limited for non-established players. Furthermore, the fragmented and inconsistent demand across European defence markets creates additional challenges, making it difficult for firms to scale their technologies across different national ecosystems.

Barriers to Innovation in the Defence Sector: Startups face significant barriers to entering the defence market due to the dominance of prime contractors such as Rheinmetall and Airbus, which act as innovation gatekeepers. One interviewee noted, ‘Our procurement system is built for established prime suppliers, not young companies...’ (Military 3). This dominance often restricts opportunities for smaller firms to lead projects, relegating them to subcontracting roles and limiting their ability to drive innovation. Despite these challenges, multiple interviewees noted that the current geopolitical landscape, including war in Europe and the likely reduction of US military presence in the region, has created new opportunities for dual-use startups to fill critical gaps, even as primes continue to hinder new market entrants. One venture capitalist emphasised this point, stating ‘The market opportunities for dual-use companies are currently better than ever. The geopolitical situation is creating increasing tensions, and the US as protector of the EU is stepping back, demanding that European NATO members take care of themselves (...)’ (VC 4).

Procurement Processes: Procurement processes represent another significant barrier for startups. The current system is slow, opaque, and heavily bureaucratic, requiring startups

to navigate complex paperwork and compliance requirements without the dedicated legal teams that larger businesses possess, making it an almost impossible task. These rigid frameworks delay the development, validation, and scaling of new technologies. One interviewee noted that to survive these long timelines, ‘being dual-use and having civil income streams is a mere necessity for young companies’ (Military 3).

The lack of sufficient communication channels between startups and government or military institutions further exacerbates these challenges. A government interviewee acknowledged this shortcoming, stating self-critically, ‘There are still no sufficient communication channels established between young companies and the government or the military. This would have to be the first step in order to remove the existing barriers’ (Scholar 4). Addressing these systemic issues will require meaningful procurement reforms and stronger partnerships between governments and the private sector to unlock the full potential of innovation in dual-use and defence technologies.

Additionally, interviewees advocated the need for greater procurement autonomy within European armies, similar to the US system. One interviewee remarked, ‘Some armies within NATO have much more flexible procurement autonomy than others, which is a big factor in the differing levels of innovation within various militaries’ (Military 4).

Decentralising the procurement process would reduce barriers for startups, allowing for a more inclusive and dynamic innovation ecosystem. By granting military divisions greater autonomy, startups could better navigate procurement volumes and guarantees, fostering an environment that supports innovation at all levels. A procurement specialist further highlighted structural inefficiencies within the German procurement system, explaining that although faster and leaner procurement tools exist, government officials rarely use them due to a lack of incentivisation. ‘Because of that, they stick to what they know – bureaucracy and prime suppliers’ (Scholar 2).

6.5.2 Structural Barriers

Structural barriers are shaped by regulatory and governance issues, market access barriers, and technology transfer challenges because these factors impose systemic constraints that hinder the development and integration of dual-use technologies. While market access barriers are primarily linked to resource constraints, they also contribute to structural barriers due to overlapping regulatory complexities and procurement restrictions. The dual positioning of market access barriers highlights how financial and administrative hurdles collectively affect firms' ability to enter and scale in the defence sector.

6.5.2.1 *Regulatory and Governance Issues*

Regulatory barriers introduce compliance complexities and slow market entry, making it difficult for new entrants to establish themselves in the defence sector. The fragmented regulatory landscape poses an additional challenge for dual-use technologies because overlapping jurisdictions, inconsistent export regulations, and slow policy updates create a complex environment where firms struggle to navigate compliance requirements effectively.

Regulatory Complexity: Dual-use companies encounter significant challenges when attempting to enter both military and civilian markets. The divergent regulatory frameworks governing these sectors add layers of complexity to market entry. Civilian markets prioritise safety, consumer protection, and commercial viability, whereas the military sector emphasises security, confidentiality, and defence procurement compliance. Navigating these distinct regulatory regimes requires extensive resources, including dedicated legal and regulatory teams, which are often unavailable to startups. In fact, multiple participants expressed the view that complying with procurement requirements, processes, and documentation is impossible for small companies (Startup 2, Startup 3, Startup 6).

Inconsistent Definitions of Dual-use: A key regulatory challenge for dual-use technologies is the lack of a universally accepted definition across countries and regions. This

inconsistency complicates compliance because companies must navigate varying regulatory regimes depending on their geographic location. Even within the EU, different funding bodies and regulatory agencies apply divergent definitions, creating confusion. This fragmented regulatory environment discourages investment and stifles innovation because companies are forced to allocate disproportionate resources to legal compliance rather than technology development. One interviewee remarked, ‘If we can’t find a way to define it in a unified way, there is no point in having such a concept as dual-use at all’ (Government & Politicians 2). The lack of definitional clarity frequently leads to prolonged debates over the ethical and practical implications of dual-use strategies, delaying collaborations and investments and complicating market entry.

This issue appears more pronounced in Germany, whereas countries such as France place less emphasis on the term. One interviewee noted, ‘I find it really interesting how the use of dual-use as well as how it is discussed differs considerably across countries. While in most countries, dual-use is either not discussed at all because there is a general understanding that today’s technologies are all omni-use or it is viewed positively as an opportunity to leverage R&D efforts from the civil market into defence applications while boosting national safety, it seems to be a Central European phenomenon to see it as highly critical or negative. There is an attempt to categorise it into pre-defined boxes that do not really fit, and then regulate it, which is mostly delusional and does not work either way’ (Scholar 5). This regional specificity suggests that historical, political, and societal factors influence the discourse, further complicating efforts to establish consistent regulatory frameworks.

In today’s technological landscape, the concept of dual-use is becoming increasingly obsolete. Modern technologies can now be transferred across various applications with minimal modification, making traditional classifications impractical. What were once considered dual-use technologies are now omni-use, highlighting the limitations of rigid

classifications. One interviewee emphasised this point stating, ‘Today’s technologies are Deep-Tech, and Deep-Tech is Omni-Use. The concept of dual-use in the context of today’s technologies is nonsense’ (Prime 2).

Experts across the defence industry and specialised venture capital sectors largely agreed that the term ‘dual-use’ has become redundant (VC 2, Prime 2, Government and Politicians 5). Technologies involved in defence are ultimately subject to military standards and regulations, making the dual-use designation irrelevant because military requirements inevitably shape their development and application.

Navigating Complex Export Regulations: Startups developing dual-use technologies face significant challenges in complying with stringent export regulations, particularly within the EU. These regulations, designed to prevent sensitive technologies from reaching hostile regions, impose a heavy compliance burden, diverting resources from innovation and slowing product development. The complexity and cost of navigating multiple national and international regulations can delay or even halt market entry, especially for smaller companies. One interviewee questioned the integrity of the EU’s dual-use export list, stating, ‘And then, if you look at the actual dual-use export list of the EU, much more than any actual fact-based evaluation, it appears to me very clearly that the products and items on this list are mostly politically driven rather than technology-based. For most products on there, like cyber surveillance or even 3D printing technologies, the decisions have mainly been driven by political agendas’ (Scholar 3).

6.5.2.2 Technology Transfer Challenges

The interviews frequently emphasised the bidirectional flow of technology between military and civilian sectors. Innovations originally developed for military purposes have often been adapted for civilian applications, and vice versa. These challenges are embedded

within Structural Barriers because institutional constraints limit formal mechanisms for technology integration.

Collaboration with Universities: Universities play a crucial role in innovation ecosystems, particularly in the development of dual-use technologies. Public–private partnerships between universities and industry have become increasingly important, particularly in advanced fields such as AI and cybersecurity. These collaborations facilitate the development and transfer of cutting-edge technologies that can be applied in both civilian and military contexts.

However, despite the advantages of university partnerships, several challenges hinder collaboration. Universities often hesitate to engage with defence-related projects due to ethical concerns and public relations risks. This reluctance creates a significant barrier to innovation, particularly in sensitive technology areas. The hesitation of universities to fully commit to defence-related partnerships slows down knowledge transfer and inhibits the development of critical technologies. Multiple interviewees identified civil clauses² as a major barrier because these clauses actively restrict many universities from engaging in defence-related research (Military 5, Scholar 2, Scholar 4).

Despite these challenges, universities are in a unique position to bridge the gap between fundamental research and commercial or governmental application, playing an essential role in the innovation ecosystem for dual-use technologies.

Military and Civilian Technology Transfer: The interviews frequently emphasised the bidirectional flow of technology between military and civilian sectors. Innovations

² Civil clauses (*Zivilklauseln*) are agreements or commitments adopted by some universities to ensure that their research and teaching activities are limited to civilian purposes, explicitly excluding any involvement in military applications or defence projects. Although these clauses are not legally mandated and are typically implemented at the institutional level, they often reflect societal and political attitudes. They wield significant political influence, shaping public discourse on the role of academic institutions in defence-related innovation and potentially impacting broader defence policy debates.

originally developed for military purposes have often been adapted for civilian applications, and vice versa. Currently, civilian sectors are innovating at a faster pace, necessitating efficient structures that promote seamless knowledge transfer from civilian to military applications. While this challenge is widely acknowledged, interviewees noted that the necessary structures to support effective technology transfer are lacking (Military 2).

Role of Innovation Hubs: Several interviews highlighted the importance of innovation hubs in supporting dual-use technologies (Government and Politicians 5, Military 4). These hubs provide critical funding and networking opportunities for startups; however, eligibility often depends on a clear and precise definition of the dual-use nature of the technology. Interview participants also pointed to the limited availability of innovation hubs specifically dedicated to dual-use technologies and the inadequate scale and scope of existing hubs, which fail to effectively support dual-use innovation and commercialisation. One interviewee noted, ‘...meanwhile, there are dual-use innovation hubs and clusters that are massively underfunded, and their scale is by orders of magnitude too small to make any meaningful difference’ (Military 4).

Risk Aversion in Technology Transfer: Another recurring theme across the discussions was the pervasive risk-averse culture, particularly in regions such as Germany. This risk aversion significantly hinders the transfer of technologies, especially in ecosystems where innovation is most needed. Industry leaders noted that the hesitancy to embrace dual-use technologies limits the potential for disruptive innovations to reach the market. This cultural barrier creates an environment where potential breakthroughs are delayed or stifled due to the unwillingness of ecosystems to manage the perceived risks associated with military technologies (Scholar 2, VC 2).

Prime Contractors as Gatekeepers: The interviews also highlighted that established companies often act as gatekeepers in the technology transfer process. These larger firms can

either facilitate or obstruct the flow of innovative dual-use technologies, depending on their strategic interests. For smaller firms and startups, this dynamic presents both opportunities and challenges. Collaborating with established players can accelerate technology transfer and provide market access. By contrast, larger firms may choose to restrict or slow the adoption of certain innovations that could disrupt their market position (Startup 3, Startup 6, Prime 2, Prime 3).

Cultural Resistance: Cultural resistance is deeply rooted in long-standing mindsets and norms, hindering collaboration, investment, and openness to innovation. One interviewee noted, ‘For decades, defence research was classified as unethical, and its attractiveness was systematically decreased by burying it with regulation’ (Government and Politicians 6). Policymakers often prioritise regulatory constraints over developing frameworks that support cross-sector collaboration, thereby limiting innovation opportunities. While startups tend to be more open to defence applications, they still face internal resistance due to reputational concerns and unfamiliarity with the sector, preventing them from fully capitalising on dual-use opportunities. One interviewee expressed this hesitation, stating, ‘We do know that our technology and products have the potential for dual-use, but due to the negative stigma surrounding everything dual-use or military-related, we never really dared to mention it externally. We fear the consequences from our current investors or the impact on our ability to apply for government funding if we were classified as dual-use’ (Startup 4). A cultural shift across various domains is necessary to establish and sustain effective innovation ecosystems.

6.5.3 Perceptual Complexity

Perceptual complexity arises from the intersection of ethical and moral concerns because negative perceptions of defence-related technologies, ethical debates, and reputational risks influence procurement decisions and limit market engagement. These

concerns shape public and institutional attitudes towards defence-related innovations, affecting investment willingness and regulatory decisions.

Moral Dilemmas: Dual-use technologies present significant moral dilemmas for companies, requiring firms to balance the commercial benefits of innovation against the potential for harmful or destructive applications. While these groundbreaking innovations offer technological advancements, the possibility that they could contribute to lethal outcomes raises profound ethical concerns. Conversely, one interviewee noted, ‘... most of our customers do not really understand what dual-use is supposed to be; they are only interested in whether the product offers added value’ (Startup 1), highlighting the confusion companies face when navigating the dual-use space. These ethical challenges become even more complex when technologies originally developed for civilian purposes, such as AI or unmanned systems, are repurposed for military applications, potentially contributing to conflict or warfare.

Long-Term Societal and Geopolitical Impacts: Ethical concerns extend beyond immediate applications to the broader societal and geopolitical consequences of deploying dual-use technologies. Innovations initially developed for defence purposes may later exacerbate conflict or instability, raising concerns about their long-term impact on global security. One interviewee remarked, ‘For decades, defence research was classified as unethical, and its attractiveness was systematically decreased by burying it with regulation’ (Government and Politicians 6). Companies must therefore consider not only the ethical implications of their technologies in the present but also their potential role in shaping future geopolitical dynamics.

6.5.4 Dual-Use Challenge Severity.

Figure 8 illustrates the quantitative assessment of dual-use challenge severity, demonstrating a composite measure derived by multiplying the frequency, urgency, and

sentiment values for each second-order theme. This approach consolidates these three criteria into a single, distinct, and interpretable metric, enabling a comprehensive assessment of their relative significance. Table 8 in the Appendix provides further details on these findings.

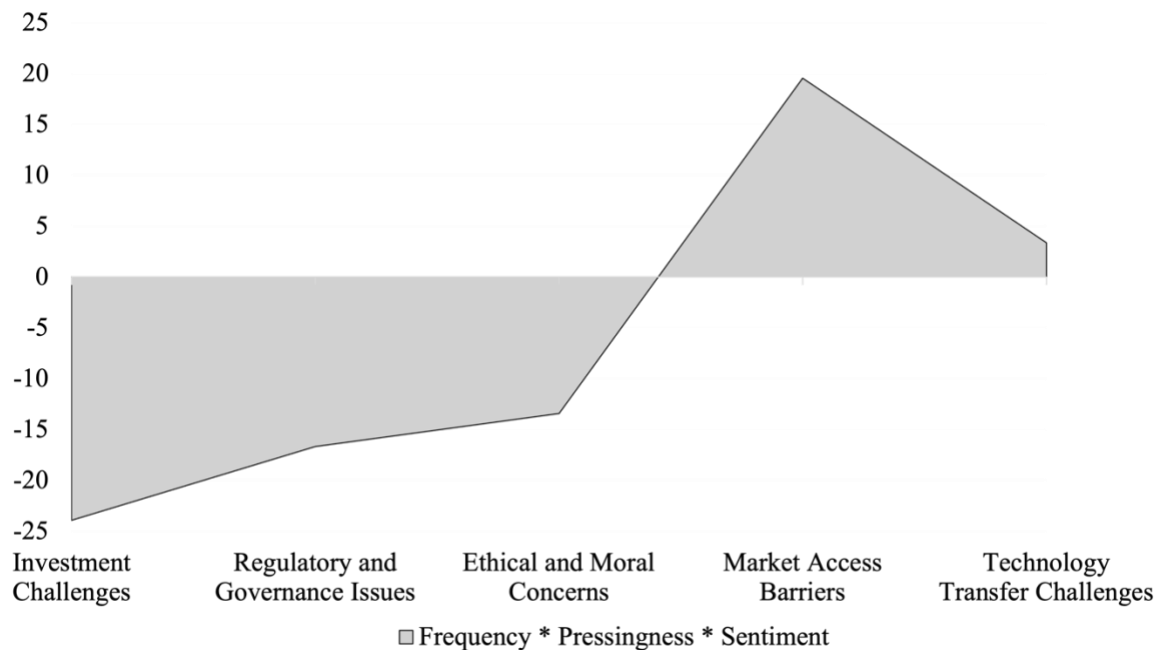


Figure 8: Quantitative Assessment of Dual-Use Challenge Severity

Investment challenges emerged as the most severe obstacle, exhibiting high frequency and strongly negative sentiment. These challenges reflect systemic funding gaps, risk-averse investor behaviour, and structural financial constraints that hinder the commercialisation and scalability of dual-use technologies. The inability to secure adequate investment impedes early-stage innovation and slows the transition from research to market deployment.

Regulatory and governance issues represented another significant barrier, characterised by negative sentiment and considerable urgency. Stakeholders frequently cited complex compliance requirements, inconsistent legal frameworks, and bureaucratic inefficiencies as key deterrents to dual-use innovation. These regulatory constraints often lead to extended approval timelines, increasing uncertainty for both startups and investors in this domain.

Ethical and moral concerns also exhibited strong negative sentiment, reflecting stakeholder apprehension regarding the potential misuse of dual-use technologies. Ethical dilemmas, particularly in defence-related applications, create hesitancy among investors, policymakers, and research institutions, further complicating efforts to integrate these technologies into broader commercial markets.

Market access barriers, although widely discussed, present a mixed perception. While some stakeholders viewed them as manageable or even an opportunity (very positive sentiment), others identified significant obstacles related to procurement challenges, entrenched incumbents, and limited commercial pathways for emerging dual-use solutions. The complexity of market entry, especially in highly regulated industries, further amplified these barriers.

Lastly, technology transfer challenges were recognised as a notable issue, although with a slightly positive overall sentiment and a lower weighted impact compared with the preceding themes. Difficulties in transitioning technologies from research institutions to commercial applications, alongside knowledge silos and intellectual property constraints, contribute to inefficiencies in dual-use innovation adoption. These barriers hinder the seamless integration of advancements across sectors, limiting the effectiveness of technology diffusion.

6.6 Discussion

Figure 9 presents a conceptual mapping of the complex interactions among key stakeholders within the dual-use technology ecosystem, illustrating how the structural, financial, and perceptual challenges identified in this study shape stakeholder dynamics. While the size and spatial distribution of the bubbles are not quantitatively representative, the

figure serves as a qualitative framework, highlighting systemic interdependencies, reinforcing constraints, and cross-sectoral fragmentation.

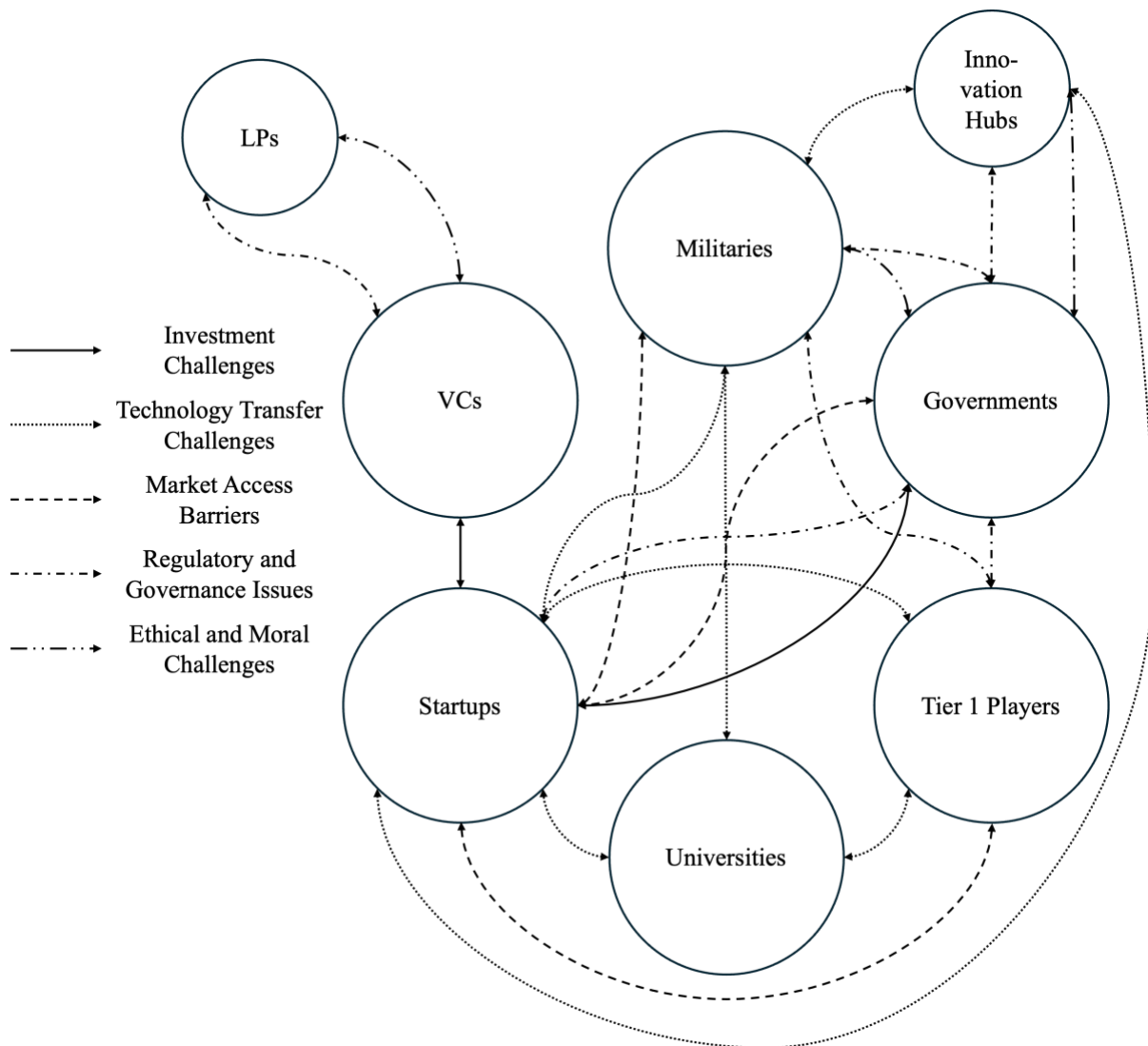


Figure 9: Challenges in the Dual-Use Ecosystem for Various Stakeholders

6.6.1 Reinforcing Constraints: The Structural–Financial Feedback Loop

A salient insight from Figure 9 is the cyclical reinforcement of structural and financial constraints, which creates a self-perpetuating cycle of limitations across multiple stakeholder groups. Financial constraints directly impact venture capitalists and government-backed investors, who, in response to regulatory uncertainty and increased risk perceptions, reduce their exposure to dual-use startups. Thus, startups, whose growth trajectories depend on private capital and public-sector grants, face significant barriers to scaling innovation. This

funding bottleneck further affects innovation hubs and research institutions, which rely on sustained investment and commercial partnerships to drive dual-use research and development.

6.6.2 Systemic Bottlenecks and Fragmentation

Beyond financial interdependencies, Figure 9 highlights the regulatory and governance bottlenecks between the government and nearly all other stakeholders, further exacerbating fragmentation within the innovation landscape. Three key structural impediments emerge:

Regulatory Inconsistencies and Procurement Barriers: Opaque procurement processes, excessive compliance requirements, and jurisdictional misalignments create significant obstacles for startups and SMEs, limiting their ability to secure government contracts.

Market Access Asymmetries: The procurement landscape is disproportionately controlled by prime contractors, who act as gatekeepers, restricting market entry for emerging dual-use ventures.

Weak Knowledge Transfer Mechanisms: Limited collaboration between civilian and military research institutions delays the commercialisation of critical dual-use technologies, further reinforcing systemic inefficiencies.

These bottlenecks not only impede innovation diffusion but also reinforce investor risk aversion, intensifying financial constraints and perpetuating a fragmented dual-use ecosystem.

6.6.3 The Stigma–Barrier Cycle: Perceptual Complexity and Institutional Hesitancy

A particularly critical insight from Figure 9 is the recursive dynamic of perceptual complexity, where ethical and reputational concerns shape institutional engagement, reinforcing structural constraints. The reluctance of universities and research institutions to

engage with defence-related projects due to reputational risks and ethical considerations directly suppresses technology transfer rates, limiting the availability of innovative dual-use solutions. This cycle manifests in three key ways:

Institutional Risk Aversion: Universities frequently reject defence-related funding due to concerns over public backlash and political scrutiny, restricting the pipeline of spin-off companies and early-stage dual-use ventures.

ESG-Driven Investment Exclusion: Increasing adherence to ESG criteria discourages investors from financing defence-related startups, despite their potential for broader civilian applications.

Regulatory Perception and Policy Uncertainty: Public sentiment exerts a tangible influence on regulatory decision-making, fostering inconsistencies that create an unpredictable environment for firms seeking to scale dual-use innovations.

This stigma–barrier cycle deepens the structural divide between research and market application, effectively immobilising critical technologies in early-stage development due to a lack of institutional and financial support.

6.6.4 Breaking Systemic Constraints: The Imperative for Cross-Sector Coordination

Figure 9 also highlights the necessity of cross-sector collaboration as a mechanism for dismantling entrenched constraints. Overcoming systemic bottlenecks requires more than isolated policy adjustments. It demands a coordinated, multi-stakeholder approach. A particularly promising intervention is the establishment of dual-use innovation hubs, which serve as mediating platforms between academia, investors, and policymakers. These hubs facilitate:

Early-Stage Risk-Sharing Mechanisms: By introducing government-backed co-financing schemes, these hubs mitigate financial risk for investors, incentivising engagement in dual-use innovation.

Regulatory Navigation Support: Advisory services tailored to export controls, procurement policies, and compliance hurdles provide startups with structured guidance, reducing regulatory friction.

Public–Private Innovation Networks: Strategic alliances between defence agencies and civilian tech firms foster pre-commercial research collaborations before regulatory constraints solidify.

By institutionalising structured engagement platforms, stakeholders can gradually dismantle systemic barriers that inhibit dual-use technology diffusion. Such a shift will transition the ecosystem from a risk-averse and fragmented model towards one that is more dynamic, adaptive, and integrative.

6.7 Implications and Recommendations

6.7.1 Short-Term Practical Implications

The findings of this study highlight the urgent need for evaluative tools that assess and clarify the position of companies and products on an ‘omni-use continuum’, rather than forcing technologies into rigid classifications. This aligns with the recent literature, which suggests that dual-use technologies are inherently multi-faceted, requiring a more nuanced classification approach (Fiott, 2014; Ulnicane et al., 2023). A continuum model could serve as a practical framework to help investors, regulators, and other stakeholders differentiate between technologies primarily suited for civilian applications, those intended for military use, and those that genuinely straddle both realms.

Such an approach aligns with calls for more flexible regulatory models that account for the dynamic nature of technological development (Chen et al., 2021). In addition, research on venture capital decision-making indicates that transparent classification mechanisms can mitigate investment hesitancy by reducing perceived risks (Quas et al.,

2022). Addressing these ambiguities could help alleviate the ‘valley of death’ problem frequently cited in dual-use innovation ecosystems, where promising technologies struggle to transition from prototype to market due to investor caution (Alperovych et al., 2020).

A classification tool that differentiates between businesses and products based on their civilian applications or potential for positive societal impact could unlock investment channels, especially for early-stage companies. Providing more nuanced insights into the potential applications of these technologies could mitigate this risk and encourage both public and private entities to increase their financial commitments.

6.7.2 Long-Term Practical Implications

Over the long term, the concept of ‘dual-use’ itself may need to be reconsidered or even abandoned in favour of a more integrative approach that reflects the omni-use nature of modern technologies. The findings of this study support arguments that the traditional dual-use classification is becoming increasingly obsolete (Vaynman & Volpe, 2023). Scholars argue that deep-tech innovations, particularly in AI, biotechnology, and advanced materials, are inherently omni-use, meaning they can be transferred across applications with minimal or no modification (Stilgoe et al., 2013).

This perspective aligns with calls for more dynamic, risk-based regulatory approaches that allow for continuous reassessment rather than static categorisation (Drew & Mueller-Doblies, 2017; Dubov, 2014). In its current form, the dual-use classification has become a barrier to technological advancement, failing to account for the complexities of modern innovation ecosystems. The increasing convergence of civilian and defence applications makes it impractical to enforce traditional dual-use regulatory frameworks without stifling innovation.

From an economic and policy perspective, Europe’s fragmented and restrictive funding landscape remains a significant barrier to scaling dual-use and defence-related

innovations. The European Commission (2024b) acknowledged the urgency of modernising dual-use governance frameworks to prevent Europe from lagging behind more agile regions, such as the United States and China. While European firms must navigate multiple, often contradictory layers of bureaucracy, their counterparts in the US benefit from clear funding pathways through the Department of Defense, In-Q-Tel, and the Small Business Innovation Research programme (Kraemer-Eis et al., 2024). Without similar mechanisms, European innovators face a prolonged struggle to secure the resources necessary for growth.

A shift towards an omni-use governance model would allow for streamlined regulatory processes, reducing administrative burdens while maintaining necessary safeguards against misuse. A governance framework focused on risk mitigation, rather than pre-emptively restricting dual-use applications, could foster technological advancements rather than hinder them. Achieving this would require a departure from the traditional, centralised approach to technology regulation and the adoption of decentralised, adaptive models, similar to those used in fintech and digital health (Grilli & Murtinu, 2014).

From a geopolitical standpoint, Europe's competitiveness in emerging technologies will depend on its willingness to adopt omni-use governance structures. As noted by Zimmer et al. (2024), nations that fail to adapt to the new realities of technological convergence risk falling behind in critical industries. Current defence-industrial policies in Europe remain oriented towards legacy procurement models, which do not sufficiently account for the rapid pace of technological change. Future governance frameworks should prioritise cross-sectoral collaboration, leveraging expertise from both civilian and military domains to ensure that regulatory frameworks evolve in tandem with technological advancements.

Long-term governance strategies must emphasise transparency, accountability, and international cooperation to prevent the misuse of powerful technologies while ensuring that innovation is not stifled by overregulation or underfunding. As one interviewee remarked,

‘There will always be a trade-off between potential risk and innovation. Here in Germany, in particular, we need to become comfortable with taking risks again. We are competing on a global stage, and choosing not to take risks is ultimately the greatest risk a nation can take, especially when it compromises national security and our ability to defend ourselves against potential aggressors’ (Government and Politicians 1).

The innovation ecosystem itself will need to evolve. As the boundaries between military and civilian technologies continue to blur, primes, venture capitalists, the military, academia, and governments must collaborate to develop a new framework that reflects the omni-use nature of modern technologies. International bodies and policymakers will need to harmonise regulatory strategies to avoid fragmented approaches that fail to address the global nature of technology transfer. This shift requires not only regulatory change but also a cultural transformation in how societies perceive and engage with omni-use technologies.

Successfully transitioning towards omni-use technology innovation is not only crucial for future defence capabilities but will also shape Europe’s overall economic performance. If European policymakers fail to modernise governance structures, the region risks not only losing technological leadership but also compromising its strategic autonomy, which is essential for long-term security and competitiveness.

6.7.3 Implications for Further Research

This paper has highlighted several critical challenges in managing dual-use and omni-use technologies, including ethical dilemmas, regulatory inconsistencies, and funding barriers. Future research should focus on developing refined frameworks and practical tools to address these specific issues.

One key area for further exploration is the development of methodologies to classify dual-use technologies at different stages of their lifecycle. Because early identification of potential dual-use characteristics is crucial for risk assessment and compliance, researchers

should investigate frameworks that enable regulators, investors, and innovators to categorise products and businesses more precisely, reducing ambiguity and easing burdens (Fiott, 2014; Ulnicane et al., 2023).

Future studies could evaluate how current regulatory frameworks address emerging omni-use technologies, particularly those that shift rapidly between civilian and military applications. A study on regulatory fragmentation indicated that inconsistent approaches create significant barriers for innovators (Chen et al., 2021). A comparative analysis of regulatory successes and failures across different geopolitical regions could provide insights into best practices for developing adaptable governance models (Quas et al., 2022).

Further research could also explore how anticipated changes in the transatlantic alliance are already manifesting in observable trends. Open-source intelligence (OSINT) and sentiment analysis of policy discourse could track shifting narratives on dual-use technologies within international policy debates (Zimmer et al., 2024). A methodological approach incorporating OSINT would enable a dynamic assessment of how national security concerns influence technological governance decisions.

The strategically fragmented landscape of innovation support for DeepTech startups in Europe requires further evaluation. A strategic assessment of the funding ecosystem is essential for identifying blind spots, gaps, and redundancies (European Commission, 2024b). Only through a coherent defence technology roadmap and a harmonised, European-oriented funding framework can Europe provide targeted support for dual-use and defence technologies, strengthening its security-critical industries.

Finally, the role of public-sector investment in bridging the ‘valley of death’ for dual-use startups warrants deeper investigation. Prior studies have highlighted that government-led initiatives, joint procurement mechanisms, and early-adopter programmes play a critical role in mitigating investment risks (Alperovych et al., 2020; Grilli & Murtinu, 2014). Future

studies should examine the effectiveness of these programmes across national and EU-wide funding structures, identifying gaps and opportunities for a more harmonised investment strategy in omni-use technology development.

6.8 *Conclusion*

The governance of dual-use technologies faces significant challenges due to rapid technological advancements and the blurring of civilian–military boundaries. This study highlights key hurdles in Germany’s dual-use landscape, including regulatory inconsistencies, ethical concerns, and funding barriers. Addressing these challenges requires adaptive governance, clearer investment structures, and harmonised policies that support innovation while ensuring security oversight.

A key takeaway is the increasing obsolescence of the traditional dual-use classification. Modern technologies, particularly in AI and biotechnology, are inherently omni-use, seamlessly applicable across multiple sectors with minimal or no adaptation. This reality necessitates a shift in governance frameworks, moving from rigid classifications to adaptive models capable of addressing the fluidity of technological applications.

At the same time, ethical considerations must remain central. The potential for misuse, especially in military contexts, raises pressing moral concerns. Robust ethical frameworks and international cooperation are essential to ensure that technological advancements deliver benefits without being outweighed by risks.

Looking ahead, the dual-use concept may serve as a transitional tool, facilitating discourse on defence-related technologies in regions where such topics remain politically sensitive. However, the long-term success of omni-use technologies will depend on stakeholders’ ability to harmonise regulatory approaches, foster cross-sector collaboration, and encourage investment while effectively mitigating security risks.

7. The Omni-Use Technology Continuum Taxonomy: Towards Systematic Evaluation (Study III)

Title	The Omni-Use Technology Continuum Taxonomy: Towards Systematic Evaluation
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Publication	Technological Forecasting & Social Change
Status	Under Review, RR1

7.1 Abstract

Dual-use technologies positioned at the nexus of civilian and military applications present complex challenges for technological classification, investment decision-making, and policy formulation. Despite their strategic importance to national security and economic development, dual-use technologies remain considerably underfunded due to, among other factors, a lack of systematic evaluation frameworks. Existing frameworks fail to adequately assess the nuanced positioning of technologies along the civilian-military continuum, exacerbating investment hesitancy and regulatory ambiguity.

This paper introduces the Omni-Use Technology Continuum Taxonomy, a theoretically grounded and empirically validated framework developed from qualitative research. The taxonomy integrates insights from industry reports, academic literature, and 32 expert interviews across venture capital, policy, and industry domains. Developed through iterative refinement and illustrative scenarios, the taxonomy systematically categorises

technologies and businesses on a continuum based on 10 evaluative criteria ranging from technological maturity and regulatory constraints to market positioning and team composition. By offering a structured framework for classifying omni-use technologies, this study contributes to the academic discourse on technology management, strategic investment, and defence innovation. The proposed taxonomy provides scholars with a robust analytical tool for investigating the intersection of technological development, security policy, and market dynamics and has practical implications for investors and policymakers seeking to reduce funding uncertainty in this domain.

7.2 Introduction

Dual-use technologies, which are technologies with both civilian and military applications, are increasingly vital for both national security and economic competitiveness (Bojnec, 2016). They underpin transformative innovations in artificial intelligence (AI), quantum computing, biotechnology, telecommunications, and advanced materials, amongst others, which have implications for technological leadership and global sovereignty (European Commission, 2020). However, despite their strategic importance, these technologies suffer from significant underinvestment, driven by a pervasive inability to classify and evaluate their dual-use potential effectively (Malik, 2018b).

A core challenge lies in uncertainty over whether businesses developing dual-use technologies operate predominantly in the civilian or military domain. This ambiguity deters venture capitalists (VCs) and governmental funding bodies, who are reluctant to engage due to the perceived risks, a lack of clear frameworks, and reputational concerns (Blom et al., 2013; Breznitz & Ornston, 2018). Without adequate tools for evaluation, stakeholders default to risk-averse behaviour, leading to a clear funding gap that threatens both economic innovation and national security readiness (Porter & Heppelmann, 2014).

However, the dual-use concept no longer fulfils its intended value in modern contexts. The regulatory frameworks associated with dual-use technologies often hinder innovation and exacerbate risk aversion among stakeholders (European Commission, 2024b). As highlighted in previous analyses, the concept has become a source of confusion and inefficiency, slowing down investment and technology transfers and failing to account for the fluid and interconnected nature of modern applications (Burmaoglu & Saritas, 2017; Quas et al., 2022; Ulnicane et al., 2023).

The assessment of modern technologies is increasingly complicated by their omni-use nature. Omni-use technologies challenge traditional frameworks by extending beyond the traditional civilian–military focus of dual-use technologies. However, rather than viewing dual-use as an obsolete concept, we argue that it has naturally evolved into omni-use. Instead of being confined to two domains, omni-use technologies span a fluid continuum of applications that encompass civilian, military, often adapting to multiple contexts simultaneously (Burmaoglu & Saritas, 2017; Vaynman & Volpe, 2023). These characteristics blur categorical boundaries and require a re-evaluation of how technologies are classified, assessed, and managed. The rigid governance structures underpinning the dual-use concept are increasingly misaligned with the realities of technological convergence, underlining the need for adaptive, resilient assessment frameworks that promote innovation while addressing ethical and security concerns (Stilgoe et al., 2013; Ulnicane et al., 2023).

By adopting the term omni-use, this study reflects the reality of modern innovation ecosystems, where governance, developmental intent, and application are inherently multifaceted. The term acknowledges the blurred boundaries and fluid interplay between sectors, providing a more accurate conceptual framework for understanding and analysing modern technologies.

To address these challenges, this paper introduces the Omni-Use Technology Continuum Taxonomy, a structured framework for classifying and evaluating businesses across the civilian-military spectrum. The taxonomy was developed using a qualitative research design, combining insights from industry reports, academic literature, expert interviews, and real-world case illustrations. This approach ensured that the framework is not only theoretically robust but also practically applicable. Drawing on previous taxonomy development methodologies and technology assessment frameworks (Nickerson et al., 2013; Palm & Hansson, 2006; Rich, 1992; Riebe, 2023; Tran & Daim, 2008), the taxonomy was systematically refined through an iterative validation process. A total of 32 semi-structured interviews with VCs, policymakers, industry leaders, and defence experts form the empirical foundation of the taxonomy, ensuring that it reflects the real-world challenges in evaluating omni-use technologies.

The taxonomy contributes to the discourse on technology evaluation, venture capital, and defence innovation by addressing a bottleneck in the funding of dual-use or omni-use technologies. Existing frameworks struggle to classify technologies that operate across the civilian and military domains, leading to investment hesitancy and regulatory uncertainty (Quas et al., 2022; Ulnicane et al., 2023). By systematically categorising these technologies along a continuum, the proposed Omni-Use Technology Continuum Taxonomy builds on previous research on technology classification (Nickerson et al., 2013; Tran & Daim, 2008) to offer a structured approach that better reflects contemporary technological convergence (Vaynman & Volpe, 2023). The taxonomy provides actionable insights for policymakers prioritising funding allocation, supports VCs in de-risking investment decisions, and helps industry leaders navigate regulatory complexities.

Furthermore, the taxonomy advances the theoretical discussion by addressing limitations of the unclear dual-use classification, which has been criticised for failing to

capture emerging technologies with hybrid applications (Clarke, 2013; Schwartz et al., 2022). Its empirical grounding, through expert validation and real-world application, bridges the gaps in existing technology evaluation methodologies (Riebe, 2023) and answers calls for more adaptive governance structures (Palm & Hansson, 2006). Future research could explore its applicability to different sectors, refine its criteria for emerging industries, and examine its role in global policy discussions. By reducing the ambiguity in technology classification, the taxonomy provides a foundation for more effective resource allocation and a deeper understanding of omni-use technologies as drivers of both economic and security innovation.

7.3 Theoretical Context

7.3.1 Dual-Use Technologies: A Complex Landscape

Dual-use technologies occupy a unique position at the intersection of civilian and military applications. Their potential to serve both public and private interests renders them pivotal to national security, economic growth, and technological leadership. Beyond their strategic significance, dual-use technologies contribute to economic growth through export multipliers and industrial development effects. Bojnec (2016) highlights that exports of dual-use goods stimulate industrial supply chains and generate indirect economic benefits, reinforcing their role in both national security and economic policy. However, their dual nature introduces significant ambiguities. For instance, AI, quantum computing, and advanced materials, as enablers, can be leveraged for defence applications while simultaneously driving commercial innovation (Schot & Steinmueller, 2018). These ambiguities in application challenge traditional evaluation frameworks, leaving stakeholders uncertain about the broader implications of their investments.

Historically, dual-use technologies have been explored within the contexts of defence innovation and policy, yet systematic methodologies for assessing them remain

underdeveloped. Existing frameworks, such as the Technology Readiness Level (TRL) scale, offer partial solutions by focusing on technological maturity but fail to address the broader strategic, economic, and geopolitical dimensions inherent in dual-use contexts (European Commission, 2020; Mazzucato, 2018). These gaps highlight the pressing need for a structured evaluation approach tailored to the specific challenges of dual-use technologies. Blom et al. (2013) highlight the policy trade-offs between fostering innovation and maintaining security constraints, arguing that existing frameworks insufficiently balance these competing priorities. A refined taxonomy could help reduce this tension by offering clearer classification criteria that align with both economic and security goals. All modern technologies inherently operate across a spectrum of civilian and military applications, reflecting the increasingly interconnected nature of technological innovation. For example, Schwartz et al. (2022) highlight the dual-use implications of autonomous driving technologies, emphasising how the same underlying systems that enable civilian applications, such as enhanced vehicle safety and efficiency, can also support military objectives like autonomous weapons manufacture. This overlap is not incidental but a consequence of the converging demands for innovation across sectors.

Similarly, Singh et al. (2022) examine the convergence of blockchain and AI technologies within transportation systems and underscore the dual-use potential of these technologies, with applications ranging from optimising logistics in civilian markets to securing military supply chains and communication networks. Such technologies exemplify the fluid boundaries between civilian and military domains, driven by shared technological foundations and overlapping stakeholder interests.

7.3.2 The Importance of Taxonomies in Technology Management

Taxonomies have long been recognised as valuable tools for structuring and simplifying complex decision-making environments. In strategic management, they help to

classify business models, technologies, or market dynamics into actionable categories (Nickerson et al., 2013; Weking et al., 2020). By reducing complexity, taxonomies provide stakeholders with frameworks to compare, prioritise, and align decisions with organisational objectives.

Recent advancements in taxonomy development emphasise iterative, empirical approaches that blend qualitative insights with theoretical rigor (Nickerson et al., 2013; Schot & Steinmueller, 2018). In technology management, taxonomies are used to classify socio-technical systems and innovation processes (Mazzucato, 2018), highlighting their role in aligning investment decisions with broader strategic priorities. This role makes taxonomies particularly relevant for evaluating omni-use technologies.

Tran & Daim (2008) further emphasise the role of taxonomies in technology assessment to reduce uncertainty and guide resource allocation. By integrating decision analysis, scenario planning, and structural modelling, taxonomies help align technological attributes with organisational objectives. For example, taxonomies allow attributes like technological readiness, market viability, and socio-political implications to be categorised systematically, enabling better investment decisions.

Taxonomies can also deal with ethical considerations in technology management. Palm & Hansson (2006) concept of ethical technology assessment highlights the need to integrate ethical dimensions into classification frameworks.

In the context of omni-use technologies, the application of advanced taxonomies provides a bridge between theoretical insights and practical implementation. By addressing the complexities of technological convergence and dual-market applicability, taxonomies not only streamline decision-making but also promote innovation that aligns with both strategic and societal goals.

7.3.3 Bridging the Gap: The Need for an Omni-Use Taxonomy

The absence of a standardised taxonomy for dual-use technologies is a clear gap in both the academic literature and practical decision-making. This gap amplifies the underinvestment problem by leaving VCs and governmental funding bodies ill-equipped to evaluate and compare businesses and products in this space. Moreover, the geopolitical and ethical complexities of dual-use applications, ranging from data privacy concerns and environmental, social, and governance regulations to national security risks, further heighten the need for a robust evaluative framework (Porter & Heppelmann, 2014).

Building on these challenges, this paper introduces the Omni-Use Technology Continuum Taxonomy, a structured framework designed to classify and evaluate businesses and products across the civil–military spectrum. The absence of structured classification tools has been a longstanding barrier to the commercialisation of defence-funded technologies. Malik (2018) notes that defence investment has historically driven high-tech innovation, but the lack of clear pathways to commercial markets has hindered technology transfer and broader industrial impact. By integrating key dimensions of technological maturity, market positioning, and regulatory considerations, the taxonomy addresses key stakeholder concerns, fosters informed decision-making, and mitigates the risks associated with funding dual-use technologies. Burmaoglu & Saritas (2017) emphasise that emerging defence technologies increasingly exhibit characteristics that defy traditional categorisation. In response, the Omni-Use Technology Continuum Taxonomy seeks to capture this fluidity and adaptability, ensuring a more accurate and policy-relevant classification mechanism. Validated by expert input, the taxonomy offers a much-needed tool for bridging the civil–military divide in innovation funding.

7.4 *Methods*

7.4.1 Research Approach

A qualitative approach was adopted to develop and validate the Omni-Use Technology Continuum Taxonomy. The approach integrated insights from industry reports, academic literature, expert interviews, and illustrative scenarios. Grounded in taxonomy development methods and technology assessments (Nickerson et al., 2013; Palm & Hansson, 2006; Rich, 1992; Riebe, 2023; Tran & Daim, 2008), this approach addresses the complexities of evaluating dual-use technologies (Palm & Hansson, 2006; Riebe, 2023). By incorporating insights from expert interviews and focusing on sufficiently mature technologies, the methodology is also aligned with best practices for applied research (Mazzucato, 2018; Schot & Steinmueller, 2018).

7.4.2 Data Collection

The first phase of taxonomy development involved a comprehensive review of policy reports, white papers, and academic literature to establish the initial structure of the taxonomy. These sources provided insights into the strategic, regulatory, and evaluative challenges associated with dual-use and omni-use technologies, as well as their classification.

Policy documents highlight the governance frameworks and strategic priorities shaping technology assessment, while the academic literature contributes conceptual and empirical insights on dual-use innovation, investment gaps, and technological readiness. The reviewed documents provided the conceptual foundation for the Omni-Use Technology Continuum Taxonomy. Table 3 summarises the key sources that informed the study.

Table 3: Key Sources of the Study

Category	Document Title	Source
Policy Reports & White Papers	On options for enhancing support for research and development involving technologies with dual-use potential	European Commission (2024)
	White Paper on Export Controls	European Commission (2024a)
	EIB Group 2024-2027 Strategic Roadmap	European Investment Bank (2024)
	Commission recommendation of 3.10.2023 on critical technology areas for the EU's economic security for further risk assessment with Member States	European Commission (2023)
	EU funding for Dual Use	European Commission (2014)
Scholarly Foundations	Advancing human-rights-by-design in the dual-use technology industry	Penney et al. (2018)
	Dual use inventions: identification and characterization using patent data	Caviggioli et al. (2023)
	Technology Assessment of Dual-Use ICTs	Riebe (2023)
	Dual Use Deception: How Technology Shapes Cooperation in International Relations	Vaynman & Volpe (2023)
	Vision or Threat - Awareness for Dual-Use in the Development of Autonomous Driving	Schwartz et al. (2022)
	Dual-Use AI Technology in China, the US and the EU	Carrozza et al. (2022)
	Problematic issues of the development of modern dual-use technologies	Levchenko et al. (2019)
	The three effects of dual-use: Firms, capabilities, and governance	Fiott (2014)
	The Technology Readiness Level (TRL) Scale	Mankins (1995)

The second phase of taxonomy development centred on 32 semi-structured interviews, primarily in German, with participants from Germany (27), France (1), Belgium (1), Italy (1), the UK (1), and the Netherlands (1), including VCs (n = 5, 15.6%), policymakers (n = 6, 18.8%), prime defence contractors (n = 4, 12.5%), military representatives (n = 5, 15.6%), scholars (n = 5, 15.6%), and entrepreneurs (n = 7, 21.9%). The participants provided rich, context-specific insights that informed the inclusion of new

criteria and the refinement of existing criteria, ensuring that the framework addresses the practical challenges of evaluating omni-use technologies.

This approach facilitated the collection of detailed insights from the participants while allowing the flexibility to explore emerging themes (Kvale & Brinkmann, 2009). The interview guide was systematically developed through a rigorous synthesis of pre-screened academic literature, ensuring that each question was grounded in established theoretical frameworks and empirically relevant constructs. Insights from unstructured interviews also informed the guide, ensuring that key contemporary issues were addressed. The guideline encompassed 32 questions across seven thematic areas: (1) Background Information (e.g., the participant's role and experience); (2) Understanding Dual-Use Technologies, focusing on their spectrum and implications; (3) Challenges of Dual-Use Technologies, such as classification issues and ethical considerations; (4) Regulatory and Policy Issues, addressing both existing frameworks and future needs; (5) Funding and Investment, exploring opportunities and barriers for omni-use ventures; (6) Future Trends and Opportunities, examining the evolution and categorisation of omni-use technologies; and (7) Evaluation Criteria and Methodology to classify modern technologies on the omni-use spectrum.

The interviews lasted between 40 and 90 minutes, allowing in-depth exploration of the participants' experiences and viewpoints.

Translation accuracy into English was ensured through a systematic process involving professional translation software, native speaker verification of key terminology, and iterative cross-referencing to preserve the semantic integrity of the original responses. The primary focus on Germany reflects the country's pronounced position within the European Union as regards funding challenges, defence technology gaps, and procurement constraints, thus offering an appropriate context for studying the dynamics of omni-use technologies in Europe.

7.4.3 Data Analysis

The analysis of the collected data followed a two-stage approach that systematically built the foundations for the development and refinement of the Omni-Use Technology Continuum Taxonomy. Both the documentary and interview data were subjected to qualitative thematic coding based on an inductive–deductive hybrid strategy informed by established methodological frameworks in qualitative research (Miles et al., 2014).

In the first stage, the reports and policy documents listed in Table 1 were coded using an inductive coding approach to identify the initial evaluative criteria and conceptual anchors. The codes reflected recurring themes such as regulatory ambiguity, technological maturity, funding bottlenecks, and strategic alignment with civilian or military markets. In the second stage, the 32 semi-structured interviews were analysed using thematic coding to validate, challenge, and extend the initial set of evaluation criteria. Coding was conducted using the MAXQDA software and followed a process of iterative categorisation and pattern recognition. A preliminary codebook was derived deductively from the taxonomy criteria developed in the first stage and expanded inductively as new themes emerged during analysis of the interview transcripts (Miles et al., 2014). Special emphasis was placed on identifying intersubjective agreement among stakeholder groups (e.g., investors, policymakers, industry experts) regarding the salience, ambiguity, and applicability of specific criteria.

Following the initial construction of the taxonomy, an iterative refinement and validation process was undertaken to enhance its clarity, granularity, and real-world relevance. Experts were presented with the preliminary taxonomy and asked to assess the validity, applicability, and distinctiveness of each proposed criterion. Their feedback served two purposes: first, to confirm the relevance of the criteria already included and second, to introduce targeted refinements based on sector-specific insights. For instance, the originally proposed criterion Impact Potential was subdivided following feedback into three distinct

criteria: Critical Infrastructure Impact, Destructive Potential, and Lethality. Similarly, the dimension Team Composition was added based on repeated emphasis from the VCs and other industry stakeholders on the strategic relevance of founding team expertise.

Triangulation was conducted through complementary application of the refined taxonomy to two real-world case studies: autonomous drones and quantum encryption technologies. These case studies served to evaluate the internal coherence and external validity of the framework and were followed by structured expert discussions. One outcome of these discussions was the introduction of a threshold rule, whereby technologies scoring the maximum value (5) on two or more criteria are automatically categorised as military-aligned, regardless of their overall average score. This rule reflects stakeholder concerns about highly sensitive technologies that might otherwise be misclassified through an averaged scoring model.

Finally, coding rigour was ensured through the double-coding of selected interviews and cross-case comparison of the analytical categories. Discrepant cases were deliberately sought to test the boundaries of the taxonomy, and peer debriefing was employed to reduce researcher bias in the thematic interpretation. This triangulated approach, combining literature coding, expert interviews, and case studies, ensured that the resulting taxonomy was both empirically grounded and analytically robust.

7.5 Development of the Omni-Use Continuum Taxonomy

7.5.1 Criteria

The following section introduces the 10 evaluative criteria of the taxonomy, which were derived through the two-step qualitative coding process outlined above. Together, the criteria capture the technical (destructive potential, lethality, critical infrastructure impact, technical impact scope), strategic (funding sources, potential use for military, regulatory

compliance), and market (competitive landscape, team composition, business model and strategy) dimensions necessary to assess omni-use applicability in a systematic and multidimensional manner.

7.5.1.1 Destructive Potential

This criterion evaluates a technology's capacity to disrupt or safeguard material assets, thereby signalling its potential alignment with security-critical applications. The inclusion of this dimension reflects the widespread recognition across the stakeholders that destructive capability remains a key proxy for military relevance, particularly in strategic planning and threat assessment. As one military representative noted, 'If a system can physically paralyse infrastructure or destroy enemy assets, even without being explicitly designed for it, it becomes a concern for every defence planner' (Interview 4, Military Officer). This insight resonates with policy discussions on the importance of assessing both intentional and emergent destructive capacities, especially in advanced robotics and unmanned systems (European Commission, 2023, 2024b). Moreover, Carrozza et al. (2022) underscore how emerging technologies exhibit latent destructive capabilities that often surpass their civilian design parameters. Therefore, the taxonomy isolates Destructive Potential as a distinct evaluative criterion, rather than subsuming it under the broader technological maturity or impact categories, in line with recommendations from the dual-use assessment literature (Levchenko et al., 2019; Riebe, 2023).

7.5.1.2 Lethality

This criterion assesses the potential of a technology to cause or prevent direct harm to human life, making it a core dimension for regulatory, ethical, and strategic evaluation. In contexts involving weapon systems, autonomous drones, or biochemical agents, lethality serves as a decisive boundary between civil and military classification. As emphasised by one policy official, 'The threshold for classifying a technology changes the moment it can be used

to end human life, or explicitly designed to save it. That is when defence ministries start paying attention’ (Interview 6, Policy Expert). The relevance of lethality is well-documented in recent European regulatory debates, particularly in the 2024 White Paper on Export Controls, which outlines lethality thresholds for dual-use classification (European Commission, 2024a). Riebe (2023) similarly positions lethality at the heart of ethical technology assessment and highlights the difficulty of adequately capturing it with existing frameworks. Given its significant implications for international humanitarian law, operational doctrine, and public perception, this criterion requires nuanced, case-specific expert judgment and cannot be reduced to purely technical performance indicators.

7.5.1.3 Critical Infrastructure Impact

This criterion captures a technology’s potential to disrupt, enable, or secure vital systems such as energy grids, communications networks, and transportation infrastructure. Technologies with broad systemic implications, such as satellite services, quantum encryption, or autonomous logistics, are increasingly at the centre of defence-industrial strategy. As one senior engineer from a prime defence contractor explained, ‘It’s not the weapon itself that matters; it’s the domino effect on infrastructure. That’s where the real strategic value or risk lies’ (Interview 20, Prime). This perspective aligns with the European Commission’s recommendation for identifying technologies that affect integral sectors in economic and security terms (European Commission, 2023). Likewise, the European Investment Bank Group’s Strategic Roadmap highlights infrastructure resilience as a core target area for omni-use innovation funding (European Investment Bank, 2024). The inclusion of this criterion recognises that even ostensibly civil technologies can acquire military significance through their infrastructural dependencies or potential for disruption.

7.5.1.4 Funding Sources

The origin of the financial backing for an innovation, whether civilian, military, or hybrid, offers a valuable lens into its intended trajectory and perceived alignment. In particular, the taxonomy draws on this dimension to reflect strategic intent and to identify potential end-user pathways. According to a managing partner at a dual-use fund, ‘You don’t just follow the money – you follow who gave the money and what they expect in return. If 60% is military procurement, that’s not a neutral investment anymore’ (Interview 13, VC). This perspective is echoed in EU-level strategic documents, which have repeatedly emphasised the importance of determining funding provenance in assessing export controls, research subsidies, and compliance regimes (European Commission, 2014; European Investment Bank, 2024). Caviggioli et al. (2023), in their quantitative analysis of patent and funding data, further validate the assumption that funding patterns are predictive of application fields and regulatory scrutiny. This criterion is therefore essential not only as a signal of institutional affiliation but also as an indicator of future market behaviour, which is particularly relevant in early-stage due diligence by venture capital firms and public funding agencies.

7.5.1.5 Potential for Military Use

Beyond the intended civilian applications, this criterion evaluates the plausibility and adaptability of a technology for offensive or defensive military use. It serves to identify latent functionalities that may be strategically relevant under various deployment scenarios. A Bundeswehr innovation officer remarked, ‘You’d be surprised how many startups pitch themselves as green energy or logistics firms until someone asks how fast their product can be weaponised. It’s rarely a hard pivot – it’s already in the tech’ (Interview 10, Military Innovation Officer). The relevance of this criterion is underscored in the defence literature, particularly by Carrozza et al. (2022), who show how AI and blockchain-based technologies

transition fluidly into security contexts. The European Commission (2023) similarly flags military adaptability as a decisive risk parameter in evaluating technology transfers. By explicitly including this dimension, the taxonomy accounts for both foreseen and unforeseen pathways through which civil technologies may enter military value chains.

7.5.1.6 Regulatory Compliance

This criterion examines the legal and policy frameworks that govern a technology's production, export, and deployment, particularly in light of international regimes such as the EU Dual-Use Regulation or the U.S. ITAR (International Traffic in Arms Regulation). Regulations shape not only a company's operational strategy but also its investability and global scalability. One compliance officer observed, 'Some founders think of regulation as a bureaucratic afterthought. But for us, it's often the first indicator of how hard or easy it will be to get their tech to market, especially abroad' (Interview 25, Compliance Expert). This insight is strongly reinforced by the European Commission, which stresses regulatory navigation as a central pillar of innovation governance (European Commission, 2024b, 2024a). Vaynman & Volpe (2023) further argue that regulatory positioning often operates as a form of soft power, influencing how technologies circulate between geopolitical blocs. Consequently, this criterion is crucial for understanding not only technical feasibility but also the international political economy of omni-use technologies.

7.5.1.7 Technology Impact Scope

This criterion reflects the breadth, both geographic and strategic, of a technology's potential consequences. Whether a system is confined to municipal infrastructure or has global surveillance capabilities fundamentally alters its classification risk and stakeholder sensitivity. As stated by a venture partner specialising in frontier technologies, 'A startup that affects 10,000 people is not the same as one that affects 10 million. The strategic oversight grows with the impact surface' (Interview 7, VC). This logic is mirrored in the European

Commission's framework for identifying fundamental technologies, in which reach and scalability are key metrics (European Commission, 2023). The Commission's ethical assessment model further emphasises that the scope of impact must be proportionate to the governance intensity (Palm & Hansson, 2006; Vaynman & Volpe, 2023). Whether a technology modifies border control, global logistics, or public health infrastructure, its reach defines its relevance in both commercial and security terms.

7.5.1.8 Competitive Landscape

This criterion examines the extent and orientation of competitive activity within the relevant technological field, offering insight into whether rival firms are pursuing civilian, military, or hybrid markets. It covers strategic positioning and saturation, both of which influence investor interest and regulatory attention. The European Commission (2023) notes that dense military competition may signal geopolitical sensitivity, whereas purely civil competitive environments suggest fewer barriers to market entry. The strategic management literature (e.g., Porter, 1998) highlights competitor analysis as a determinant of market viability, particularly in emerging sectors. This criterion also flags potential technology convergence in adversarial contexts, where military-aligned competitors may shape global norms or procurement trends. A scholar with dual-use expertise stated, 'Competitor dynamics often signal where opportunities or barriers lie, especially when looking at the U.S. or China, which tend to lead in technology advancements compared to European counterparts' (Interview 8, Researcher). Including this criterion allows evaluators to situate a firm not just in terms of its intrinsic capabilities but also in its relation to broader geopolitical and market forces.

7.5.1.9 Team Composition

This criterion assesses the background and experience of a company's founding and leadership team, particularly in terms of their exposure to civil, defence, or dual-use

ecosystems. A multidisciplinary team combining technical expertise with policy or military domain knowledge is often seen as essential for navigating omni-use complexities, including procurement cycles, compliance, and stakeholder management. Riebe (2023) emphasises that founder backgrounds heavily influence product-market fit and funding access, particularly when operating in ambiguous regulatory environments. Similarly, Schwartz et al. (2022) show that dual-use AI firms led by former defence personnel are more likely than others to secure military contracts and anticipate compliance risks. This finding was echoed by a VC: ‘Teams with diverse civilian and military expertise are better positioned to bridge application gaps, but the backgrounds and past experiences heavily shape the market focus and success of a new application or product’ (Interview 17, Investor). As omni-use technologies often require interaction with both commercial and institutional stakeholders, team composition is a predictive factor for strategic flexibility and execution capacity.

7.5.1.10 Business Model and Strategy

This final criterion captures the commercial logic and strategic orientation of a company’s value creation, specifically whether its revenue model, target markets, and partnerships are aligned with civil, military, or hybrid domains. It is often the most decisive variable in venture capital and public funding evaluations, given its implications for scalability, reputational risk, and governance. Some argue that business models rooted in defence supply chains tend to follow different innovation and funding logics from civilian ventures (Fiott, 2014). The European Commission (2014) has similarly warned that ventures with unclear market alignment risk falling into the so-called ‘valley of death’, unable to secure either civilian market traction or military procurement. As one investor summarised, ‘In the end, the business model, target market and revenue strategy of a business are the clearest indication of a product’s future use’ (Interview 22, VC). Including this criterion

ensures that evaluators do not treat technology as decoupled from its monetisation strategy, an oversight in many existing classification schemes.

7.5.2 A Hybrid Evaluation Approach

Evaluating the 10 criteria outlined in the taxonomy requires a nuanced approach that balances quantitative and qualitative measurable metrics. This hybrid method is essential to ensure that the evaluation process captures the complexity of omni-use technologies while maintaining academic and practical rigour. As technology assessment frameworks are interdisciplinary by nature, they often combine qualitative and quantitative elements to address multifaceted phenomena (Tran & Daim, 2008).

To achieve clarity and coherence within this hybrid evaluation framework, the 10 criteria are categorised based on whether they require qualitative expert judgement or can be assessed using measurable, objective metrics. Certain criteria, such as destructive potential, lethality, critical infrastructure impact, potential for military use, and regulatory compliance, require qualitative expert assessment due to their inherently context-dependent nature. For instance, the destructive or lethal potential of emerging technologies often cannot be accurately quantified without considering hypothetical deployment scenarios or adversary responses. Evaluations in these cases require expert knowledge and the leveraging of scenario analyses and tacit expertise to account for intangible factors such as strategic alignment or unforeseen consequences.

In contrast, other criteria lend themselves more readily to quantitative measurement. Funding sources, for example, can be assessed through financial disclosures or audits, ensuring clear and reproducible data. Similarly, team composition can be analysed based on the professional backgrounds of key individuals, distinguishing between expertise in defence, military applications, and civil markets. The business model and strategy of a technology can be evaluated using structured documentation and financial modelling, providing insights into

market objectives and revenue distribution. The competitive landscape can be assessed through quantifiable market analyses that incorporate data about civilian and military competitors. Finally, the technology impact scope can be measured using both geographical reach and broader strategic foresight.

By distinguishing between quantitative and qualitative evaluative approaches, the hybrid method reinforces the taxonomy's adaptability to the multifaceted nature of dual-use technologies while ensuring consistency and rigour. The structured approach anchors subjective judgements in measurable data where possible, strengthening the overall validity and transparency of the evaluation process (Nickerson et al., 2013).

7.5.3 Scoring and Placement on the Continuum

The taxonomy evaluates technologies at TRL 5 and above, where systems or components have been validated in a relevant environment (Mankins, 1995). Technologies below TRL 5 are considered 'not sensitive for investment' due to the absence of clearly defined civil or military applications. This approach ensures that the taxonomy focuses on technologies with sufficiently developed application potential while providing a pathway for early-stage innovations to attract investment. The TRL 5 threshold is a pivotal transition point in the development process and is the point at which dual-use relevance often begins to emerge. This adjustment broadens the taxonomy's applicability, ensuring inclusivity for sectors with faster iteration cycles or less resource-intensive R&D processes (European Commission, 2020; Héder, 2017).

To further refine the scoring process, the taxonomy employs a weighted evaluation system for the 10 criteria. These weights were established through a systematic pairwise comparison process validated by experts during the interviews. The pairwise comparisons allowed the relative importance of each criterion to be quantified, ensuring that the taxonomy reflects the practical and strategic priorities of VCs, policymakers, and industry leaders.

Table 4 summarises the weighted relevance of each criterion and specifies whether the evaluation process relies on qualitative expert judgement or quantitative data. This distinction helps clarify the hybrid evaluation logic underpinning the taxonomy.

Table 4: Overview of the Evaluation Criteria: Weighting and Methodological Classification

Criteria	Weight (%)	Type of Evaluation
Destructive Potential	16	Qualitative
Lethality	16	Qualitative
Critical Infrastructure Impact	9	Qualitative
Funding Sources	7	Quantitative
Potential for Use in Military	9	Qualitative
Regulatory and Compliance	3	Qualitative
Technology Impact Scope	9	Quantitative
Competitive Landscape	3	Quantitative
Team Composition	12	Quantitative
Business Model & Strategy	20	Quantitative

These weights reflect the criteria’s relative importance in assessing the alignment of technologies with civilian or military applications. For example, Destructive Potential and Lethality are heavily weighted due to their implications for national security, while Business Model and Strategy holds the highest weight, given its role in shaping a technology’s market trajectory and alignment with end-user objectives.

The weighted scoring system enhances the taxonomy’s precision, enabling it to account for the varying significance of different criteria across technologies. By incorporating expert input and systematically derived weights, the taxonomy ensures that evaluations are both rigorous and aligned with stakeholder priorities. The use of weights also improves the transparency of the scoring, providing a clear rationale for the placement of technologies along the continuum.

Each of the taxonomy’s 10 criteria in Table 5 is scored independently on a scale from 1 to 5, with higher scores indicating stronger alignment with military characteristics. The total score determines the technology’s placement along the civilian–military continuum. However, to enhance the robustness and precision of the classification process, the taxonomy

incorporates an additional threshold rule: any technology receiving a score of 5 on two or more criteria is automatically classified as military technology. This rule accounts for the outsized significance of certain characteristics, such as Destructive Potential or Lethality, in signalling strong military alignment. Drawing on the strategic management literature (Mazzucato, 2018; Nickerson et al., 2013), this threshold-based approach ensures that high-impact factors trigger automatic reclassification, reducing the risk of misclassification and enhancing decision-making reliability.

This combined approach, employing both weighted scoring and a threshold rule, ensures that the taxonomy is robust, flexible, and capable of addressing the complexities inherent in evaluating omni-use technologies. By recognising the differing degrees of alignment without necessitating rigid categorisation, the taxonomy supports informed decision-making for all stakeholders.

Table 5: Full Criteria Overview

Criteria	Short Description	Literature
Destructive Potential	Evaluate the ability of the technology to destroy or protect material goods, equipment, or other physical assets. 1: No potential for destruction or protection. 2: Minor potential for destruction or protection, requires significant modifications. 3: Moderate potential for destruction or protection with some adaptations. 4: High potential for destruction or strong defensive protection with minor modifications. 5: Significant potential for destruction or critical protection of material assets.	Carrozza et al. (2022), Levchenko et al. (2019)
Lethality	Estimate potential to cause or prevent injury or death. 1: No potential to cause or prevent injury or death. 2: Minor potential for harm or protection, requires significant modifications. 3: Moderate potential to cause or prevent injury with some adaptations. 4: High potential to cause harm or prevent significant injuries or deaths. 5: Significant potential for causing death or preventing large-scale casualties.	Riebe (2023), Carrozza et al. (2022)
Critical Infrastructure Impact	Assess the potential to damage or protect critical infrastructure such as utilities, transportation, and communication networks. 1: No impact on or protection of critical infrastructure. 2: Minor impact or limited protection of specific areas. 3: Moderate impact on multiple areas or moderate defensive protection. 4: Significant impact or strong protection of several critical areas. 5: Major destructive impact or widespread defensive protection of critical infrastructure.	European Commission (2024b), European Commission (2024a), European Commission (2014), European Commission (2023), European Investment Bank (2024), Riebe (2023)
Funding Sources	Identify the sources of funding for the technology's development. To be measured is the proportion of funding from military versus civilian sources (e.g., % military funding). 1: Entirely funded by civil sources; 0-20% military funding 2: Primarily civil funding with minor military interest; 21-40% military funding 3: Balanced civil and military funding; 41-60% military funding	European Commission (2024b), European Commission (2014), European Investment Bank (2024), Caviggioli et al. (2023), Riebe (2023), Schwartz et al. (2022), Carrozza et al. (2022)

	4: Primarily military funding with minor civil interest; 61-80% military funding 5: Entirely funded by military sources; 81-100% military funding	
Potential for Use in Military	Determine if the technology is used or planned to be used offensively or defensively by military organisations. 1: No military use or interest. 2: Minor military interest, primarily civil use. 3: Some military use for offensive or defensive purposes, but mainly civil. 4: Significant military use, but with civil applications. 5: Exclusively or predominantly military, either offensive or defensive.	European Commission (2024b), European Commission (2023), Caviggioli et al. (2023), Schwartz et al. (2022), Carrozza et al. (2022), Levchenko et al. (2019)
Regulatory and Compliance	Check for export controls, regulatory restrictions, or dual-use classifications. 1: No regulatory or export controls 2: Minor regulatory considerations, mainly civil 3: Moderate regulatory restrictions applicable 4: Significant regulatory controls indicating dual-use 5: Strict regulatory controls, clearly dual-use or military	European Commission (2024b), European Commission (2024a), Riebe (2023), Carrozza et al. (2022), Vaynman & Volpe (2023)
Technology Impact Scope	Consider the security measures, sensitivity, and scope of the technology's impact, whether it is local, national, or global. Quantitative assessment of geographic and strategic reach. 1: No special security or sensitivity concerns, with a limited impact scope, primarily local; Impact limited to local area or single municipality. 2: Minor security concerns, generally open use, with an impact scope that is mostly local or regional; Impact at the regional level (e.g., within a state or province). 3: Moderate security measures needed, with an impact scope that extends beyond the local level, potentially affecting national or regional environments; Impact at the national level. 4: Significant security measures required, with a broad impact scope at the national level; Impact across multiple nations (e.g., continental level). 5: High security and sensitivity, restricted use, with a global impact scope and the highest level of security and sensitivity concerns; Global impact.	Carrozza et al. (2022), European Commission (2023), European Investment Bank (2024), Palm & Hansson (2006), Vaynman & Volpe (2023)

Competitive Landscape	Examine competitors' offensive and defensive products and their applications for military use. Percentage of competitors in civilian vs military sectors 1: Competitors' products are entirely civil, with no offensive or defensive military applications; 0-20% of competitors from military sectors. 2: Competitors have minor military applications for offensive or defensive purposes; 21-40% of competitors from military sectors. 3: Competitors have balanced civil, military, offensive, and defensive applications; 41-60% of competitors from military sectors. 4: Competitors' products are predominantly military, with a focus on either offense or defense; 61-80% of competitors from military sectors. 5: Competitors' products are exclusively military, designed for advanced offensive or defensive applications; 81-100% of competitors from military sectors.	European Commission (2014), European Commission (2023), European Investment Bank (2024)
Team Composition	Examine the team's experience in offensive and defensive military involvement. Percentage of team members with civilian vs military backgrounds 1: Team members have entirely civil backgrounds with no military or defensive experience; 80-100% civilian team backgrounds 2: Team members have predominantly civil backgrounds with some military or defensive experience; 60-79% civilian team backgrounds 3: Balanced mix of civil, military, and defensive backgrounds; 50-59% mix of civilian and military expertise 4: Predominantly military backgrounds, with some civil and defensive experience; 20-39% civilian team backgrounds 5: Exclusively military backgrounds, with advanced experience in offensive and defensive technology; 0-19% civilian team backgrounds	Riebe (2023), Schwartz et al. (2022)
Business Model & Strategy	Evaluate the alignment of the business model and strategic objectives with military or civil markets. Market revenue split or targeted market share (e.g., % military market focus). 1: The business model is exclusively civil, with no focus on military markets or applications; 0-20% market focus on military markets. 2: The business model is primarily civil, with a minor strategic focus on military markets or applications; 21-40% market focus on military markets. 3: The business model balances both civil and military markets, with strategic objectives that cater	European Commission (2014), Penney et al. (2018), Caviggioli et al. (2023), Fiott (2014)

	equally to both sectors; 41-60% market focus on military markets. 4: The business model is predominantly military, with civil applications as secondary considerations; 61-80% market focus on military markets. 5: The business model is exclusively military, with no focus on civil markets or applications; 81-100% market focus on military markets.	
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7.6 Application Example

To illustrate the taxonomy's utility, two illustrative case studies are presented: autonomous drones and quantum encryption technologies. These case studies highlight how the taxonomy evaluates technologies across its 10 criteria, providing clear classifications along the civilian-military continuum. The data for the case studies were collected through a virtual discussion between one of the authors, a VC, and the two startups to rate and evaluate the two companies.

Table 6: Case Study Rating Table

<i>Criteria</i>	<i>Weight</i>	Autonomous Drones		Quantum Encryption	
		<i>Rating</i>	<i>Weighted Rating</i>	<i>Rating</i>	<i>Weighted Rating</i>
TRL		8		5	
Destructive Potential	16%	3	0.48	1	0.16
Lethality	16%	2	0.32	1	0.16
Critical Infrastructure Impact	9%	4	0.36	5	0.45
Funding Sources	7%	3	0.21	2	0.14
Potential for Use in Military	9%	4	0.36	4	0.36
Regulatory and Compliance	3%	3	0.09	4	0.12
Technology Impact Scope	9%	3	0.27	5	0.45
Competitive Landscape	3%	4	0.12	2	0.06
Team Composition	12%	3	0.36	2	0.24
Business Model & Strategy	20%	4	0.80	3	0.60
Totals	100%	33	3.37	29	2.74
Percentage Score (based on total score)			59%		44%

on Scale from 1-5)					
Two 5-point rating condition met?		No		Yes	

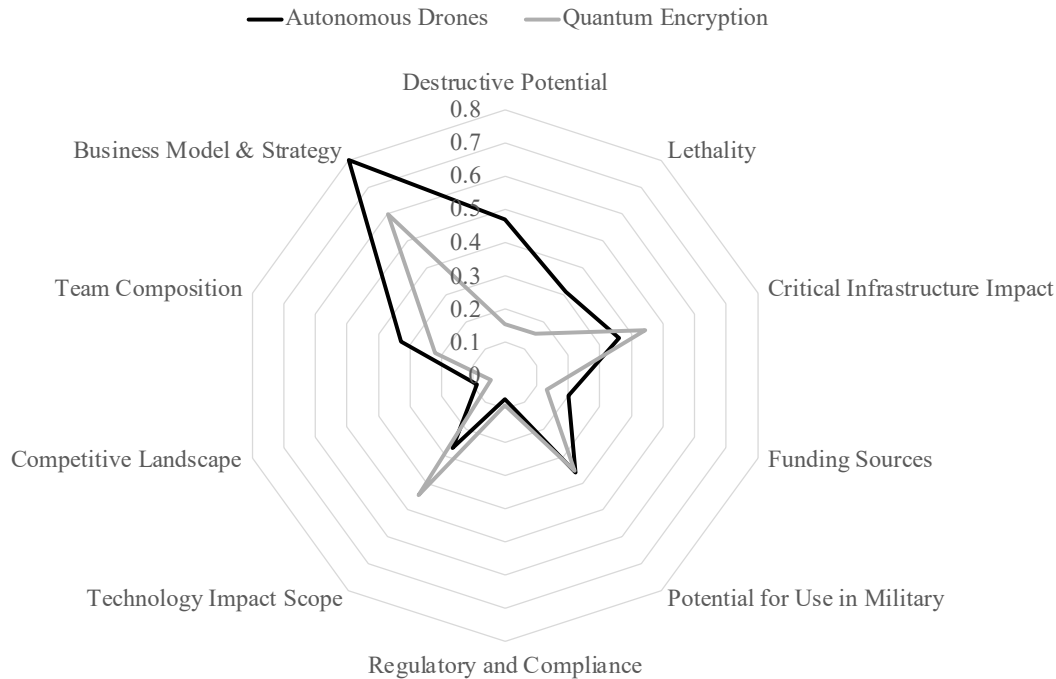


Figure 10: Case Study Weighted Criteria

The first case involved a startup developing autonomous drones with applications in both civilian logistics and military surveillance, which was evaluated as having a TRL of 8. The technology exhibited moderate Destructive Potential (3/5), reflecting its ability to disrupt operations in specific contexts when adapted for military use. Its Lethality was rated lower (2/5), as it posed minimal direct harm but supported reconnaissance missions. The technology's Critical Infrastructure Impact was high (4/5), with potential to safeguard or disrupt transportation networks, depending on its application. In terms of Funding Sources, the startup demonstrated a balanced mix of private investment and government contracts (3/5), and its Potential for Military Use was high (4/5) due to its relevance for battlefield surveillance. Additional evaluations considered Regulatory Compliance, which was rated as moderate (3/5) due to export controls on drone technologies, and Technology Impact Scope,

which was broad (3/5) given the technology's applications across regional and national levels. The Competitive Landscape revealed significant competition in military markets, but fewer competitors focused on civil applications (4/5). The team's Composition was balanced (3/5), with expertise in both civilian logistics and defence. Finally, the company's Business Model and Strategy reflected a dual-revenue approach, targeting both civilian and military markets (4/5). Overall, the technology was evaluated as 3.37 on a scale of 1–5 and was therefore positioned near the military end of the continuum, reflecting its strong defence applications but commercial viability.

The second case involved a company specialising in quantum encryption technologies and a secure communication innovation, which was assessed as TRL 5. The innovation had negligible Destructive Potential (1/5) and Lethality (1/5), as it was non-physical and posed no direct harm. However, its Critical Infrastructure Impact was rated highly (5/5) due to its ability to protect sensitive communication networks. The company's Funding Sources were primarily civilian (2/5), although government interest was growing. Its Potential for Military Use was significant (4/5), particularly for secure military communications.

The company faced strict Regulatory Compliance controls (4/5), reflecting the sensitivity of its dual-use classification. Its Technology Impact Scope was global (5/5), given its applications in securing international data exchanges. The Competitive Landscape mainly comprised civil applications (2/5). The team's Composition showed strong expertise in cryptography but limited defence experience (2/5). Its Business Model and Strategy balanced civilian and military markets (3/5). Although the company received an overall rating of 2.74, it was classified as military under the special rule stipulating that two 5-point ratings on any criteria automatically elevate a technology's classification due to the heightened risk profile associated with its products and technologies.

7.7 Discussion

This study developed a systematic evaluation framework for omni-use technologies that addresses the limitations of existing dual-use classifications. The objective was to create a taxonomy that provides a structured and transparent mechanism for assessing technologies along the civilian–military continuum. To achieve this, a qualitative methodology was employed that integrated outcomes from industry reports, academic literature, and 32 expert interviews. The result is the Omni-Use Technology Continuum Taxonomy, which systematically categorises technologies and companies based on 10 evaluative criteria. The application of the taxonomy demonstrates that traditional dual-use classification is inadequate and that a continuum-based approach offers a more precise evaluative model.

The validation process yielded several important insights. First, the elimination of the ‘dual-use’ category was widely supported by stakeholders, who agreed that a two-pole continuum better captures the omni-use nature of modern technologies. By focusing on civilian and military alignment, the taxonomy provides a more flexible and realistic framework for evaluating innovations.

Second, the taxonomy improves decision-making for VCs and policymakers. For investors, it clarifies the risks and opportunities associated with omni-use technologies, reducing funding hesitancy. For policymakers, the taxonomy provides actionable insights for prioritising technologies that are aligned with national security objectives.

Third, the taxonomy’s criteria is adaptable across diverse sectors, demonstrating its utility for both software-driven and hardware-intensive innovations. Its structured approach allows stakeholders to evaluate technologies comprehensively while accommodating sector-specific nuances.

By providing a structured framework that eliminates the ambiguity of the traditional ‘dual-use’ classification, the taxonomy offers significant implications for practice,

particularly for VCs, policymakers, and industry leaders. Furthermore, its theoretical contributions challenge existing paradigms in technology assessment and strategic management while supporting a more comprehensive understanding of omni-use innovation.

7.7.1 Theoretical Contributions

The taxonomy replaces the traditional dual-use paradigm with a two-pole continuum that reflects the inherent omni-use nature of modern technologies. Previous research has highlighted the limitations of rigid dual-use classifications in technology assessment (Burmaoglu & Sarıtas, 2017; Quas et al., 2022), particularly in cases where emerging technologies rapidly evolve and are adapted to different applications. By removing this category, the taxonomy aligns with contemporary technological realities and provides a more dynamic framework for evaluating the civilian and military relevance of technologies.

Additionally, the taxonomy integrates concepts from strategic management and defence innovation, creating a multidimensional framework that bridges these traditionally separate domains. Criteria such as Business Model and Strategy and Competitive Landscape draw on the strategic management literature, which has long emphasised the role of structured classification in reducing uncertainty and guiding investment decisions (Mazzucato, 2018; Nickerson et al., 2013). The criteria Regulatory Compliance and Technology Impact Scope reflect considerations central to defence innovation and national security, extending existing frameworks that primarily focus on technological maturity scales such as TRLs (European Commission, 2020; Mankins, 1995).

This interdisciplinary approach enhances the taxonomy's utility for both academic and practical audiences and builds upon previous research by offering a structured mechanism to evaluate technologies that do not fit neatly into either the civilian or military categories. Unlike traditional methods that prioritise single-domain applications (Clarke, 2013; Schwartz et al., 2022), this taxonomy expands the scope of evaluation by systematically incorporating

both market-driven and security-oriented dimensions. By doing so, it advances the discussion on technology assessment (Riebe, 2023; Tran & Daim, 2008) and provides a more adaptable model for contemporary innovation ecosystems.

7.7.2 Implications for Practice

For VCs, the taxonomy will reduce the uncertainty associated with evaluating technologies that operate across the civilian and military markets. Investment hesitancy in this area often stems from a lack of clear criteria for assessing the potential risks and returns of omni-use technologies. By integrating criteria such as Business Model and Strategy, Funding Sources, and Competitive Landscape, the taxonomy provides actionable insights into the alignment of technologies with market opportunities. This structured approach clarifies ambiguities and fosters confidence in funding technologies and businesses that might otherwise be overlooked due to perceived or unclear risks.

Policymakers will benefit from the taxonomy's ability to align evaluations with national security and innovation priorities. By emphasising criteria such as Regulatory Compliance, Critical Infrastructure Impact, and Technology Impact Scope, the taxonomy offers a robust tool for prioritising funding allocation. These criteria will help policymakers identify technologies and businesses that address pressing defence and economic needs, while the flexible framework accommodates the evolving nature of omni-use innovations. Moreover, the taxonomy's removal of the dual-use category simplifies decision-making by eliminating an outdated classification that often fails to capture the fluidity of modern technologies.

For industry leaders, the taxonomy will serve as a diagnostic tool for understanding their company's positioning within the civilian and military markets. By scoring themselves across the 10 criteria, organisations can assess their strengths and weaknesses relative to strategic priorities, market competition, and regulatory requirements. This clarity will enable

companies to refine their business models and improve their attractiveness to both private investors and government stakeholders.

The taxonomy's implications extend beyond individual stakeholders to influence the broader ecosystem of innovation. By providing a common framework for evaluating omni-use technologies, the taxonomy will foster collaboration amongst VCs, policymakers, and industry leaders. This shared understanding will reduce fragmentation and support a more cohesive approach to funding and developing strategically important innovations.

The taxonomy will also address systemic barriers to investment in omni-use technologies, particularly the underfunding caused by a lack of clear evaluative tools. By clarifying risks and opportunities, it will encourage greater resource allocation to technologies with dual economic and national security benefits. This, in turn, will support the growth of innovations that drive economic competitiveness and strategic resilience in a globalised, technology-driven landscape.

7.8 Limitations and Future Research

The Omni-Use Continuum Taxonomy represents a significant advancement in evaluating technologies that span civilian and military applications. However, like any evaluative framework, it operates within certain constraints.

One key constraint is the taxonomy's generalised criteria, which are designed to apply across a range of technological sectors. While this approach ensures flexibility and broad applicability, certain industries may require additional criteria to reflect their unique dynamics. For instance, the biotechnology and energy sectors often involve heightened ethical or environmental considerations, which are not explicitly captured by the current criteria. Adapting the taxonomy to include sector-specific criteria or weighting mechanisms could enhance its precision and relevance for specialised contexts.

Another limitation is the focus on technologies at or above TRL 5. By applying this threshold, the taxonomy ensures that only innovations with sufficiently defined application potential are evaluated. This provides clarity and actionable insights for stakeholders. However, excluding earlier-stage technologies may overlook high-potential innovations that lack immediate alignment with civilian or military markets. Many of these technologies are often in the ‘valley of death’ phase where securing funding is particularly challenging. Developing a parallel framework for evaluating technologies below TRL 5 could address this gap, enabling the taxonomy to support early-stage innovation more effectively.

The taxonomy also involves a degree of subjectivity in scoring, as certain criteria rely on qualitative judgments. Dimensions such as Competitive Landscape and Regulatory Compliance are influenced by the evaluator’s expertise, priorities, and interpretation. While qualitative assessments are inevitable in multidimensional evaluations, this reliance on subjective input introduces variability. Exploring the integration of quantitative techniques, such as predictive modelling or machine learning, could enhance consistency and reduce potential biases in scoring across different evaluators.

Geographic validation represents another opportunity for expansion. The taxonomy has been developed and validated primarily within the European context, reflecting the regulatory frameworks and funding ecosystems of this region. While this focus ensures depth and relevance for European stakeholders, its applicability to other regions, such as North America, Asia, or the Middle East, remains untested. Comparative studies in these regions would provide valuable insights into how the taxonomy can be adapted to different regulatory, cultural, and market environments, informing refinements that enhance its global applicability.

Finally, the taxonomy applies static weighting to its 10 criteria, reflecting their perceived importance based on the expert interviews. While this approach provides simplicity

and uniformity, it may not adequately capture the varying relevance of criteria across different technologies or industries. For example, Technology Impact Scope may be more vital for satellite technologies, whereas Team Composition could hold greater importance for medtech startups. Research into dynamic or context-sensitive weighting systems could further enhance the taxonomy's flexibility and accuracy in evaluating different innovations.

Despite these limitations, the taxonomy contributes substantially to the evaluation of omni-use technologies. Its focus on actionable insights and its elimination of outdated classifications like 'dual-use' represent major advancements in technology evaluation. By continuing to refine the taxonomy through sector-specific adaptations, expanded scope, and global validation, future research could ensure its ongoing relevance and contribution to fostering innovation and investment.

7.9 Conclusion

The Omni-Use Continuum Taxonomy advances both the theoretical and practical understanding of technology evaluation at the civilian–military nexus. By replacing the static and increasingly obsolete notion of dual-use with a continuum-based framework, it offers a more granular, dynamic, and realistic lens for classifying technologies that defy traditional sectoral boundaries. Rather than simply relabelling, the taxonomy reconfigures the underlying logic of evaluation by embedding 10 interdependent criteria across the technical, strategic, and market dimensions, affording evaluations both descriptive accuracy and strategic utility.

This study highlights that ambiguity in dual-use classification is not merely a semantic issue but also a substantive barrier to investment, policy alignment, and innovation diffusion. The taxonomy's empirical grounding in expert interviews and scenario testing demonstrates its capacity to resolve these barriers by introducing a common evaluative

language for VCs, policymakers, and industry stakeholders. The feedback collected during the validation process affirmed the framework's usability, particularly in uncovering latent risk dimensions and clarifying the implications of technological convergence for funding decisions.

Importantly, the taxonomy is not presented as a static endpoint but as an adaptive platform. Its design enables context-sensitive application and future modification, whether by adjusting weighting schemes, integrating emerging regulatory regimes, or accommodating sector-specific indicators. While the current iteration focuses on technologies at or above TRL 5, its conceptual architecture lays the groundwork for expansion into earlier development stages, potentially addressing the investment deadlock that often characterises pre-commercial omni-use innovations.

Beyond its practical relevance, the taxonomy contributes to interdisciplinary discourse by bridging the technology governance, strategic management, and defence innovation literature. It challenges conventional approaches, adopts a multidimensional evaluation logic, and foregrounds the systemic nature of innovation in security-sensitive domains. As national security, economic competitiveness, and ethical governance become increasingly entangled in technology policy, this taxonomy offers a theoretically sound and empirically validated instrument for navigating these tensions.

In sum, the Omni-Use Continuum Taxonomy offers a robust and timely framework for understanding and evaluating technologies that operate across the civil–military spectrum. Its capacities to reduce ambiguity, foster inter-stakeholder alignment, and support strategic decision-making mark it as a valuable practical and theoretical tool. With further refinement and international application, it holds the potential to shape future research, guide public and private investment and inform policymaking in an era in which omni-use innovation is no longer the exception but the norm.

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9. Appendix

9.1 Appendix Study I

Table 7: Studies included in the literature review

No.	Author(s) (Year)	Study	VC Ecosystem	Methodology	Key Findings
1	Alhorr, Hadi S.; Moore, Curt B.; Payne, G. Tyge (2008)	The Impact of Economic Integration on Cross-Border Venture Capital Investments: Evidence From the European Union.	Dynamic Drivers	Examined cross-border VC investment flows within the EU in relation to the adoption of common market and currency policies, using data on national changes in VC investing across the EU from 1985 to 2002.	• EU integration policies significantly increased cross-border VC flows. • Common market and currency policies both positively impact VC investments. • The study underscores the importance of economic and monetary union policies on investment dynamics.
2	Alperovych, Yan; Groh, Alexander; Quas, Anita (2020)	Bridging the equity gap for young innovative companies: The design of effective government venture capital fund programs.	Stable Drivers	Analysed the impact of design features of GVC funds across Europe using a dataset of 1230 transactions from 72 GVC funds operating in 16 countries, assessing their effectiveness in achieving growth and	• Identifies a "scale-up gap" where European ventures struggle to secure late-stage financing compared to their US counterparts. • The gap is influenced by the relative immaturity of the European venture capital market and smaller average fund sizes. • Policy interventions and increased institutional investment are recommended to address these disparities.

				innovation for backed companies.	
3	Balboa, Marina; Martí, José; Tresierra-Tanaka, Álvaro (2017)	Are firms accessing venture funding more financially constrained? New evidence from capital structure adjustments.	Dynamic Drivers	Used a dynamic model to examine the speed of adjustment to target debt levels in a sample of 237 Spanish unlisted firms that received venture capital between 1995 and 2007 and a matched control group. The model, based on the generalized method of moments estimator, considered several firm characteristics including size, profitability, and asset tangibility.	- Firms that received venture capital exhibited a significantly lower speed of adjustment to their target debt ratio compared to their matched peers, indicating higher financial constraints before obtaining venture capital. - The results suggest that these firms prioritize funding investments over adjusting their debt ratios to target levels. - The study underscores venture capital's role in filling the equity gap for financially constrained firms, helping them balance their capital structures during growth phases.
4	Bertoni, Fabio; Colombo, Massimo G.; Croce, Annalisa (2010)	The Effect of Venture Capital Financing on the Sensitivity to Cash Flow of Firm's Investments.	Target Perf during Holding Period	Empirical analysis using a longitudinal sample of 379 Italian unlisted NTBFs observed from 1994 to 2003, examining the effects of VC financing on firms' investments.	- VC financing reduces investment-cash flow sensitivity, particularly for firms backed by IVC funds. - CVC-backed firms remain sensitive to cash flow shocks, indicating different types of VC influence. - The presence of VC leads to an overall increase in the investment rates of NTBFs, regardless of the type of VC investor.
5	Bertoni, Fabio; Colombo, Massimo;	The patterns of venture capital investment in Europe.	Multiple	Utilised the VICO database, covering 1,663 first VC investments made by	Governmental VC (GVC) investors are distinct, heavily investing in early-stage and high-risk startups, contrary to typical expectations.

	Quas, Anita (2015)			846 investors in 737 young high-tech entrepreneurial ventures in seven European countries to examine investment patterns by different types of VC investors (independent, corporate, bank-affiliated, and governmental).	- Independent VC (IVC) investors in Europe focus more on later-stage investments, contrasting with their US counterparts who engage more with early-stage ventures. - Investment patterns of VC investors are consistent over time and similar across different European countries, significantly differing from those in the USA.
6	Bertoni, Fabio; D'Adda, Diego; Grilli, Luca (2016)	Cherry-picking or frog-kissing? A theoretical analysis of how investors select entrepreneurial ventures in thin venture capital markets.	Dynamic Drivers	Developed a formal theoretical model to analyse the selection behaviour of venture capitalists in thin VC markets, distinguishing between selecting ventures in desperate need ("frog-kissing") versus selecting the best performers ("cherry-picking").	- In thin VC markets, venture capitalists are likely to invest in firms in need rather than the best performers, due to a lack of sufficient viable options. - High-performing ventures often self-select out of the VC market in these conditions, potentially due to high opportunity costs or insufficient VC availability. - The model predicts that this selection behaviour leads to a mismatch where potentially high-impact ventures may forego VC, while less promising ventures receive funding.
7	Bertoni, Fabio; Colombo, Massimo G.; Quas, Anita (2019)	The Role of Governmental Venture Capital in the Venture Capital Ecosystem: An Organisational	Key Stakeholders, Investment Decision	Utilises organisational ecology theory to analyse 1,239 PVC investments in Europe, exploring the interaction between GVC and PVC in	- Greater presence of GVC leads PVCs to invest in younger, smaller, and riskier ventures, supporting a mutualistic relationship between GVC and PVC. - GVC use of syndication strategies effectively attracts PVCs to invest in less competitive markets and industries.

		Ecology Perspective.		shaping investment behaviours.	• Even without direct syndication with GVCs, PVCs are more likely to invest in less competitive regions and smaller companies when GVC density is greater.
8	Bottazzi, Laura; Da Rin, Marco; Hellmann, Thomas (2008)	Who are the active investors?: Evidence from venture capital	Investment Decision	Employed a hand-collected dataset of European venture capital deals to explore the effects of venture capital firm characteristics on investor activism.	• Venture capital firms with partners who have previous business experience are significantly more active in their investment approach. • Independent venture capital firms exhibit more investor activism compared to captive firms. • A positive correlation exists between higher levels of investor activism and the success of portfolio companies.
9	Bottazzi, Laura; Da Rin, Marco; Hellmann, Thomas (2016)	The Importance of Trust for Investment: Evidence from Venture Capital.	Multiple	Utilizes econometric models to explore the impact of trust on venture capital investments, using a dataset covering various country dyads and considering trust at both the general and specific levels between investors and firms.	• Trust significantly influences investment decisions and is crucial in the early stages of investment. • Syndication is more prevalent in low-trust scenarios, suggesting a strategy to mitigate risk. • The geographic distance and cultural proximity significantly affect investment flows and success rates in venture capital.
10	Buzzacchi, Luigi; Scellato, Giuseppe; Ughetto, Elisa (2013)	The investment strategies of publicly sponsored venture capital funds	Stable Drivers	Used data from 179 VC funds that received financial support from the European Investment Fund, covering all venture capital transactions in Europe from 1998 to	• Public ownership in venture capital funds leads to a more cautious investment strategy, with a weak negative correlation to write-off likelihood and a tendency for longer investment durations. • Funds with higher public shares are less likely to invest in ventures that go bankrupt and more likely to hold

				2007. This study explores the relationship between the level of public ownership in these funds and their investment strategies and outcomes	investments longer, especially those yielding intermediate financial returns. • The findings suggest that public venture capital can help moderate the risk profile of venture capital investments and extend the duration of investment for more sustainable growth.
11	Coad, Alex; Srhoj, Stjepan (2021)	Entrepreneurial ecosystems and regional persistence of high growth firms: A 'broken clock' critique.	Investment Decision	The study uses a critique approach, re-evaluating the established assumptions about entrepreneurial ecosystems through a comprehensive review of existing literature combined with new empirical insights.	• The regional persistence of high-growth firms is not as straightforward as traditional entrepreneurial ecosystem models suggest. • Policy implications derived from these models may be misleading if the unique, dynamic characteristics of regions are not considered. • Calls for a revised model that incorporates a broader range of socio-economic factors and their interactions over time.
12	Colombo, Massimo G.; D'Adda, Diego; Quas, Anita (2019)	The geography of venture capital and entrepreneurial ventures' demand for external equity.	Investment Decision, Dynamic Drivers	Analysed data from 533 high-tech entrepreneurial ventures across Europe from the VICO database, assessing external equity-seeking behaviour from 1984 to 2009.	• Proximity to venture capital hubs significantly increases a startup's chances of securing VC funding. • Startups located beyond a 250km radius from a VC hub face sharply diminished prospects for funding. • National borders and cultural differences further complicate cross-border venture capital investments.
13	Croce, Annalisa; Martí, José;	The impact of venture capital on the productivity	Target Performance during	Used the VICO dataset to analyse 696 entrepreneurial firms across Europe,	• No significant productivity differences between VC-backed and non-VC-backed firms before venture capital financing, suggesting that screening based on past

	Murtinu, Samuele (2013)	growth of European entrepreneurial firms: 'Screening' or 'value added' effect?	Holding Period	employing a matching procedure and robust econometric models to differentiate the effects of venture capital financing on firm productivity from mere financial injections.	performance is not the differentiator for venture capital decisions. • Post-financing, VC-backed firms showed significantly greater productivity, indicating a strong value-added effect from venture capital involvement. • The value-added impact of venture capital is persistent, not diminishing significantly after venture capital exit, which suggests that venture capital investment leaves a lasting imprint on firm operations.
14	Cumming, Douglas (2008)	Contracts and Exits in Venture Capital Finance.	Target Performance at Exit	Analysed a dataset of 223 European VC investments between 1996 and 2005, exploring the impact of VC contractual control rights on exit outcomes such as IPOs and acquisitions.	• Contractual agreements significantly affect the likelihood and success of IPO exits compared to other exit strategies. • The specificity of covenants in venture capital contracts can either facilitate or hinder the process of taking a company public. • Stronger investor protections are associated with higher probabilities of successful IPOs, indicating the critical role of detailed contractual terms in exit strategies.
15	Cumming, Douglas J.; Grilli, Luca; Murtinu, Samuele (2017)	Governmental and independent venture capital investments in Europe: A firm-level performance analysis.	Target Performance at Exit	The study analysed the impact of GVC and IVC venture capital backing on exit performance of entrepreneurial firms using the VICO dataset, which encompasses a wide	• Private independent VC-backed companies exhibit better exit performance compared to government-backed ones. • Mixed syndicates of private-independent and governmental VC investors show higher, albeit not statistically different, probabilities of positive exits than those backed solely by IVCs.

				range of European countries and companies. The methodology employed econometric techniques to control for endogeneity concerns, selection biases, and omitted variable biases.	The study's findings hold across various robustness checks and do not change significantly after adjusting for legal and institutional differences across countries or potential biases in the data.
16	Cumming, Douglas; Schmidt, Daniel; Walz, Uwe (2010)	Legality and venture capital governance around the world	Multiple	Analysed a dataset of 3,828 VC investments across 39 countries from 1971 to 2003 to investigate how different legal systems affect venture capital governance structures.	- Strong legal protections correlate with more favourable VC governance and management practices. - Diverse governance structures across countries reflect variations in legal and regulatory environments. - Effective VC governance contributes to better investment outcomes and lower risk profiles.
17	Cumming, Douglas; Zambelli, Simona (2017)	Due Diligence and Investee Performance.	Investment Decision	Examined the economic value of DD in private equity by assessing the relationship between DD and investee performance, using a unique hand-collected dataset covering the majority of funds actively involved in the Italian private equity market. The study considers the impact of different types of DD	- A thorough DD process carried out by fund managers significantly correlates with improved investee performance, particularly in terms of Return on Assets (ROA) and EBITDA/Sales. - DD mainly performed by external agents like consultants, lawyers, and accountants showed no significant impact on performance, suggesting potential agency costs associated with external DD. - The study reinforces the importance of internal management of DD processes over delegation to external agencies for achieving better investment outcomes.

				(internal vs. external) on firm performance.	
18	Devigne, David; Manigart, Sophie; Wright, Mike (2016)	Escalation of commitment in venture capital decision making: Differentiating between domestic and international investors.	Dynamic Drivers	Conducted a longitudinal analysis of 1,618 VC investment rounds in 684 technology-based companies across seven European countries, using a competing risks model to compare the escalation of commitment between domestic and international venture capital investors.	• Domestic VC investors are more likely to escalate their commitment to underperforming ventures compared to international VCs, who make more rational termination decisions. • International VCs, including those operating through local branches, benefit from less emotional and social attachment and lower normative pressures, reducing biases in termination decisions. • The presence of an international investment committee helps mitigate escalation biases for branch VCs, suggesting that organizational structures can influence investment termination decisions.
19	Devigne, David; Vanacker, Tom; Manigart, Sophie; Paeleman, Ine (2013)	The role of domestic and cross-border venture capital investors in the growth of portfolio companies.	Target Performance during Holding Period	Utilised a longitudinal research design, tracking sales, total assets, and payroll expenses of 761 European technology companies over seven years following their initial venture capital investment. The study differentiated the impact of domestic versus cross-border venture capital	• Domestic venture capital investors contribute to quicker early-stage growth compared to cross-border investors. • Cross-border venture capital investors contribute significantly to a firm's international expansion and overall growth in later stages. • Firms financed by a mix of domestic and cross-border investors show the strongest growth performance over time.

				investors on these growth metrics.	
20	Diller, Christian; Kaserer, Christoph (2009)	What Drives Private Equity Returns?– Fund Inflows, Skilled GPs, and/or Risk?	Target Performance at Exit	Weighted least squares (WLS) regression and bootstrapping approach to analyse the impact of fund inflows, GPs skills, and standalone investment risk on the returns of private equity funds.	• There is a significant negative correlation between the amount of money directed towards the private equity industry during a fund's investment phase and the fund's performance, supporting the 'money chasing deals' hypothesis. • Fund returns are positively associated with the skills of GPs and standalone investment risk, suggesting that management skills significantly influence fund outcomes. • Private equity funds' returns are not correlated with stock market returns and often negatively correlate with broader economic indicators.
21	Espenlaub, Susanne; Khurshed, Arif; Mohamed, Abdulkadir (2015)	VC investments and global exits.	Target Performance at Exit	Analysed data on exits of UK VC backers from portfolio companies worldwide. The study assessed the frequency and success of exit routes such as M&A, IPO, and MBO, considering the role of market liquidity, legal systems, and characteristics of VCs and companies.	• M&A is the most common exit route globally, especially for UK investments; IPOs are more common abroad than in the UK. • Successful exits are more likely with experienced VC firms and when part of a syndicate including reputed firms. • Countries with high market liquidity and strong legal systems facilitating investor protection are more likely to see successful exits through IPOs or M&As.
22	Falconieri, Sonia; Filatotchev,	Size and diversity in VC syndicates and	Target Performance at Exit	Analysed a dataset of VC-backed US IPOs between 1985 and	• Larger and more diverse VC syndicates are associated with higher IPO underpricing and lower company

	Igor; Tastan, Mesut (2019)	their impact on IPO performance.		2012, focusing on the influence of syndicate size and diversity on IPO and post-IPO performance. The study employed regression analyses with controls for various firm and offer characteristics, supplemented by robustness tests using instrumental variables to address potential endogeneity issues.	valuations at IPO, indicating a negative impact on immediate financial performance. • This negative impact persists long-term, as larger and more diverse syndicates also correlate with poorer long-term performance metrics like lower cumulative abnormal returns and industry-adjusted EBITDA. • The study suggests that the coordination problems and internal agency conflicts inherent in larger, more heterogeneous syndicates diminish their effectiveness in enhancing portfolio company performance.
23	Gompers, Paul; Kovner, Anna; Lerner, Josh; Scharfstein, David (2008)	Venture capital investment cycles: The impact of public markets	Target Performance at Exit	This study uses empirical data from 1975 to 1998 to examine the relationship between venture capital investment and public market signals, particularly using metrics like Tobin's Q and IPO activity.	• Venture capital investments are highly sensitive to public market signals, with a significant increase in investment activities when public market conditions are favorable. • Investment activities by the most experienced venture capitalists are most responsive to these market signals, suggesting that industry-specific experience plays a critical role in investment decisions. • The success rate of investments does not deteriorate with increased investment rates during favorable market conditions, indicating that experienced venture capitalists can effectively capitalize on these conditions without increasing the risk of failure.

24	Grilli, Luca (2014)	High-Tech Entrepreneurship in Europe: A Heuristic Firm Growth Model and Three “(Un-)easy Pieces” for Policy-Making.	Stable Drivers	The paper develops a heuristic firm growth model based on empirical literature concerning high-tech entrepreneurial ventures in Europe, focusing on identifying key policy interventions to support such enterprises.	• Entrepreneurial success in high-tech sectors is closely tied to the specific skills and previous sectorial experience of founders rather than broad management knowledge. • European venture capital (VC) tends to engage in 'building winners' through active involvement rather than merely selecting the most promising firms, contrasting with the U.S. approach which focuses more on selecting winners. • Public policies should focus on reducing the stigma and regulatory burdens associated with entrepreneurial failure to foster a more dynamic high-tech entrepreneurial environment in Europe.
25	Grilli, Luca; Murtinu, Samuele (2014)	Government, venture capital and the growth of European high-tech entrepreneurial firms.	Multiple	Used the VICO dataset, a firm-level longitudinal dataset, to examine the impact of GVC and IVC funds on the growth of high-tech entrepreneurial firms in Europe.	• IVC funds have a positive and statistically significant impact on firm sales growth, unlike GVC funds which show negligible effects. • Co-financed ventures, especially those led by IVCs, tend to perform better, suggesting a higher efficacy of IVCs in fostering company growth. • The impact of venture capital on firm growth varies significantly based on the type of VC (governmental vs. independent) and the presence of co-financing between these entities.
26	Groh, Alexander Peter; von Liechtenstein,	The European Venture Capital and Private Equity country	Stable Drivers, Dynamic Drivers	Created composite indexes comparing the attractiveness of 25 European countries for	• The UK led the rankings due to superior investor protection, corporate governance, and a robust capital market,

	Heinrich; Lieser, Karsten (2010)	attractiveness indices		venture capital and private equity investments using 42 different criteria. The methodology included a robust statistical approach with sensitivity analyses to ensure the reliability of the index scores.	which is crucial for financial transactions and exit opportunities. • Countries like Germany scored slightly above average, while France, Italy, Spain, and Greece had lower scores due to less favourable investor protections and smaller, less liquid capital markets. • The study established a significant correlation between the attractiveness indices and actual venture capital and private equity fundraising activities, validating the predictive power of the indices.
27	Guerini, Massimiliano; Quas, Anita (2016)	Governmental venture capital in Europe: Screening and certification.	Target Performance during Holding Period	Endogenous switching regression model to differentiate between GVC and PVC impacts.	• GVC financing is crucial for companies to obtain PVC funding in subsequent rounds. • Companies backed by GVC are more likely to have a successful exit compared to those without GVC. • GVC facilitates the screening process for future private funding rounds.
28	Haeussler, Carolin; Hennicke, Maria; Mueller, Elisabeth (2019)	Founder– inventors and their investors: Spurring firm survival and growth.	Target Performance during Holding Period	Panel data analysis of 1,498 firms with various regression models including Cox hazard model and IV probit model for survival analysis, and Canay quantile model for growth analysis.	• Founders involved in inventive activities significantly improve firm survival and growth, particularly when backed by venture capital. • Venture capitalists enhance the positive impact of founders' inventive activities on firm growth. • Ongoing founder involvement in R&D beyond initial stages further increases a firm's chances of survival and growth.

29	Hartmann-Wendels, Thomas; Keienburg, Georg; Sievers, Soenke (2011)	Adverse Selection, Investor Experience and Security Choice in Venture Capital Finance: Evidence from Germany.	VC Investment Process	Empirical analysis of 336 German VC transactions (1990-2005) with a focus on financial security choice related to agency problems.	• Experienced VCs prefer equity to manage adverse selection and moral hazard. • Start-ups and high-tech firms predominantly financed by equity or mixed securities. • Market conditions significantly influence security choice.
30	Henrekson, Magnus; Sanandaji, Tino (2018)	Stock option taxation: a missing piece in European innovation policy?	Stable Drivers	Reviewed empirical and theoretical literature on the role of stock option taxation in venture capital and startup ecosystems, comparing tax policies between the US and European countries. The paper analysed the correlation between the tax rates on employee stock options and the level of venture capital activity in different countries using regression analyses.	• Lower tax rates on employee stock options are associated with higher levels of venture capital activity and entrepreneurial growth, particularly in the US compared to Europe. • European countries with higher taxes on stock options tend to have less vibrant venture capital markets, suggesting that tax policy plays a critical role in entrepreneurial finance. • The study advocates for European policymakers to consider reducing taxes on stock options to stimulate venture capital investment and entrepreneurial activity, mimicking more successful models seen in the US.
31	Imad'Eddine, Gael; Schwenbacher, Armin (2013)	International Capital Flows into the European Private Equity Market.	Dynamic Drivers	Examined the flow of private equity capital from the US to Europe, focusing on the choices US LPs make between investing in US funds with European targets	• US LPs with operational facilities in Europe are more likely to invest directly in European funds due to lower transaction costs and better access to local market information. • Pension funds and other large financial institutions are major contributors to

				or directly in European funds. The study utilised a comprehensive dataset from VentureXpert covering investments between 1985 and 2002.	European private equity, preferring direct investments in European funds despite the absence of local facilities. • The overall volume of capital from US LPs to European private equity has increased significantly, indicating growing US interest and confidence in European markets.
32	Inderst, Roman; Mueller, Holger M. (2009)	Early-stage financing and firm growth in new industries	Target Performance during Holding Period	Theoretical model and empirical analysis based on a dataset of new firms in high-tech industries, analysing the impact of early-stage financing on long-term growth.	• Early-stage financing significantly impacts the growth trajectory of firms, with those receiving more substantial early investments tending to achieve higher long-term growth. • The structure of financing (e.g., the presence of venture capital vs. angel investors) influences the strategic decisions and growth rates of new ventures. • The competitive dynamics of the industry play a crucial role in determining the effectiveness of early-stage investments, with more competitive sectors seeing greater benefits from early large investments.
33	Karsai, Judit; Wright, Mike; Dudzinski, Zbigniew; Morovic, Jan (1998)	Screening and valuing venture capital investments: Evidence from Hungary, Poland and Slovakia.	Investment Decision	The study utilised surveys and interviews of venture capital firms in Hungary, Poland, and Slovakia to investigate their screening and valuation practices for investments. It	• Venture capital firms in these countries tend to seek more equity ownership and use different financial benchmarks during deal screening compared to their UK counterparts. • Due diligence in these markets relies more on personal connections and direct market evaluations due to less developed

				compared these practices to the established UK venture capital market to identify developmental and operational differences.	financial systems and professional services. • There are significant variations in the valuation methods used, with a stronger reliance on discounted cash flow analyses in CEE countries due to the unavailability of reliable market comparable.
34	Kräussl, Roman; Krause, Stefan (2014)	Has Europe Been Catching Up? An Industry Level Analysis of Venture Capital Success over 1985-2009.	Target Performance at Exit	Tracked over 40,000 VC-backed firms from six industries in 13 European countries and the USA between 1985 and 2009 to examine the type of exit chosen and the success rates across different industries and stages of company development.	• Industry-specific characteristics significantly affect the performance of VC investments, with sectors like biotech performing well due to high levels of IPO exits. • Europe shows lower overall entrepreneurial activity compared to the USA, which negatively impacts successful exits, particularly IPOs, in European VC markets. • There are marked differences in VC success rates between early-stage and mature companies, with mature companies typically showing better outcomes.
35	Lahr, Henry; Mina, Andrea (2014)	Liquidity, Technological Opportunities, and the Stage Distribution of Venture Capital Investments.	Dynamic Drivers	Analysed 35,240 European private equity investments from 1990 to 2011, using econometric models to assess how liquidity conditions and technological opportunities influenced the stage distribution of investments.	• Liquidity crises increase the likelihood of venture capital firms investing in earlier stages of company development relative to all private equity investments. • Technological opportunities are a major driver of early and late stage venture capital investments, more so than liquidity conditions. • The recent financial crisis significantly altered the stage distribution, favouring early and late stage investments over expansion stages, which contrasts with the

					patterns observed during the dotcom crash.
36	Leleux, Benoit; Surlmont, Bernard (2003)	Public versus private venture capital: seeding or crowding out? A pan-European analysis	Stable Drivers	Utilised a dataset of venture capital investments from 15 European countries over 1990-1996, examining the impact of public versus private venture capital on the growth and dynamics of the venture capital industry.	• Public venture capital does not seed the industry nor does it crowd out private investment; instead, it is associated with smaller overall market sizes. • Public venture capital tends to be reactive, following rather than initiating industry growth, with significant investments in later-stage deals that align with regional development goals. • The presence of public venture capital is correlated with greater overall investment in the venture capital industry, possibly due to its legitimizing effect.
37	Manac, Radu- Dragomir; Martin, Jens; Wood, Geoffrey (2022)	Varieties of funds and performance: the case of private equity.	Key Stakeholder, Target Performance at Exit	The study investigates eleven different types of private equity funds to understand variations in performance and the underlying factors influencing these differences. It utilizes extensive dataset covering 1990–2013 and applies various econometric models to assess performance metrics such as internal rate of return (IRR) and investment	• There is considerable heterogeneity in performance between different types of funds, with certain fund types, like buyout funds, consistently outperforming others such as venture capital and distressed funds. • Larger funds often exhibit poorer performance relative to smaller ones, a phenomenon not fully explained by conventional metrics but suggesting issues such as difficulty in maintaining high investment returns at increased scales. • Despite varied performance outcomes, riskier and underperforming fund types continue to attract substantial investment, possibly due to structural market dynamics and investor behaviour influenced by economic conditions and expectations.

				multiples across these fund types.	
38	Manigart, Sophie; De Waele[*], Koen; Wright, Mike; Robbie, Ken; Desbrieres, Philippe; Sapienza, Harry; Beekman, Amy (2000)	Venture capitalists, investment appraisal and accounting information: a comparative study of the USA, UK, France, Belgium and Holland.	Dynamic Drivers	Conducted a comparative analysis of VCs investment appraisal practices across several European countries, employing survey data to examine the role of accounting information in their decision-making processes.	• VCs in different countries vary significantly in their reliance on accounting information, with variations influenced by local market characteristics and the maturity of the venture capital market. • VCs from more mature markets (such as the UK and France) tend to place greater emphasis on sophisticated financial metrics and forecasts compared to those in less developed markets. • The integration of accounting information into investment appraisal is influenced by the institutional context, including the regulatory environment and the development of financial markets.
39	Manigart, Sophie; Lockett, Andy; Meuleman, Miguel; Wright, Mike; Landström, Hans; Bruining, Hans; Desbrières, Philippe; Hommel, Ulrich (2006)	Venture Capitalists' Decision to Syndicate.	Syndication	Utilized a questionnaire-based approach combined with data from the European Venture Capital Association to examine VC syndication motives in six European countries, exploring both fund-level and deal-specific factors.	• Portfolio management motives, such as risk sharing and access to larger deals, are predominant for syndication over deal management motives like selection and monitoring. • Value-adding is more significant as a motive for early-stage investors than for later-stage ones, reflecting greater involvement at the venture's formative stages. • Syndication patterns reflect reciprocal relationships among VCs, with non-lead investors typically joining for the lead's selection and value-adding abilities.

40	Manzaneque, Montserrat; Merino, Elena; Priego, Alba María (2016)	The role of institutional shareholders as owners and directors and the financial distress likelihood. Evidence from a concentrated ownership context.	Target Performance during Holding Period	The study examines the impact of institutional shareholders as both owners and directors on the likelihood of financial distress within firms operating in concentrated ownership environments like Spain. It utilizes a conditional logistic regression model based on data from Spanish firms.	• High ownership concentration by institutional shareholders doesn't significantly decrease financial distress likelihood. • Directors' ownership aligns interests with shareholders, potentially reducing financial distress. • Different types of director ownership (executive, independent, proprietary) have varying impacts on distress likelihood.
41	Meuleman, Miguel; Jääskeläinen, Mikko; Maula, Markku V.J.; Wright, Mike (2017)	Venturing into the unknown with strangers: Substitutes of relational embeddedness in cross-border partner selection in venture capital syndicates.	Stable Drivers, Syndication	Empirical analysis using data on 1355 cross-border VC investments involving 873 target companies across 12 European countries from 2000 to 2008.	• Direct and indirect relational ties between syndicate members significantly influence the formation of new partnerships, with indirect ties partially substituting for the absence of direct ties. • High-quality legal frameworks and industry associations facilitate cross-border partnerships, reducing the reliance on previous relational ties. • The study highlights the interplay between relational and structural embeddedness and how they are moderated by macro-level institutional contexts in cross-border VC investments.
42	Meuleman, Miguel; Wright, Mike (2011)	Cross-border private equity syndication: Institutional	Syndication	Utilized a novel hand-collected dataset of UK private equity (PE) firms investing in	• Institutional contexts significantly affect the structure and success of cross-border private equity syndications.

		context and learning		continental Europe from 1990 to 2006 to analyse the impact of institutional context and organizational learning on cross-border syndication decisions.	• Learning from past syndication experiences is crucial for success in different institutional contexts. • There is a high degree of variability in syndication outcomes based on institutional strengths and weaknesses.
43	Metrick, Andrew; Yasuda, Ayako (2011)	Venture Capital and Other Private Equity: a Survey.	VC Investment Process	This paper reviews the existing literature on venture capital and other private equity forms to explore the roles of private equity funds in the economy and their effects on innovation, competition, and employment. It integrates empirical evidence and theoretical frameworks from numerous studies to form its conclusions.	• Professional private equity exists mainly due to the private ownership advantages and the illiquidity and information asymmetry associated with it. • Private equity managers significantly influence their portfolio companies' strategies and operational execution. • The design of contracts between private equity managers and their investors, and between managers and portfolio companies, critically affects investment outcomes.
44	Murray, Gordon (1996)	A Synthesis of Six Exploratory, European Case Studies of Successfully Exited, Venture Capital-Financed, New	Target Performance at Exit	Exploratory case study analysis of six European new technology-based firms (NTBFs) that successfully exited venture capital financing.	• NTBFs that successfully exit share common characteristics such as exceptional management teams and strategically defensible product positions. • Successful exits require not just financial investment but also significant competency in managing growth and navigating market challenges.

		Technology-Based Firms.			European venture capital is often cautious with technology investments, impacting the potential for high returns.
45	Murray, Gordon; Marriott, Richard (1998)	Why has the investment performance of technology-specialist, European venture capital funds been...	Target Performance at Exit	Utilized a spreadsheet model based on input costs and expected output values from several independent European technology-focused, early-stage venture capital firms. The model simulated the Internal Rate of Return (IRR) and Net Present Value (NPV) for both investors and venture capitalists under various assumptions about fund size and state support mechanisms.	- The performance of European technology-specialist VC funds is heavily dependent on fund size, with smaller funds particularly vulnerable to poor returns. - Public support mechanisms can mitigate, but not eliminate, the negative performance impacts of small fund sizes, showing that without sufficient capital management, even state interventions are limited in effect. - The study underscores the importance of adequately scaled venture capital funds to achieve significant economic returns, emphasizing that the U.S. model of higher returns might not be directly translatable to European contexts due to structural and market differences.
46	Ooghe, Hubert; Manigart, Sophie; Fassin, Yves (1991)	Growth Patterns of the European Venture Capital Industry.	Stable Drivers, Syndication	Descriptive analysis based on EVCA data from 1984-1989 on venture capital growth and investment patterns in Europe.	- Significant differences in VC growth between emerging and established European markets. - Banks and corporate investors are major VC contributors, with considerable variation across countries. - The majority of VC investments are domestic, with a focus on expansion and MBO stages.
47	Patzelt, Holger; zu Knyphausen-	Upper echelons and portfolio strategies of	Investment Decision	Examined the influence of TMT characteristics	VC firms with a higher proportion of TMT members having science/engineering education and entrepreneurial experience

	Aufseß, Dodo; Fischer, Heiko T. (2009)	venture capital firms		(education and experience) on portfolio strategy choices in 136 European venture capital firms using regression analysis.	are more likely to invest in early-stage ventures. • TMTs with more management education diversify their portfolios more across industries. • The broader geographic scope of investees is associated with TMTs that have more international experience.
48	Petty, Jeffrey S.; Gruber, Marc (2011)	“In pursuit of the real deal”: A longitudinal study of VC decision making	Investment Decision	Employed a longitudinal study of VC decision-making over 11 years using archival data from a European VC firm.	• VC decision-making criteria evolve over time and differ across various stages of the evaluation process. • The primary criteria for deal rejection include the VC fund's composition and the management time available, along with changes in decision-making priorities between funds. • Rejected deals often have an opportunity for reconsideration, indicating that initial rejection by a VC does not preclude future investment.
49	Popov, Alexander; Roosenboom, Peter (2013)	Venture capital and new business creation.	Opportunity Space	Conducted a comprehensive study using a database of firms from 21 European countries over 1998-2008 to assess the impact of VC on new business creation.	• Increased venture capital availability is linked to a higher rate of new business creation. • The positive impact of venture capital is stronger in environments with high entry costs, strong IP protections, and low capital gains taxes. • Venture capital significantly enhances aggregate productivity and innovation at the industry level.

50	Pradhan, Rudra P.; Arvin, Mak B.; Nair, Mahendhiran; Bennett, Sara E. (2019)	Sustainable economic growth in the European Union: The role of ICT, venture capital, and innovation.	Opportunity Space	The study used a panel vector autoregressive model to examine causal relationships among ICT diffusion, innovation diffusion, venture capital investment, and economic growth for 25 European countries from 1989 to 2016.	• Both unidirectional and bidirectional causality were found among the variables, impacting economic growth. • In the long run, venture capital investment, ICT diffusion, and innovation diffusion significantly influence economic growth in Europe. • The direction of causality varies in the short run, depending on the specific measures of ICT diffusion and innovation diffusion used.
51	Quas, Anita; Mason, Colin; Compañó, Ramón; Testa, Giuseppina; Gavigan, James P. (2022)	The scale-up finance gap in the EU: Causes, consequences, and policy solutions.	Dynamic Drivers	The paper synthesizes findings from a seminar involving 117 experts from various backgrounds, discussing the scale-up finance gap in the EU. The seminar utilized a collaborative approach to gather insights from start-ups, financial intermediaries, academics, and EU policymakers.	• There is a substantial finance gap at the scale-up stage across Europe, primarily due to the immaturity of the EU's venture capital markets compared to the US. • The smaller average size of EU venture capital funds and regulatory hurdles are significant contributors to this gap. • Recommended policy solutions include fostering larger VC funds and improving regulatory frameworks to facilitate larger scale investments.
52	Reid, G. C.; Terry, N. G; Smith, J. A. (1997)	Risk management in venture capital investor-investee relations.	Syndication	Empirical analysis based on interviews with 20 UK venture capital investors and their investees, using principal-agent analysis to examine	• Investors employ advanced risk management, including portfolio balancing and strategic risk sharing. • Effective communication between investors and investees is crucial for managing risk.

				risk management strategies.	• Venture capitalists face significant inherent risks, despite careful risk management practices.
53	Revest, Valérie; Sapio, Alessandro (2012)	Financing technology-based small firms in Europe: what do we know?	Stable Drivers	The paper reviews literature and empirical evidence concerning the financing of TBSFs in Europe, analysing various sources of capital, from internal financing to venture capital and public equity markets, focusing on how these sources impact the growth and sustainability of TBSFs.	• TBSFs in Europe primarily rely on internal funds due to market failures related to asymmetric information. • The European venture capital market has grown, particularly in the UK, but it's unclear if it enhances company quality as effectively as US venture capital. • Public venture capital and R&D tax incentives in Europe have shown some success in supporting high-tech firms by mitigating financial constraints.
54	Romain, Astrid; Van Pottelsberghe de la Potterie, Bruno (2003)	The Determinants of Venture Capital: A Panel Data Analysis of 16 OECD Countries	Dynamic Drivers	Utilizes a panel data analysis involving 16 OECD countries from 1990-1998 to examine the impact of macroeconomic conditions, technological opportunities, and the entrepreneurial environment on VC intensity using various econometric models.	• Interest rates and the corporate income tax rate significantly influence VC intensity, with different impacts depending on the type of interest rate (short-term vs long-term). • Higher levels of entrepreneurship and less rigid labour markets enhance the positive impacts of GDP growth and available knowledge stock on VC intensity. • Technological opportunities, indicated by R&D investment growth and the number of triadic patents, significantly and positively affect VC intensity,

					highlighting the importance of innovation and technology in attracting VC.
55	Schumpeter, Joseph Alois (1934)	The theory of economic development	Introduction, Dynamic Drivers	The methodology involves a historical and analytical review of Joseph Schumpeter's 1918 article on the tax state, focusing on its long-term dynamic views and the political and legal crises of tax states.	• Schumpeter's article is considered a foundational element of his politico-economic analysis, emphasizing the complex interactions between the public budget, legal frameworks, and political crises. • The crisis of the tax state is analyzed not only as a financial crisis but also a legal and political one, integrating public finance with broader societal structures. • Schumpeter's concept remains relevant for understanding the limits of the welfare state and discussing the reorganization of the tax state in modern contexts.
56	Serrasqueiro, Zélia; Nunes, Paulo Maças; da Rocha Armada, Manuel (2016)	Capital structure decisions: old issues, new insights from high-tech small- and medium-sized enterprises.	VC Investment Process	Used panel data models to compare capital structure decisions of high-tech small- and SMEs and non-high-tech SMEs, focusing on their alignment with Pecking Order Theory and Trade-Off Theory. The study involves data from unquoted Portuguese SMEs categorized into these two groups, analysing factors like financing	• High-tech SMEs' capital structures align more closely with Pecking Order Theory, showing a preference for equity over debt when internal funds are exhausted due to higher perceived risks and intangible assets. • Non-high-tech SMEs align more closely with Trade-Off Theory, aiming for an optimal debt level balancing tax shields against bankruptcy risks. • Venture capital involvement modifies Pecking Order behaviours in high-tech SMEs, influencing them to prefer equity to debt significantly more than those without such backing.

				preferences and capital structure adjustments.	
57	Tavares-Gärtner, Miguel; Pereira, Paulo J.; Brandão, Elísio (2023)	Designing a public-private co-investment mechanism to foster venture capital.	Stable Drivers	The study uses a real options approach to analyse co-investment mechanisms involving PVCs and IVCs. It explores optimal investment timings and how these might differ between PVCs and IVCs, integrating financial models with venture capital market dynamics.	• Co-investment by PVCs and IVCs can reduce the investment threshold required to initiate venture capital funding, making it a potentially more effective approach than strategies involving only PVCs or IVCs. • Public venture initiatives can significantly influence venture capital market dynamics, especially in terms of reducing investment risks and aligning investment timings between public and private actors. • The real options modelling shows that uncertainties typically deter investments; however, a well-structured co-investment strategy can mitigate these effects, encouraging earlier and potentially more profitable investments.
58	Tyebjee, Tyzoon; Vickery, Lister (1988)	Venture Capital in Western Europe.	Stable Drivers, Dynamic Drivers	Examined the emergence and characteristics of the venture capital industry in Western Europe, focusing on differences in venture capital activity across countries. The analysis included a review of the cultural, economic, and regulatory factors	• Venture capital in Western Europe is heavily influenced by cultural attitudes towards entrepreneurship and economic policies, which vary significantly across countries. • Countries with secondary markets for shares, like the UK, France, and the Netherlands, have higher levels of venture capital activity, demonstrating the importance of exit opportunities for venture capitalists. • The paper highlights the lack of cross-border venture capital mobility despite

				influencing venture capital dynamics.	economic integration efforts within the European Community, attributing this to national differences in market size, culture, and regulatory environments.
59	Verwaal, Ernst; Bruining, Hans; Wright, Mike; Manigart, Sophie; Lockett, Andy (2010)	Resources access needs and capabilities as mediators of the relationship between VC firm size and syndication.	Syndication	Utilized a sample of 317 venture capital firms across six European countries to empirically assess the impact of VC firm size on syndication frequency mediated by resource access needs and capabilities, using structural equation modelling.	• Smaller VC firms have greater needs for accessing external resources due to limited in-house capabilities, which drives them towards syndication. • Larger VC firms exhibit stronger capabilities for deal-flow reciprocation and syndicate more frequently due to their established network positions. • Both firm size and syndication strategies are influenced significantly by the firms' resource access needs and capabilities, highlighting the complex interplay in venture capital syndication decisions.
60	Wuebker, Robert; Hampl, Nina; Wüstenhagen, Rolf (2015)	The Strength of Strong Ties in an Emerging Industry: Experimental Evidence of the Effects of Status Hierarchies and Personal Ties in Venture Capitalist Decision Making.	Investment Decision	Employed an adaptive choice-based conjoint experiment involving 3,132 investment decisions by 86 venture capitalists from the United States and Europe, examining the influence of personal ties and status hierarchies on investment decisions in environments characterized by high market uncertainty.	• Personal ties have a more pronounced influence on investment decisions compared to the status of other venture capital firms participating in the investment syndicate. • The influence of personal ties is significantly stronger among U.S. investors compared to European investors, attributed to differences in network density. • A U-shaped relationship was found between venture capitalist experience and the influence of personal networks, with both very inexperienced and very experienced investors relying more on

					personal ties than those in the middle range of experience.
61	Invest Europe (2023)	Investing in Europe: Private Equity Activity 2022	Dynamic Drivers	This report relies on data from the European Data Cooperative (EDC) and other third-party sources. The data encompasses comprehensive statistics about private equity and venture capital activity across Europe, validated through audits and consistent methodology for pan-European comparability.	• European private equity and venture capital fundraising reached record highs in 2022. • Significant investment in Information & Communication Technology and Consumer Goods & Services sectors. • The geographical distribution of investments highlighted significant regional disparities within Europe.

9.2 *Appendix Study II*

Table 7: Interview Quotes and Coding

No.	Stakeholder Group	Quote	2 nd -Order Concept	Aggregate Dimension
1	VC 1	We need to win the war but survive peace. Commercially, seen, dual-use as a strategy does exactly this, ensuring civil revenue streams stabilise the company even if peace is being achieved and the funding in defence does dry up.	Investment Challenges	Resource Constraints
2	VC 2	To be very honest, the classification of dual-use does not make any sense, nor does it create any value, its definition is unclear, it creates confusion and slows things down, all it does is making things more vague, complicated and slow. It presents an excuse for people who are not convinced of an investment or the risks, might it be ethical or reputations wise, of committing the investment and therefore to a business.	Regulatory and Governance Issues	Structural Barriers
3	Government & Politicians 1	At the end, what we need to strive for is an 80% solution which enables us to deal with 80% of the cases in a fast, efficient and standardised way, without excluding the option that the other 20% might not fit in the framework of the 80% and therefore might need individual attention.	Regulatory and Governance Issues	Structural Barriers
4	Prime 2	Today's technologies are Deep-Tech and Deep-Tech is Omni-Use, the concept of dual-use in the context of nowadays technologies is nonsense and the thought that we can regulate the export of such technologies with increasing accessibility to all of those technologies and the open innovation approach in the civil industry most of these technologies are developed in is an illusion, just extremely unrealistic.	Market Access Barriers	Structural Barriers
5	Startup 1	Many criticise the fact that this dividing line between civil and military technologies is becoming increasingly blurred. Therefore, most of our customers do not really understand what dual-use is supposed to be, they are only interested in whether the product offers added value.	Technology Transfer Challenges	Structural Barriers

6	Government & Politicians 2	We need a sufficient definition of what dual-use is and what not, which then needs to be adopted globally but at least Europe wide. If we can't find a way how to define it in a unified way, there is no point in having such a concept like dual-use at all.	Regulatory and Governance Issues	Structural Barriers
7	Military 1	The investments I have seen in Germany as well as the volume overall going into dual-use technologies, whatever they might be, are still substantially too low to make any meaningful difference, especially in the international comparison.	Investment Challenges	Resource Constraints
8	Scholar 1	The procurement requirements and the demanded documentation used today are so high that it is impossible for young companies to seriously compete with the prime players.	Market Access Barriers	Structural Barriers
9	Government & Politicians 3	We can hardly imagine technologies that can be clearly assigned to either military or civilian use, everything is omni-use nowadays.	Regulatory and Governance Issues	Structural Barriers
10	Government & Politicians 4	There is still almost no communication between us as the ministry of defence and the startups and investors in defence or dual-use, which also leads to the situation that although we have financial resources to invest, they are not sufficiently utilised. Furthermore, the blurry definition of dual-use makes it at the end a wild guess whether we can or cannot invest which essentially one person needs to take the responsibility for.	Technology Transfer Challenges	Structural Barriers
11	Prime 2	One challenge to justify high investments in young companies is that because we as the primes hold the vast majority of the market, the remaining market is fairly small, especially since the NATO armies are peace armies, they don't have such high demands and they don't really buy much to stock it either to be prepared for an extreme scenario. That makes the market difficult for startups and investors alike.	Market Access Barriers	Resource Constraints
12	Government & Politicians 5	In my opinion dual-use is a strategy, a strategy of a company to tackle both civil and military markets, trying to use the dual-use concept to classify entire technologies	Ethical and Moral Concerns	Perceptual Complexity

		does not make any sense at all since it depends on what you're doing with the technology.		
13	Military 2	I think we have the massive challenge that we simply do not have the innovation mentality and culture embodied when it comes to defence innovations or technologies. This hinders innovations to emerge from within the active forces but also massively hinders the transfer of dual-use solutions from civil to military markets. There are also challenges around culture overall, civil players don't want to be associated with anything to do with the military.	Technology Transfer Challenges	Structural Barriers
14	VC 3	The amount of really VC ready and worthy investments in Europe is extremely limited, the markets are fragmented, demand is low, the market entry is extremely challenging and the exit routes and evaluations are unclear.	Investment Challenges	Resource Constraints
15	Startup 2	One of the major challenges is about raising enough money to scale up extremely fast and to a big size as fast as possible to then being able to deal with the demands of the defence industries, especially when it comes to documentation. So there is no way that you can get involved as a small startup, you need to scale first to even be on the map, but you need to find a way to do this without having the first government contracts which is extremely risky because most of the time the only way to do it is by raising massive amounts of money, burning through it while building a big team and then hoping to get into big contracts before the money runs out.	Investment Challenges	Resource Constraints
16	Startup 3	There is a massive challenge around the primes gate keeping access to the government as well as data and information. This often times means that innovation is stopped by them and there have been incidence where the primes worked with startups and then copied what the startup was working on, developed it internally and sold it to the government since they have better connections and more funding.	Market Access Barriers	Structural Barriers

17	Military 3	Our procurement system is built for established prime suppliers, mostly, young companies are not being considered because they don't reach the technology or product readiness level as well as the testing amount which is necessary to be considered. On top of that, these companies, technologies or products usually have long development cycles which further increases their reliance on funding.	Market Access Barriers	Structural Barriers
18	Prime 3	We as primes are very well aware of the power we have in this ecosystem, but we also are aware that a lot of disruptive innovation is coming from small players, therefore we're working on being in a position to acquire promising companies and integrating them in our systems. Dual-Use therefore has no relevance for use because as soon as we use it or integrate it into a system it is being considered a defence product either way and regulated to the highest limitations.	Market Access Barriers	Structural Barriers
19	Prime 4	One very pressing issue we see all the time is that it's not the initial investment which is the biggest problem, it is the follow up investment and the really large investment rounds which are needed to scale. The reason for that is that by now, there are a hand full of small, specialised funds which supply the early stage startups and have found ways to work around this very unclear dual-use definition. The problem is that the large funds are all generalist funds who don't have the structure to deal with the unclear definition and mostly can't invest because of ESG regulation of their funds. This leads to the situation that as soon as the young companies need to scale, they run into a massive scale-up gap which they either have to find funding on the global stage for, or they can't and go bankrupt.	Investment Challenges	Resource Constraints
20	Government & Politicians 6	For decades defence research was classified as unethical and its attractiveness was systematically decreased by burying it with regulation. Dual-Use is one such concept which massively hinders innovation by	Technology Transfer Challenges	Structural Barriers

		introducing regulation with minimal transparency which leads to a lot of assumptions and uncertainty leading to people going on distance to this topic.		
21	Startup 4	We do know that our technology and products do have the potential for dual-use, but because of the negative stigma around everything dual-use or military related, we never really dared to mention it externally since we fear the consequences from our current investors or our ability to being able to apply for government funding if we would be classified as dual-use.	Technology Transfer Challenges	Structural Barriers
22	Military 4	Some armies within the NATO have much more flexible procurement autonomy than others which is a big part of the different levels of innovation within the various militaries. Whilst innovation is something good, if our militaries develop at different paces this massively influences operability and impact when those need to work together. Furthermore, meanwhile there are dual-use innovation hubs and cluster, they are massively underfunded and their scale is by orders of magnitude too small to make any meaningful difference.	Market Access Barriers	Structural Barriers
23	Startup 5	The combination of small amounts of funding in the market and massive amounts of regulation around dual-use technologies and the work with defence clients is absolutely deadly for startups and the innovations these startups are trying to bring to the market. On top of that, because defence related innovation was such a taboo topic for the last decades, there is barely any networks or infrastructure to overcome those challenges. We are also just really concerned about the misuse potential of our products, that's why we for the most time did not consider to get involved with the military.	Ethical and Moral Concerns	Perceptual Complexity
24	Scholar 2	The public procurement system has tools in place to procure much smaller amounts and to offer more flexibility around the requirements which need to be fulfilled, which is exactly what startups need in this	Market Access Barriers	Structural Barriers

		dual-use context. Unfortunately, the main issue is that the people who should use it are groups of people which are extremely risk averse and have absolutely no incentivisation to do so, so they stick to what they know and what has less risks, the primes.		
25	Military 5	We really struggle with innovating from within the military. We don't have systems in place to support intrapreneurship, nor is there a culture of innovation and building businesses around new ideas in the military. The collaboration with universities has also been notoriously difficult because they have civilian clauses that prevent them from conducting research on military topics. That is why dual-use technologies are crucial because the only reasonable way to innovate we currently see is to take on and adopt innovations from the civil market, which have much better funded R&D efforts.	Technology Transfer Challenges	Structural Barriers
26	Startup 6	For us working with Primes when spinning in our dual-use technology from the use in civil markets into the defence marks has been challenging. On the one side are they the only ones which seem to understand the complexity of the system, thereby I mean the regulatory requirements, and on the same time, you get slowed down by them as well as you need to expose yourself and your technology to them which obviously has the risk of them copying or taking on your knowledge. That creates a really uncomfortable dynamic of them gate keeping what will be used and what not.	Market Access Barriers	Resource Constraints
27	Startup 7	We realised two extremes fairly quickly when speaking about the dual-use potential for our technology. "Old" established institutions like banks do still massively devalue your ideas the moment you mention dual-use potential and put you in the same risk category and profile than prostitution and gambling, so essentially, they don't want to work with you. For more forward-thinking institutions like VCs, it is mostly an ethical question, and it is all about	Ethical and Moral Concerns	Perceptual Complexity

		how defensive or offensive your technology could be used. They quite clearly find creative solutions to play around the dual-use classification if they really want to invest and believe in your business model and team.		
28	VC 4	The market opportunities of dual-use companies are currently better than ever. The geopolitical situation is continuing to create fiercer and fiercer tensions, the US as protector of the EU is stepping back and demanding from the European NATO members to take care of themselves, which leaves uncovered ground and therefore spaces to fill, Governments are forced to put much more money in their defence capabilities and technologies develop faster than ever before, bringing opportunities for fast exits.	Market Access Barriers	Resource Constraints
29	VC 5	Due to ESG regulations, most generalist funds are not able to invest into dual-use technologies. This can also not be changed easily. What that means is that you need to set up an entirely new fund with adjusted ESG regulations and raise new capital for this fund. Whilst this might sound straight forward, this process takes years until a new fund is set up, raised money, and can execute investments. To go through this process is a massive commitment and then the question arises if there are even enough VC investment worthy targets and a liquid and attractive market environment for an exit, which within the fragmented European market often is hard to answer.	Regulatory and Governance Issues	Structural Barriers
30	Scholar 3	From an academic point of view, I highly question the concept dual-use. The fact that there is no acknowledged definition presents the first detrimental issue. Also, technologies develop so fast, I struggle to imagine any kind of definition which can stand the challenge of time in such an environment. And then, if you look at the actual dual-use export list of the EU, much more than any actual fact-based evaluation, it appears to me very clearly that the	Regulatory and Governance Issues	Structural Barriers

		products and items on this list are mostly politically driven, rather than technology based. For most products on there, like cyber surveillance or even 3D printing technologies have mainly been driven by political agendas.		
31	Scholar 4	The dual-use concept and defence innovation from an academic point of view, especially in the European context, has been widely ignored for the last decades, leaving us with the situation we're in right now. The dual-use concept is being used, without a sufficient understanding of the influences this concept has on our modern ecosystems and technologies. This is a situation which needs to be addressed promptly, otherwise I do question the continued use of this decades old concept.	Regulatory and Governance Issues	Structural Barriers
32	Scholar 5	I find it really interesting how the use of dual-use as well as how it is discussed considerably differs across countries. Whilst in most countries dual-use is either not discussed at all because there is a general understanding that today's technologies are all omni-use, or discussed very positively as an opportunity to leverage R&D efforts from the civil market into defence applications, it seems to be a middle European phenomenon to see it as a very critical ethical issue or much more negative and to try to put it in pre-defined boxes it does not really fit into then try to regulate it, which mostly is delusional and does not work either way.	Ethical and Moral Concerns	Perceptual Complexity

Table 8: Key-Data

	Frequency of Theme (Sum)	Pressingness (1-5)	Sentiment Intensity (-2-2)	Frequency * Pressingness	Pressingness * Sentiment	Frequency * Sentiment	Frequency * Pressingness * Sentiment
Investment Challenges	96	3.75	-1.85	90.00	-1.73	-44.40	-23.93
Regulatory and Governance Issues	143	3.33	-0.98	118.87	-0.81	-34.86	-16.66
Ethical and Moral Concerns	64	3.65	-1.6	58.40	-1.46	-25.60	-13.43
Market Access Barriers	117	4.9	0.95	143.33	1.16	27.79	19.57
Technology Transfer Challenges	80	3.35	0.35	67.00	0.29	7.00	3.37