Mechanisms Linking Technology Cycles to the Entrepreneurial Performance of University Technology Commercialization

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Abstract: Commercializing university technologies through university spin-offs is a high-uncertainty organizing process that embeds scientific knowledge into industrial and market contexts. Prior research explains heterogeneity in spin-off outcomes mainly via university entrepreneurship support infrastructures, technology transfer offices (TTOs), founding teams and networks, and institutional and regional environments, while paying less attention to the evolution stage of the underlying technology as an exogenous structural condition. Drawing on recent research on technology evolution and technology life cycles and on the idea that the emergence of dominant categories and designs opens and closes entry windows, this paper develops a stage-based theoretical chain—technology cycle stage -> reconfiguration of the constraint set -> entrepreneurial performance. We consolidate the constraint set into three mechanisms: (1) uncertainty and selection pressures, (2) appropriability and complementary-asset barriers, and (3) resource allocation and governance environments. Based on these mechanisms, we propose three core propositions regarding how technology cycles shape spin-off formation, survival and growth, value capture, and diffusion externalities. The paper offers an integrated conceptual framework and a parsimonious set of testable propositions for future research on academic entrepreneurship and university technology commercialization.

Keywords: Technology Cycles; University Spin-Offs; Academic Entrepreneurship; Dominant Design

1. Introduction

Why are university technologies more likely to be commercialized successfully through new venture creation in some periods, while in others the odds of success and the room for value capture shrink markedly? Explaining such variation solely by internal university factors—such as TTO efficiency, incubation resources, or research quality—can be insufficient. Academic entrepreneurship does not unfold on top of a "static" technology. Instead, it is embedded in the cyclical evolution of technology: discontinuities trigger exploratory experimentation and selection among competing trajectories; subsequent convergence around a dominant design shifts innovation toward incremental improvement and efficiency, thereby reshaping competitive bases and entry opportunities.

University entrepreneurship research has accumulated a relatively systematic body of knowledge. Recent reviews and conceptual work have mapped the field in terms of entrepreneurial universities, TTO performance, new venture creation, and network and environmental contingencies, and have provided integrative frameworks for understanding the antecedents and consequences of university spin-off activity [1,2]. Yet much of this literature treats the "technology environment" as a background condition. We still lack a more integrated theoretical explanation of how technology cycles systematically reconfigure entrepreneurial opportunity structures and constraints for university spin-offs.

Accordingly, this paper asks: through what core mechanisms do technology cycles influence the entrepreneurial performance of university technology commercialization? Our goal is not to exhaust all possible determinants. Rather, we distill the influence of technology cycles into three interpretable, extensible, and testable mechanisms and, on that basis, develop three core research propositions.

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2. Theoretical Background and Conceptualization

2.1 Technology Cycles and a Four-Stage Typology

Technology cycles can be conceptualized as oscillatory evolution rather than linear accumulation. Across a period, technological development often exhibits high design variety and exploratory experimentation; through market selection, technological complementarities, and industry coordination, designs progressively converge into a more stable improvement regime; subsequent generational shifts may again induce variation and recombination. Recent management scholarship explicitly frames technology evolution as a cyclical movement between design variety and design convergence, with identifiable phases that systematically alter innovation activities and competitive logics [3]. Related technology life-cycle perspectives further suggest that technological change can occur at multiple layers—applications, paradigms, and generations—implying that stage structures may be observable at different levels of analysis [4].

From an industry and organizational standpoint, the key issue is not only "how much" the technology has advanced, but "how" the industry coordinates around the technology. Building on dominant design ideas, more recent work argues that the formation of a dominant category and a dominant design creates a window of opportunity for entry, and that this window opens and closes with category consensus and design convergence—thereby shaping the strategic space available to entrants, including university spin-offs [5]. In addition, research on standards along the technology life cycle highlights that the determinants of successful standardization may vary by stage, reinforcing the notion that coordination mechanisms and selection pressures are phase-dependent [6].

Consistent with these recent traditions, and for the purpose of mechanism development and proposition building, we adopt a four-stage typology of technology cycles: (I) Emergence/discontinuity, where new principles or key breakthroughs appear and application domains and performance frontiers remain unclear; (II) Ferment, where multiple competing trajectories and architectures coexist and competition centers on standards, interfaces, and ecosystem positions under intense selection; (III) Dominant design formation and diffusion, where trajectories converge and market expansion shifts innovation toward engineering and scale-up execution; and (IV) Maturity/saturation and the prelude to substitution, where incremental improvement and efficiency competition prevail, marginal performance gains flatten, and substitution pressures associated with the next generational shift accumulate. This stage-based treatment is also compatible with broader life-cycle views of technological innovation systems.

2.2 Entrepreneurial Performance in University Technology Commercialization

Entrepreneurial performance in university technology commercialization is not equivalent to generic start-up performance. University spin-offs (academic spin-offs) combine the attributes of a market organization with those of an extension mechanism for public science. Accordingly, performance evaluation is inherently multi-goal, multi-horizon, and multi-stakeholder. Recent reviews emphasize substantial heterogeneity in outcomes and measurement in the spin-off literature, calling for multidimensional performance conceptualizations that go beyond single financial indicators. Moreover, recent studies highlight goal and performance heterogeneity among academic spin-offs, driven by different combinations of scientific impact, academic identity preservation, societal value creation, and financial return objectives [7,8].

In terms of theoretical roots, the firm-level dimension of entrepreneurial performance is grounded in core perspectives in organization theory and strategic management. Resource-based reasoning emphasizes how scarce resources and capabilities shape survival and growth; transaction cost and contractual views highlight governance costs under uncertainty and asset specificity; knowledge-based and learning perspectives stress cumulative knowledge acquisition and integration capabilities, including absorptive capacity [9]. More recent conceptual work explicitly argues for importing theories of the firm into academic spin-off research to better capture the distinctive resource origins, goal structures, governance relationships, and growth paths of academic spin-offs [10]. From this perspective, entrepreneurial performance reflects not only whether a spin-off

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is formed and survives, but also whether it builds critical capabilities and realizes value (e.g., financing continuity, productization, market expansion, and value realization through exit or sustainable operations).

Beyond firm-level outcomes, entrepreneurial performance in university commercialization has strong roots in theories of publicness and externalities. A recent research agenda on public-science commercialization argues that focusing solely on entrepreneurial outputs (e.g., number of start-ups, funding volumes, short-term financial returns) is insufficient; instead, commercialization should be assessed in terms of broader societal impacts generated through diffusion and application [11]. In line with this view, scholarship has begun to examine how non-economic goals embedded in academic contexts—such as identity, control, and prosocial motivations—shape behaviors and outcomes in academic spin-offs. Therefore, we conceptualize entrepreneurial performance as four related but distinct outcome domains: spin-off formation and entry (E1), survival and growth (E2), value capture and resource recycling (E3), and diffusion and societal externalities (E4).

3. Conceptual Framework: From Stage to Constraint Set to Performance

We treat the technology cycle stage as an exogenous contextual variable that can complement existing explanations of university spin-off performance by adding an explicitly dynamic technology-environment dimension. Spin-off research suggests that understanding commercialization requires moving beyond the binary question of "whether a spin-off is created" to examining developmental trajectories and performance over time, and to recognizing diverse determinants and outcomes across multiple levels. More broadly, research on academic engagement and university–industry interaction indicates that knowledge interactions and commercialization outcomes are shaped by individual, organizational, and institutional contingencies, implying that the environment should be treated as a structural condition rather than background noise. Accordingly, we argue that technology cycle stages shape entrepreneurial performance by structuring the opportunity landscape and the constraints confronted by university spin-offs.

Our core theoretical move is to "mediate" the influence of technology cycles through a constraint set that is analytically comparable across stages. Technology cycles do not mechanically determine entrepreneurial success; rather, they reconfigure the key obstacles and viable pathways confronting entrepreneurial projects at each stage. We aggregate this constraint set into three mechanisms: (1) uncertainty and selection pressures (how technical and market uncertainty are distributed, the speed of trajectory convergence, and the intensity of standards/interface competition); (2) appropriability and complementary-asset barriers (whether innovation rents can be captured, and whether critical complementary assets are accessible and concentrated); and (3) resource allocation and governance environments (the tightness and volatility of financing windows, the effectiveness of "markets for ideas" such as licensing and M&A, and institutional and organizational governance costs).

This logic aligns with work emphasizing that technology entrepreneurs often face multiple constraints and may employ dynamic commercialization strategies to circumvent or temporarily relax them. It is also consistent with findings that the success factors for standards vary across the technology life cycle, underscoring the stage dependence of coordination and selection.

Building on this mediation structure, we conceptualize entrepreneurial performance as the outcome of a stage–constraints–responses chain: technology cycle stages first reshape the three constraint mechanisms; these constraints influence entrepreneurial responses—such as commercialization path choices, partner collaboration, capability building, and strategic switching; and responses ultimately manifest in multidimensional performance outcomes (E1–E4). As shown in Figure 1, this conceptual model outlines the mediating role of the constraint set and the moderating effects of university and ecosystem factors. Two sets of moderators can amplify or buffer these relationships: the university support system (e.g., TTOs, incubators, policies, and shared infrastructure) and the external entrepreneurial ecosystem (e.g., capital markets, complementary partners, institutional infrastructure). University support is most effective when aligned with the demand-side challenges faced by spin-offs, while entrepreneurial ecosystems shape opportunity recognition, resource mobilization, and scaling conditions.

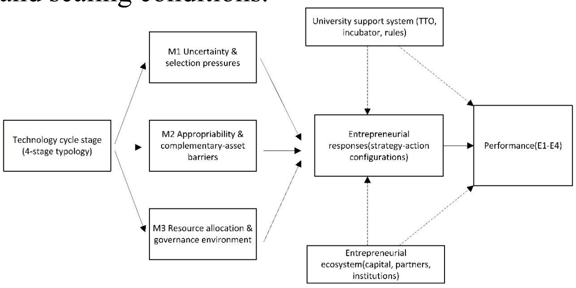

Figure 1. Conceptual model of Technology Cycles, Constraint Mechanisms, Entrepreneurial Responses, and Performance

4. Mechanisms

4.1 Mechanism 1: Uncertainty and Selection Pressures

Core argument: Technology cycle stages reshape the structure of uncertainty and the intensity of selection, thereby changing both the distribution and the drivers of entrepreneurial performance.

In stages I–II, uncertainty is concentrated in technical feasibility, performance frontiers, trajectory choice, and application discovery. Selection pressures are strong because multiple competing trajectories coexist and are rapidly experimented with and eliminated until convergence occurs. In this setting, entrepreneurship resembles an exploratory organizational experiment under high uncertainty, leading to high performance variance: a few ventures may cross the uncertainty threshold and gain early-mover advantages, whereas many others exit due to trajectory displacement or failed market validation.

Moreover, discontinuities can be competence-enhancing or competence-destroying for incumbents, which changes the opportunity window for entrants, including university spin-offs. When a discontinuity undermines incumbents' core capabilities or depreciates their existing asset base, entrants can gain room to compete by leveraging novel knowledge and rapid experimentation; when it primarily reinforces incumbents' capabilities, incumbents are more likely to absorb the new technology and retain advantage, making independent scaling harder for entrants.

In stages III–IV, dominant designs and stronger category consensus reduce technical uncertainty; however, competition increasingly shifts toward scale-up execution, reliability, and cost efficiency. As a result, "betting on the right trajectory" gradually yields to "executing effectively within the converged architecture," which is consistent with the idea that entry windows open and close with category consensus and design convergence.

Implications for entrepreneurial performance:

(1) Earlier stages primarily determine performance variance (E2 becomes more dispersed), whereas later stages increase average predictability (survival may improve, but the sources of high growth change).

(2) In ferment, the focal task is to align with—or help shape—future dominant designs; in diffusion, the focal task is to scale and execute within the dominant design.

4.2 Mechanism 2: Appropriability and Complementary-Asset Barriers

Core argument: Technology cycle stages change the conditions for profiting from innovation—especially the structure of complementary assets and the appropriability regime—thereby shaping scaling prospects and the feasibility of value capture.

Teece's analysis of profiting from innovation emphasizes that returns to innovators depend on the appropriability regime and the control of complementary assets (manufacturing, marketing, distribution, services), which in turn affects choices among integration, collaboration, and licensing (Teece, 1986). Embedding this logic into technology cycles yields the following stage-based implications.

(1) Stages I–II: complementary assets are not yet stabilized, but building them is costly. The emerging ecosystem is immature; critical complementary assets (supply chains, standard interfaces, certification systems, channels, and customer education) may be missing or unstable. Spin-offs can attempt to "create" complementary assets through trial-and-error, but resource consumption and failure risk are high.

(2) Stages III–IV: complementary assets become stabilized and increasingly concentrated. Once dominant designs and division of labor crystallize, complementary assets are more likely to be held by platform firms, system integrators, or large incumbents. Spin-off growth and value realization thus depend more on gaining access to these assets (e.g., strategic partnerships, M&A, channel bundling), while the marginal advantage of technical superiority declines.

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condition these dynamics. Absorptive capacity theory highlights that organizations require relevant prior knowledge to recognize, assimilate, and exploit external knowledge and that capability development is path dependent (Cohen & Levinthal, 1990). Therefore, in early stages, interdisciplinary integration and translational/industrial experience in the founding team are especially consequential for converting scientific breakthroughs into productization pathways; in later stages, the relative importance shifts toward supply-chain, channel, and scaling management capabilities.

Implications for entrepreneurial performance:

(1) In later stages, E2 (growth) and E3 (value capture) become more sensitive to access to and control over complementary assets.

(2) In earlier stages, complementary-asset deficits more often manifest as “technology–productization gaps” and the inability to cross the engineering ‘valley of death’.

4.3 Mechanism 3: Resource Allocation and Governance Environment

Core argument: Technology cycle stages shape how capital and institutions allocate resources to entrepreneurial projects and how costly it is to govern key transactions, thereby affecting formation, financing continuity, exit paths, and value realization.

First, the commercialization environment determines whether entrepreneurs compete primarily in product markets or realize value through a “market for ideas” via licensing, collaboration, or acquisition. Gans and Stern (2003) argue that commercialization strategies depend on conditions in product markets versus markets for ideas [12]. Mapped onto technology cycles, as trajectories become clearer in late ferment and early diffusion and valuation becomes easier, markets for ideas are more likely to function, increasing the plausibility of transaction-based exits (M&A/licensing). In very early stages or when markets for ideas are underdeveloped, spin-offs are more likely to shoulder full-stack commercialization burdens.

Second, macro-level capital supply can co-evolve with technology diffusion rhythms. Perez (2002) highlights stage differences in how financial capital interacts with technological revolutions (e.g., ‘installation’ and ‘deployment’ phases) [13], implying cyclical variation in financing windows and volatility. For university spin-offs, financing booms can increase formation and experimentation, whereas contractions can trigger funding discontinuities and premature failure; more stable diffusion phases are more conducive to scale-up and sustained iteration.

Third, institutions and governance arrangements shape transaction costs and boundary choices. Transaction cost economics stresses that under uncertainty and contractual incompleteness, governance structures affect efficiency and risk. In university commercialization, the clarity of IP rules, revenue sharing, and technology transfer policies (e.g., how universities may hold and commercialize publicly funded inventions) influences the governance costs of venture formation and subsequent transactions. At the organizational level, incubation strategies differ across research institutions, suggesting that “support–needs alignment” is crucial for performance. At the ecosystem level, the availability of capital, partners, and institutional infrastructure shapes entrepreneurial opportunities and scaling conditions.

Implications for entrepreneurial performance:

(1) When uncertainty is high and governance is complex, E1 (formation) depends more on institutional clarity and universities’ governance capabilities.

(2) When markets for ideas are effective and financing environments are stable, E3 (value capture) is more likely to be realized through transaction-based exits.

(3) When capital and institutional support are misaligned across stages, performance may display a structural pattern of “high formation but low survival and weak value realization.”

5. Core Research Propositions

Based on the three mechanisms, we distill the argument into three core propositions, each corresponding to one mechanism.

Proposition 1 (Uncertainty and selection). The earlier a technology is in the discontinuity/ ferment stages, the greater the variance in university spin-off entrepreneurial performance. Moreover, the primary drivers of survival and growth shift from technological feasibility and trajectory alignment toward scale-up execution as dominant designs converge.

Proposition 2 (Appropriability and complementary assets). As a technology enters dominant design formation and diffusion, access to and control over complementary assets increasingly determine spin-off growth and the university's ability to capture value. In this stage, the direct effect of technological superiority on performance weakens and is partially mediated by complementary-asset barriers and the appropriability regime.

Proposition 3 (Resource allocation and governance environment). Technology cycle stages shape spin-off formation speed, financing continuity, and exit modes by altering financing windows, the effectiveness of markets for ideas, and governance costs. When financing becomes more volatile or markets for ideas remain underdeveloped, early-stage spin-offs are more likely to exhibit higher formation but constrained growth and weakened value realization.

6. Preliminary Conclusions and Implications

6.1 Preliminary Conclusions

Based on the mechanisms and propositions above, we offer three preliminary conclusions:

(1) Technology cycles are a structural source of heterogeneity in entrepreneurial performance in university commercialization. They are not background noise; rather, they reshape the basic conditions for entrepreneurial success by reconfiguring uncertainty and selection environments.

(2) The core constraints underlying entrepreneurial performance migrate across stages: early stages resemble a high-variance process of exploration and selection, whereas later stages resemble capability competition centered on complementary assets and scale-up execution.

(3) Resource allocation and governance environments determine whether spin-offs can cross a continuity threshold. Financing windows, markets for ideas, and institutional clarity jointly affect whether spin-offs can start, avoid funding discontinuities, and exit or scale in ways that realize value—effects that are especially salient in early stages.

6.2 Managerial and Policy Implications

For universities and TTOs, incubation governance should explicitly account for technology cycle stages. Early-stage support should emphasize proof-of-concept infrastructure and milestone-based funding, while tolerating exploratory failures; in diffusion stages, support should emphasize access to complementary assets and negotiation capabilities for partnerships and exits, thereby improving the realizability of value capture. This aligns with the view that university support is most effective when tailored to spin-offs' demand-side challenges.

For policymakers and regional innovation systems, expanding the sheer number of start-ups is less useful than ensuring the continuity of financing and institutional support across stages. Policy instruments that smooth financing discontinuities can reduce "funding-cutoff failures" caused by cyclical volatility. Strengthening markets for ideas—institutions and platforms for licensing, M&A, and collaboration—can also raise the efficiency of multi-path commercialization.

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