

Stage-Aware Public Finance for Deep-Tech Transformation: An Agent-Based Model of Congestion, Signalling, and Funding Efficiency

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1. Problem, Aims, and Research Questions

Deep-tech innovation confronts public funders with a structural portfolio problem: capital requirements escalate sharply at the Prototype-to-Scaling interface, and private finance is conditional on credible quality signals. The result is the "Valley of Death"—viable ventures fail not from lack of merit but from mis-staged finance (Beard et al., 2009; Murphy & Edwards, 2003). Building on an initial model presented at EMS 2025, this study asks: (RQ1) Under what conditions does public support crowd in private co-investment, and how does signalling strength affect public efficiency? (RQ2) For a fixed marginal budget increase, which innovation stage should be targeted to maximise bankable outcomes?

2. Justification

Fewer than 10% of deep-tech ventures progress beyond prototyping and only 2–3% reach commercial scale (EIB, 2018; OECD, 2025). Public innovation agencies—including the European Innovation Council (EIC) and national innovation funds—allocate billions annually without a fully transparent framework linking stage-specific budget rules to system-level outcomes. This work provides programme designers, policy evaluators, and innovation scholars with a computationally explicit, diagnostics-driven framework for stage-aware portfolio management.

3. Theoretical Basis

Three innovation-studies frames (Schot & Steinmueller, 2018) structure the analysis. Frame 1 (market failure) grounds intervention in spillovers and information asymmetries (Arrow, 1962; Nelson, 1959). Frame 2 (systems of innovation) treats the Prototype-to-Scaling interface as a systemic bottleneck (Freeman, 1987; Lundvall, 1992). Frame 3 (mission-oriented) casts the state as a portfolio architect—responsible for downstream conversion capacity, not merely early-stage gap-filling (Mazzucato, 2013, 2018). Signalling theory (Spence, 1973; Kleer, 2010) underpins the private co-investment mechanism: public selection reduces information asymmetry and can crowd in complementary capital (Hall & Lerner, 2010). ABM is adopted for its capacity to represent heterogeneous agents, discrete institutional constraints, and non-linear feedbacks that generate congestion endogenously (Epstein & Axtell, 1996; Farmer & Foley, 2009).

4. Research Design

A three-stage Agent Based Model - ABM (Idea → Prototype → Scaling) is developed in which heterogeneous ventures accumulate capital under stage-specific operating costs, face stochastic attrition, and progress when capital thresholds are met. Public awards are rationed under finite stage-specific annual envelopes with a one-time-per-stage constraint. Private co-investment probability is amplified by a signalling multiplier (ϕ) conditional on receiving a public award. Bankability requires sustained operation in Scaling for ≥ 3 years. Population closure enables steady-state scenario comparison across $T = 100$ years, 100 Monte Carlo replications, evaluated over years 20–100. Parameters are calibrated to stylised facts from EIC programme data (European Commission, 2023), EIB deep-tech reports (2018), the 2025 European Deep Tech Report (Jacobs et al., 2025), and OECD (2025). Scenario experiments vary $\phi \in \{0, 0.05, \dots, 0.30\}$ at fixed budgets, and marginal budget top-ups (+10% to +40%) allocated proportionally or targeted to a single stage.

5. Findings

The baseline reproduces robust Prototype-stage congestion: a persistent mid-pipeline stock accumulates as inflows expand faster than bridging capacity, and operating costs erode capital during waiting periods. Exits concentrate at Prototype—a classic survival bottleneck.

Signalling: Stronger ϕ monotonically increases annual bankable exits (~8% gain at $\phi = 0.30$) and reduces public cost per bankable outcome (~14%), confirming certification as an efficiency lever rather than a substitute for follow-on capacity.

Budget reallocation: At +40% budget increase, Scaling-focused allocation yields +32.2% annual bankable ventures; proportional yields +22.6%; Prototype-focused +12.1%; Idea-focused yields -8.4%. The negative result for upstream-only allocation is the central counterintuitive finding: adding early-stage grants under congestion enlarges the Prototype queue without expanding exit capacity, raising depletion risk and reducing throughput.

6. Relevance and Practical Importance

Three governance heuristics follow for public innovation funders. First, marginal budget increases should target the binding stage constraint—proportional or upstream-only allocation under congestion is mechanism-blind and can reduce throughput. Second, Prototype bridging should be evaluated against throughput KPIs (progressions into Scaling, time-to-bankability), not award counts. Third, signalling is a genuine efficiency lever but cannot substitute for missing downstream capacity. A practical monitoring dashboard—stage stocks, stage-specific deaths, bankable exits, and public and private euros per bankable—operationalises these heuristics within existing governance frameworks. The approach generalises to any capital-intensive innovation domain characterised by staged public–private co-investment.

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