Submission to International System Dynamics Conference (ISDC) 2025

Title: Investigating the Valley of Death and Dynamics of Deep Tech Commercialization from the Firm's Perspective

ABSTRACT:

Introduction	*The technology "valley of death" (VOD) phenomenon is widely researched but limited work has been published in the system dynamics field. This study provides a generic structure of the VOD from firm perspective and analyses one of the many potential causes – a firm's inability to sufficiently de-risk the business case for venture capital investment, resulting in a funding gap.*
Approach	*We developed a model to analyze the development of a deep tech firm. The model structure can produce both desired and undesired scenarios, with the key differentiator being a graphical function, which represents the shift, or failure to shift, the firm's budget allocation from technology to business development sufficiently. The feedback loops and dynamic interactions, as well as policies to improve the behavior were analyzed.*
Results	*The simulations show that the shift of budget from technology to business development, at the right timing and to a sufficient degree, is crucial for firm survival. Conversely with the desired scenario, in the undesired scenario the firm does not shift their budget to business development and thus fails to de-risk the business case, resulting in a funding gap and failure in the VOD.*
Discussion	*It could be useful to calibrate this generic structure of the VOD to specific sectors, industries or technologies, to yield more nuanced analysis and policy insights. Multivariate analysis of large datasets could be useful to model interacting factors affecting firm survival and identifying key drivers of market adoption and growth. Firm-market and firm-investor information asymmetries and perception gaps warrant future study.*
Use of AI	*None*

1 INTRODUCTION

Innovation and new technologies have been a fundamental aspect of human progress. While they can have nefarious impacts, they are viewed as key drivers of economic growth and social progress, and are assigned an important role in achieving sustainable development goals (Blanco, 2022). However, the full positive impact on society is often unrealized, as approximately 90% of technology-driven firms fail to even enter the market (Gompers & Lerner, 2021). Technology-driven firms encounter a series of challenges throughout their innovation cycle, which include research and development (R&D), demonstration, and deployment and diffusion (Blanco, 2022). Developing through the innovation cycle requires overcoming multiple 'valleys of death' (Gbadegeshin et al., 2022).

The term valley of death (VOD), which has gained popularity in technology commercialization, is characterized in literature in various ways. It can refer to a funding or resource gap between invention and commercialization, an inability for a business to break even, a failed technology commercialization, or a lack of startups' governmental support (Gbadegeshin et al., 2022; Markham, 2002). This paper will focus on the VOD caused by a funding gap, particularly concerning the challenges faced by deep tech firms. This focus is justified because deep tech firms are characterized as being capital-intensive and have lengthy time-to-market due to scientific and technological complexity. Startups need to consistently raise funding as they develop their technology and business through the innovation cycle to overcome the VODs. This profile makes them a far riskier investment target for generalist venture capital (VC) investors, who are accustomed to fast, high returns with relatively little upfront cost in the era of digital technologies (Bessemer Venture Partners, 2023; Dealroom, 2023).

The reference mode in Figure 1 illustrates the evolution of a deep tech firm's cash flow over a ten-year span, highlighting multiple potential VODs as the firm develops through the innovation cycle. The desired scenario represents a trajectory in which the firm overcomes the VODs, and in contrast, the undesired scenario exhibits instances where the firm runs out of cash flow at any point at various phases of development. The spikes in cash flow reflect the successful raising of venture capital, which, as identified in the literature, is critical for deep tech companies to successfully navigate the VODs (Blanco, 2022). Conversely, a lack of funding results in the depletion of cash flow. The reference mode is particularly puzzling as it shows that, despite securing investment, even multiple times, a firm may still fail to overcome the next VOD. In addition, there is a significant time delay between investment and growth in cash flow.

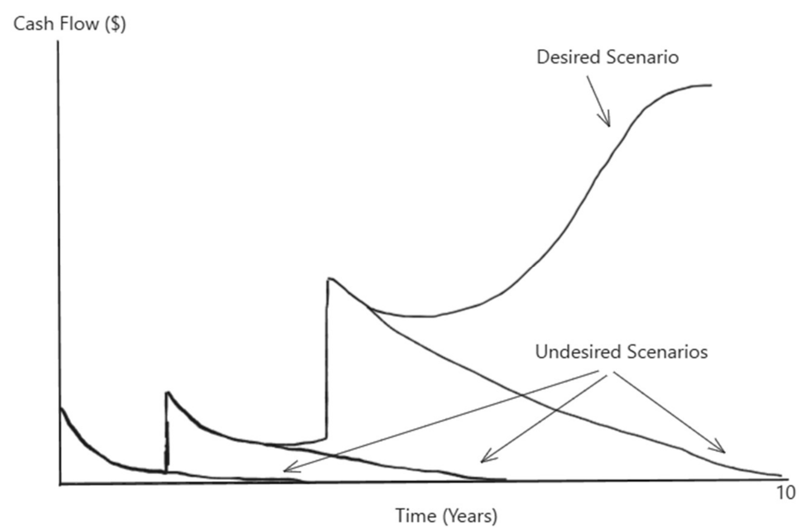

Figure 1. Reference mode of behavior over time for the main KPI, Cash Flow.

This reference mode is further reinforced by insights from Zaz Ventures, a leading consulting firm specializing in raising public and private capital for deep tech companies, as well as the lead author's professional experience at Zaz Ventures. It has been observed that deep tech entrepreneurs, particularly those with a scientific background, often over-emphasize technology development. As a result, they fail to account for other factors that venture capital investors analyze when making investment decisions, such as market traction and market creation. Various reasons may hinder firms from navigating the VODs successfully. However, to delineate the scope of this project, attention will be specifically directed towards the firm's inability or lack of awareness to *shift* focus from technology development to business development early enough in their lifecycle and to a sufficient degree.

The purpose of this study is to analyze the feedback dynamics between technology development, business development, and investment decisions, which influence deep tech firms' ability to overcome the VODs.

2 MATERIALS AND METHODS

2.1 Methodology

System dynamics (SD) modeling is particularly well-suited for analyzing challenges associated with deep tech commercialization. Deep tech commercialization is embedded in a complex system, characterized by continuous change, high uncertainty and delays. SD allows for capturing the system structure at the firm level and understanding the underlying feedback mechanisms that cause the problem behavior and how the different components interact with one another. As emphasized by Blanco (2022), the innovation process is characterized by numerous kinds of interactions and feedback between knowledge generation, knowledge translation and application, and knowledge use. Additionally, using SD allows for developing policy insights into how firms can successfully navigate the VODs and for running multiple simulations under various scenarios.

2.2 Model Structure

The first objective of this study was to construct a simplified model that captures the dynamic structure of the commercialization process for a generic deep tech company. This was accomplished through a comprehensive literature review and analysis of corporate reports. Since the focus is at firm level, the model adheres to accounting principles and microeconomic rules. The second step involved calibration of the model to a specific sector. Given that cash flows, funding levels, and risk profiles vary across sectors; the study selected the biomaterials sector for calibration. This choice is justified by the authors' familiarity with the sector and their access to insider information on parameter values and qualitative risk assessments.

Figure 2 represents the simplified causal loop diagram (CLD), which retraces the main feedback structure and interrelationships between technology development, business development and financial management, that a typical deep tech company undergoes. It also retraces the cause-and-effect relationships linked to cash flow, the critical lifeblood of the firm, with the main costs displayed on the left side, and the revenue-generating elements on the right side. The following paragraphs explain some of the main feedback mechanisms, while the formal model structure and full model documentation is available in appendix A and B respectively.

The initial funding, an exogenous variable linked by a solid line to cash flow, feeds the cash flow stock, thereby initiating the innovation process. In practical terms, this funding is indicative of a non-dilutive government grant available to deep tech firms in the United States and Europe (National Science Foundation, n.d.; European Commission, n.d.). A percentage of the cash flow is allocated monthly to business development and R&D, leading to the depletion of the stock of cash flow (this dynamic is similarly reflected in the balancing cost loops B6 to B9).

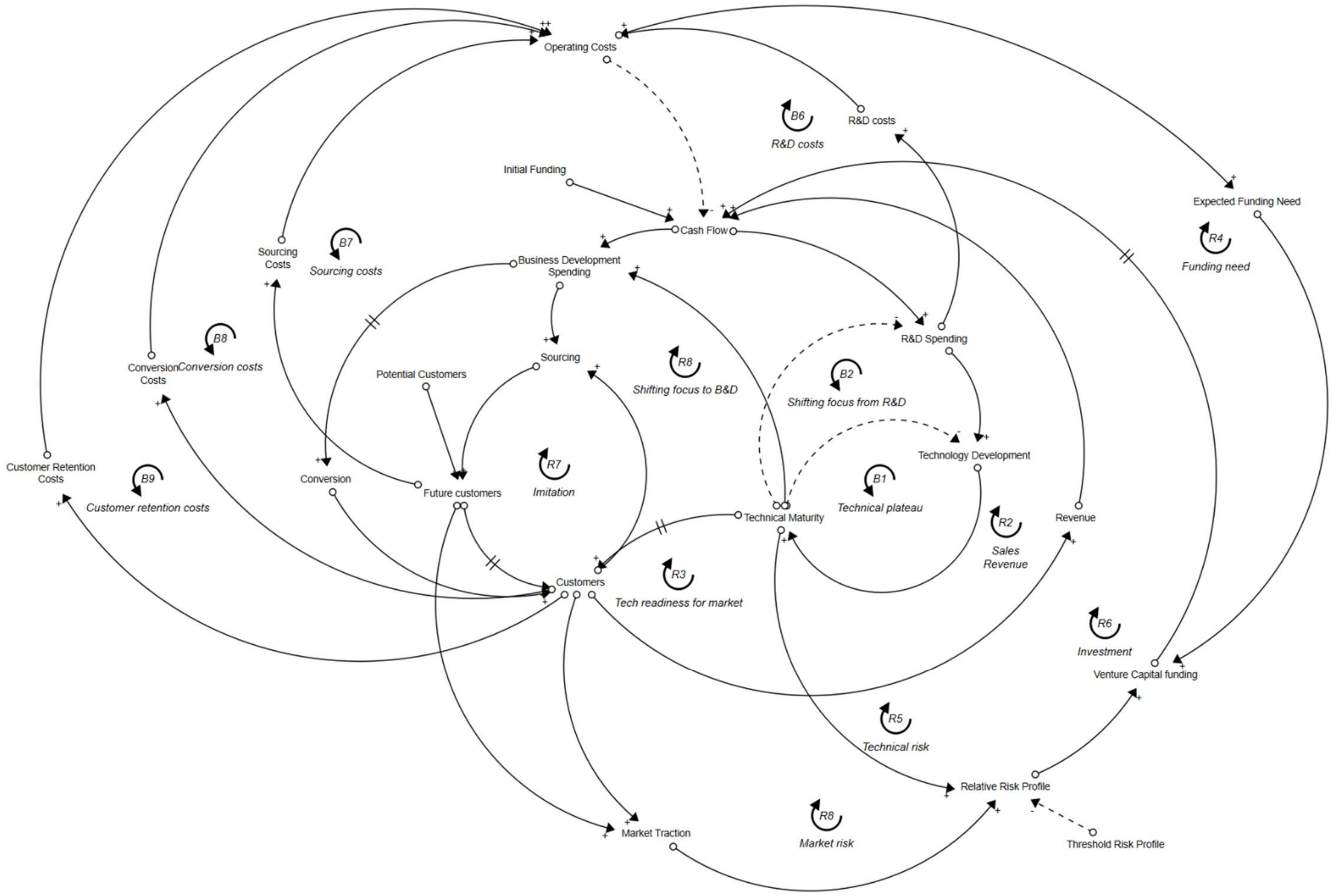

Figure 2. Causal loop diagram of deep tech commercialization dynamics at a firm level[1].

Focusing first on the R&D allocation decision, the amount allocated is informed by the technical maturity of the innovation. As technology approaches technical maturity, the rate of technology development plateaus, suggesting that it becomes more expensive to develop the technology in the later stages (B1). Additionally, as technical maturity increases, the firm must shift its focus and budget from technology development and R&D spending to business development (B2).

The budget dedicated to business development is distributed among sourcing, conversion, and customer retention. Customers demand a certain level of technical maturity before purchasing the technology, and investors assess technical maturity when determining the financial risk of their potential investment in the firm (R3, R5). Once the technology reaches sufficient technical maturity for the market, customers purchase it, thus increasing revenues and cash flow for the firm (R2, R3). As customers experience the benefits of the firm's innovation and encounter potential customers in the market, adoption increases due to imitation (R7). Furthermore, as the firm improves its market traction, its risk profile in the analysis conducted by venture capital investors improves (R8). The overall risk profile of the company is determined not only by market traction but also by technical maturity (R5). If the firm possesses a sufficiently good risk profile, they can successfully raise venture capital funding, resulting in increased cash flow for further technology and

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[1] *An arrow ↷ indicates the direction of the causal relationship (A is affecting B and not the other way around). The use of the + or – signs denote the polarity of the relationship. + signifies that both sides are evolving in the same direction (for instance an increase in A induces an increase in B), while – indicates a change in the opposite direction (an increase in A causes a decrease in B). Positive polarities (+) are displayed as solid lines and negative polarities (-) as dashed lines. Note that some variables are exogenous and do not belong to any feedback loop.*

The letter R is used to indicate a reinforcing feedback loop, and B refers to a balancing one.

business development (R6). The amount of venture capital funding is determined by the expected funding needs of the firm, which is a function of increasing operating costs as the firm's customer base grows (R4).

Overall, the technical maturity is an interplay point between the main loops. Its impact on budget allocation is a critical differentiator between the desired and undesired scenarios outlined in the reference mode (see Figure 1). In the desired scenario, budget allocation shifts appropriately from R&D expenditures to sourcing and conversion. Conversely, in the undesired scenario, budget allocation remains static, indicating an excessive focus on R&D. Consequently, the causal effects and overall behavior of the system differ significantly.

2.3 Model Validation and key assumptions

The model was developed based on insights from a comprehensive literature review and the authors' professional experience. To validate its structure, a confirmation test was conducted by comparing the model's behavior with the VOD cash flow curve documented in the literature, as well as various data sources on deep tech commercialization. The model successfully reproduces the reference mode of behavior for both the desired and undesired scenarios.

For illustrative purposes, technical maturity is modeled as a stock variable based on the technology readiness level (TRL) scaling system, originally defined by NASA as a means for measuring or indicating the maturity of a given technology, from a paper sketch to its entry into the market. The TRL scale is used by the European Commission as an indicator to position proposals and projects in the Horizon Europe funding program (BRIDGE2HE, 2022). The initial value is set to 3, estimated to be passed the inflection point of the technology s-curve, based on that the European Commission and National Science Foundation both award grants to companies in this development stage of the TRL scale (European Innovation Council, n.d-a; National Science Foundation, n.d.).

Key assumptions regarding financial management, technology development, and business strategy were validated through stakeholder interviews with co-founders of Woamy Oy, a Finnish deep tech company in the biomaterials sector. Appendix B provides a comprehensive documentation of the variables and assumptions used in calibrating the model to real-world scenarios.

Other validation testing was applied throughout the model development process to ensure the reliability of both the model structure and simulation results, following best practices outlined by Barlas (1996). The model was tested for integration errors by running simulations using both Euler and RK4 methods across a range of time steps (Δt). Euler's method was applied at various Δt values, starting at 1/2 and iteratively halving the step size until no numerical differences were observed in model outputs at $\Delta t = 1/64$. All the variables were tested under extreme conditions and yielded no irrational behavior.

A local sensitivity analysis was performed for both the undesired and desired scenarios on all parameters with uncertain values. In the undesired scenario, one parameter—the percentage of expected cash flow allocated to the monthly budget—showed behavioral sensitivity. In the desired scenario, two parameters—percentage of expected cash flow allocated to the monthly budget and average market size—exhibited behavioral sensitivity. The remaining parameters were either not sensitive or only numerically sensitive, increasing confidence in the model's output. A comprehensive table of selected parameters and local sensitivity results for the behaviorally sensitive variables can be found in Appendix C.

A global sensitivity analysis was conducted for both the undesired and desired scenarios to assess confidence in the model's ability to produce different cash flow behavior patterns under random variations of uncertain parameters. The results suggest high confidence in the model's predictions for cash flow behavior between months 0 and 60. However, from month 60 to 120, significant variation in model output emerges, reflecting the inherent uncertainty in deep tech firm growth trajectories.

Correlation analysis across simulation runs for all model input variables informed policy alternatives. The analysis identified units per customer, average price, and initial market size as high leverage points due to their strong correlation with cash flow. Expanding into new markets is a common strategy for deep tech firms once they have established a foothold in an initial market; thus, this expansion could serve as a potential policy intervention.

Additionally, the percentage of expected cash flow allocated to the monthly budget showed a strong negative correlation with cash flow growth, indicating that excessive budget constraints may hinder financial growth. Once a firm achieves stable cash flow and builds a large pipeline of future customers ready to be converted into paying customers—particularly if the firm aims to enter new markets and expand its customer base—investing more in growth becomes crucial. Therefore, increasing the monthly budget allocation emerges as another potential policy measure to maximize cash flow growth.

Policy alternatives will be further analyzed in the results section. Global sensitivity analysis output for cash flow, as well as correlation analyses outputs for all key performance indicators (KPIs) can be found in Appendix C.

3 RESULTS

The model's simulation runs over a ten-year horizon, based on the typical development times of deep tech startups (Murray et al., 2024). The model runs monthly, enabling analysis of feedback and firm decision-making at that scale. The following section will analyze the behavior over time of the key performance indicators: **cash flow, technical maturity, future customers, and customers,** while discussing the patterns in the undesired and desired scenario simulations (Figures 3 and 4).

In the undesired scenario, the company fails to overcome the VOD. The effect of relative technical maturity on R&D spending is minimal, limiting the strength of the balancing loop that decreases R&D spending (B2). This simulation highlights the root cause of the problem behavior: an insufficient shift of the monthly budget from R&D spending to sourcing and conversion.

Conversely, in the desired scenario, the firm successfully navigates the VOD by effectively reallocating resources from R&D spending to sourcing and conversion as its technology matures. This shift is reflected in the balancing loop that decreases R&D spending (B2). With sufficient market traction from future customers and current customers, the company can raise venture capital funding and allocate the resulting increased cash flow to customer acquisition, ultimately strengthening the revenue feedback loop (R2).

The following section will disaggregate the analysis of the behavior into three main phases:

<u>Month 0 to 24</u>

From month 0 to 24, the desired and undesired scenarios display similar behavior (Figure 3 and 4). The firm is burning its cash flow at an asymptotically decreasing rate, with the R&D cost loop (B6) being the most dominant. The balancing loop controlling the technical maturity strengthens (B1), weakening technology development as technical maturity approaches the threshold limit. The sourcing and conversion cost loops (B7 and B8) are also activated, but they are minimal in strength. The firm successfully sources future customers above the threshold future customers during this period, indicating market traction. The relative risk profile is above 1, and the firm manages to raise venture capital funding at month 24, as indicated by the spike in cash flow (Figures 3 and 4).

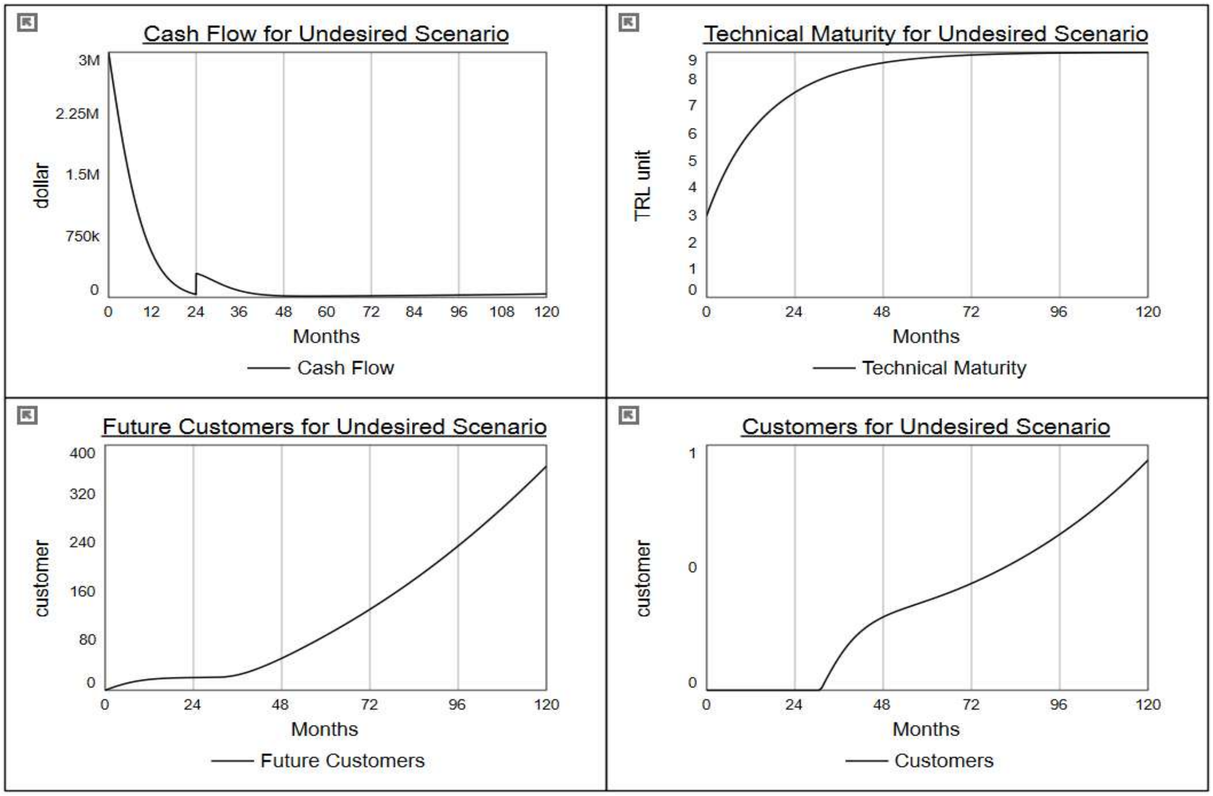

Figure 3. Graphs of KPIs behavior over the full simulation time of the undesired scenario. Gray vertical lines at 24-month intervals distinguish when venture capital investment decision is made.

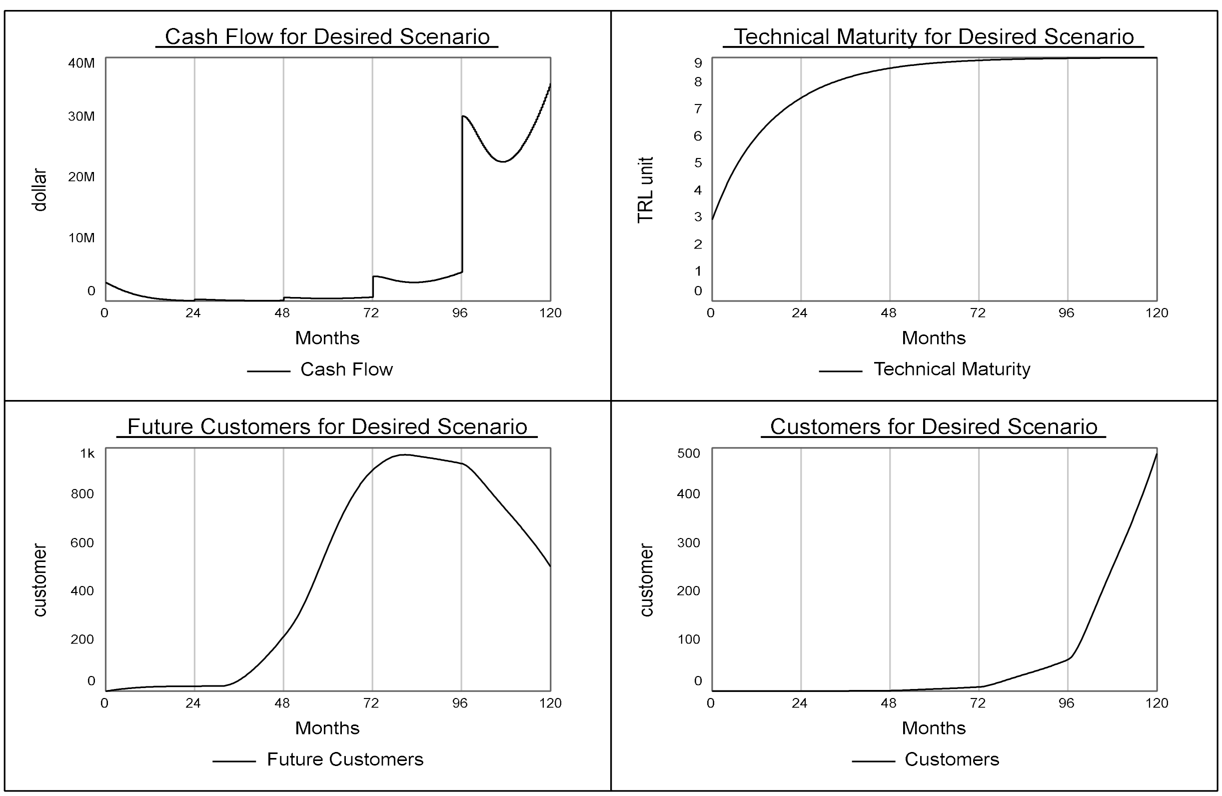

Figure 4. Graphs of KPIs behavior over the full simulation time of the desired scenario simulation. Gray vertical lines at 24-month intervals distinguish when venture capital investment decision is made.

Month 24 to 48

From month 24 to 48, the desired and undesired scenarios display different behaviors (Figure 3 and 4). This is because the indicated percentage of budget to R&D in the desired scenario shows an s-shaped decline, decreasing increasingly until about month 11 and then decreasing decreasingly towards a minimum value. This indicates that the balancing R&D spending loop (B6) is stronger than in the undesired scenario simulation and thus a greater shift towards business development spending. After the funding injection at month 24, the balancing cost loops (B6 to B8) are strengthened more than in the undesired scenario, highlighting the behavior of cash flow decreasing at an increasingly slower rate until it reaches the inflection point around month 31 (Figure 5). At that point, technical maturity reaches the threshold for customers (Figure 4 - Top Right), sparking a significant change in the system by activating the reinforcing sales and imitation loops (R2 and R7), but also the balancing customer retention cost loop (B9), which offsets some of the revenue from sales. Despite the decreasing percentage of allocation to sourcing, the sourcing flow increases rapidly due to the reinforcing imitation loop (R7). The model reveals that imitation, rather than the indicated sourcing fraction, is responsible for the increasingly accelerating behavior of future customers in the early stages (Figure 4 - Bottom Left). At month 41, the reinforcing sales revenue loop (R2) begins to dominate the balancing cost loops (B6 to B9), and thus cash flow begins increasing at an accelerating rate. The sales revenue loop (R2) strengthens the cost loops (B6 to B9), which in turn increases operating costs. As operating costs increase, the reinforcing funding need loop (R4) strengthens. At month 48, the company raises almost twice the amount it did in the last round, $481k (Figure 5).

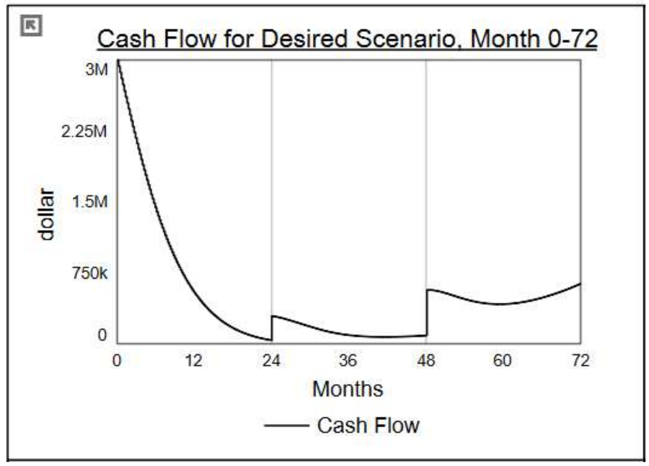

Figure 5. Behavior graph of cash flow for desired scenario simulation from month 0 to 72.

Conversely, in the undesired scenario, the company continues to overly focus on technology development, and thus the R&D cost loop (B6) remains dominant. At month 31, the reinforcing revenue and imitation loops (R2 and R7) activate as the company's technical maturity reaches the threshold for early adopters of the technology. However, because the company does not shift enough budget to conversion, the strength of the revenue loop (R2) is weak. At month 42, the company's cash flow falls below the threshold, resulting in a risk profile below the threshold for investment and a failure to raise venture capital investment at month 48 (Figure 6).

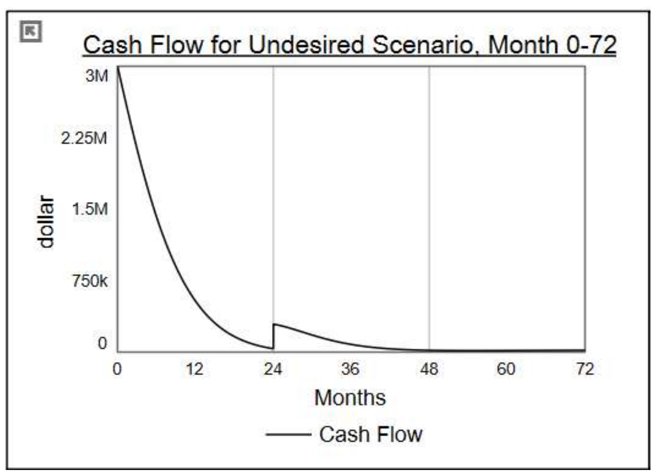

Figure 6. Behavior graph of cash flow for undesired scenario simulation from month 0 to 72.

Month 48 to 120

From months 48 to 120, the undesired scenario is characteristic of a company falling into the VOD (Figure 3 - Top Left). Due to insufficient cash flow, the firm cannot acquire customers. The reinforcing sales revenue loop (R2) does begin to dominate the balancing cost loops (B6 to B9) in the system at month 54 and throughout the rest of the simulation. However, the revenue inflow is so minimal that the company remains below $30k in cash flow until month 99.

Conversely, the desired scenario shows a company successfully navigating the VOD. Once again, the balancing cost loops (B6 to B9) are strengthened as the company's monthly budget allocation increases relative to the spike in cash flow. The increasingly decreasing cash flow indicates that the rate at which the company can acquire paying customers and thus strengthen the revenue loop (R2) is less than the sharp upturn in operating costs, which reacts immediately to the injection of cash. At month 59, when the reinforcing sales loop (R2) begins to dominate the balancing cost loops (B6 to B9) again, the customers' stock is increasing at a decreasing rate (Figure 5). However, after month 62, the stock of customers begins increasing increasingly, as indicated by the accelerating customer conversion flow (Figure 4 - Bottom Right). At month 72, the company raises $3.4 million, an exponential increase from month 48 (Figure 4 - Top Left).

In the desired scenario, the firm's percentage of allocation to conversion is what drives the growth dynamics and increases the customer base. Whereas in the undesired scenario, the percentage allocated to conversion is around 10%, in the desired scenario it is 74% of the total budget. In other words, in the desired scenario, the company effectively capitalizes on the venture capital funding injection by converting customers and strengthening the revenue loop (R2), rather than keeping its focus more heavily on R&D spending.
As the firm acquires more customers, the imitation loop (R7) also strengthens and effectively sources potential customers to future customers. Despite having a smaller allocated budget to sourcing than conversion, the company is relatively much more effective at sourcing customers than converting customers due in part to the strong reinforcing feedback of the imitation loop (Figure 4 - Bottom Left, Bottom Right).

Months 72 to 120 are characteristic of the mature growth phase of a deep tech firm (Figure 4 - Top Left). The firm raises $25 million at month 96, and now the feedback dynamics of customer stock take a very sharp increase as the percentage of the budget allocated to conversion is about 75% of the total (Figure 4 - Bottom Right). The conversion rate increases from 3 customers per month at month 96 to 18 customers per month 5 months later, indicating the system change caused by the relatively large amount of funding. At the end of the desired simulation horizon of 120 months, the company has 488 customers, and thus there is still significant market share to be capitalized on.

3.2 Policy Analysis

Local and global sensitivity analyses identified two potential leverage points for enhancing the development of key performance indicators (KPIs), specifically cash flow and customer base. Correlation graphs across simulation runs provide insights into when these policies would have the most impact.

The two identified leverage points are (1) increasing the percentage of cash flow allocated to the monthly budget and (2) expanding market size. These policies are initially tested separately before being combined. Deep tech firms often enter smaller markets first, proving their technology before expanding into more lucrative sectors that require greater investment to remain competitive. Therefore, implementing these two policies together is a realistic scenario.

<u>Policy 1: Double down</u>

Policy 1 tested the effects of increasing the monthly budget by 5% or 10% starting at month 62, with the entire simulation horizon extended from 10 to 15 years to capture any delayed effects that might not be observed with a shorter simulation period. The selection of month 62 as the policy start time is justified by two factors: first, by month 59, the reinforcing sales loop had begun to dominate the cost loops in the system, and cash flow stock was increasing; second, the firm requires three months to adjust to expectations based on the model structure, making month 62 a more realistic intervention point than month 59. Additionally, the analysis of the correlation across simulation runs for customers and cash flow suggests a strong positive correlation at this time step (see Appendix C).

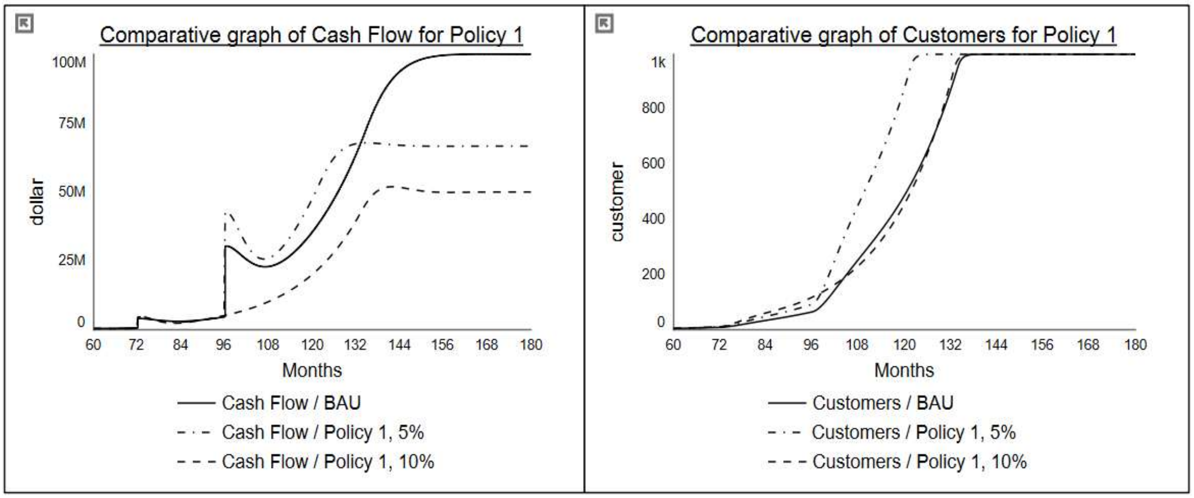

Figure 7. Comparative graphs showing results of Policy 1 alternative implementations against the business as usual (BAU) scenario on Cash Flow (left) and Customers (right) behavior over time.

As observed in Figure 7, a 5% increase in the monthly budget leads to an immediate improvement in the customer conversion rate (Figure 7 - Right). This increase strengthens both the balancing cost loops (B6 to B9). As operating expenses rise, the funding need also increases, prompting the company to secure a larger amount of venture capital at month 92 (Figure 7 - Left). Following this funding injection and the initial drop, the company's cash flow rebounds more quickly around month 108, due to a higher customer conversion rate compared to the business-as-usual (BAU) scenario. Consequently, the reinforcing sales loop (R2) becomes stronger than in the BAU scenario thus the company converts customers at a higher rate and reaches the cash flow and customers inflection point sooner in the 5% increase scenario than in BAU (Figure 7 - Left and Right).

In the case of a 10% increase in the monthly budget, the company does not raise venture capital funding at month 96 because they have managed to surpass the threshold of 100 customers (meaning they no longer have a funding need) leading to different behavior in cash flow stock (Figure 7 – Left). Thus, it is deduced that a higher increase in the monthly budget percentage ultimately has an adverse effect on cash flow in the long term: the greater the percentage increase, the lower the cash flow limit reached. This is due to the limited number of customers in the market, resulting in no additional "new revenue" as an outcome of sourcing and conversion spending. The company continues to allocate a fixed portion of their growing cash flow with no significant results. This reveals that the percentage of budget allocation should be endogenized which will be expanded further in the conclusion section.

If the goal is to capture the entire market more quickly, a 5% increase may be a wise policy alternative. However, if maximizing cash flow is the primary objective and market size is limited, then Policy 1 "Double down" strategy is not advised.

Policy 2: Expansion

Policy 2 tests the effectiveness of allocating 20% of the existing budget to expand into a new 2000 customer market, compared to 0% under the business-as-usual scenario. Deep tech firms often expand to new markets and, following an injection of funding, it makes sense to pursue future growth opportunities. This is also a scenario that a venture capital investor might support or even initiate when joining a company as a shareholder.

This expansion occurs in month 78, six months after the latest venture capital funding. The simulation runs until month 200 to capture delayed development and show that growth plateaus instead of continuing to increase. The selection of the policy timing has been informed by the analysis of correlation across runs (see Appendix C), where it has been observed that the total market size has a positive correlation with cash flow and customers.

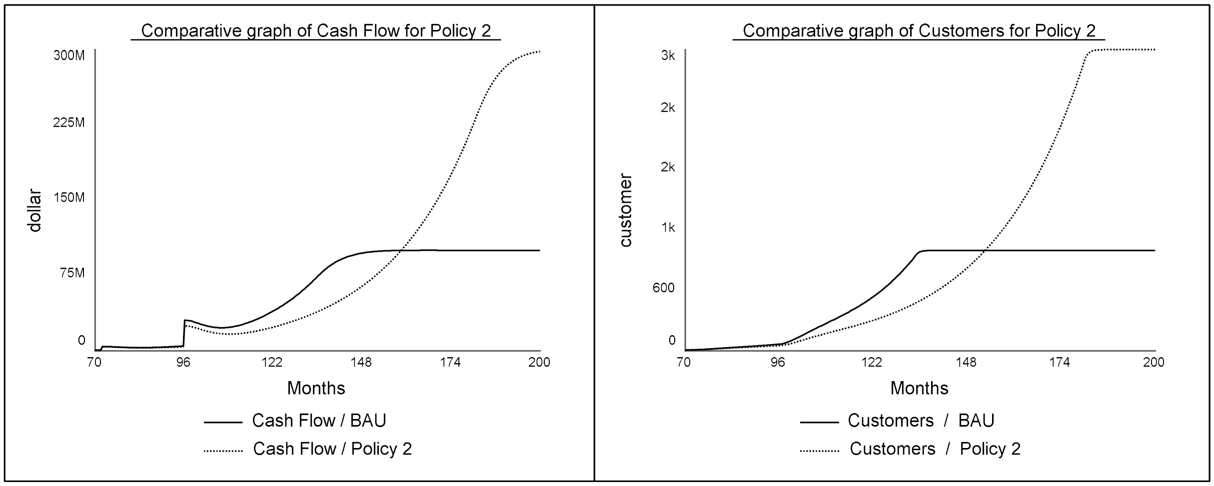

Figure 8. Comparative graphs showing results of Policy 2 implementation against the business as usual (BAU) scenario on Cash Flow (left) and Customers (right) behavior over time.

Following the increased total market size from 1000 to 3000 customers, as expected, cash flow and customer volume are observed to triple by the end of the simulation horizon (Figure 8 - Left and Right). However, the policy initially results in a slower progression of both indicators before accelerating. This initial lag occurs because resources are allocated to market creation rather than customer conversion, whereas in the BAU scenario, customer conversion already operates at full capacity. In fact, in the BAU scenario, customers are converted more rapidly, as the reinforcing revenue loop (R2) operates at its fullest before being counterbalanced by balancing loops (B7 to B9) at an earlier stage when market saturates. In contrast, under policy 2, this loop interplay occurs later, as the resources are more directed to market expansion. Consequently, with a larger market size, cash flow and customer volume ultimately reach higher levels (Figure 8 - Left and Right).

Policy 1 & 2: Doubling Down on Expansion

The combination of Policy 1 and Policy 2 yields a lower output for cash flow compared to Policy 2 individually. Cash flow plateaus at a lower level due to the increased strength of the balancing cost loops (B6 to B9) counteracting the increased revenue from new customers (Figure 9 - Left). The amount of customers reaches the plateau earlier than with either policy alone primarily due to the increased strength of the reinforcing sales revenue (R2) and imitation (R7) loops with the increased budget allocation (Figure 9 - Right). Similarly to the Policy 1 analysis, if the goal is to capture the market quickly then Policy 1 and 2 together yield the best outcome, but if maximization of cash flow in the long term is the goal then Policy 2 alone would be advised.

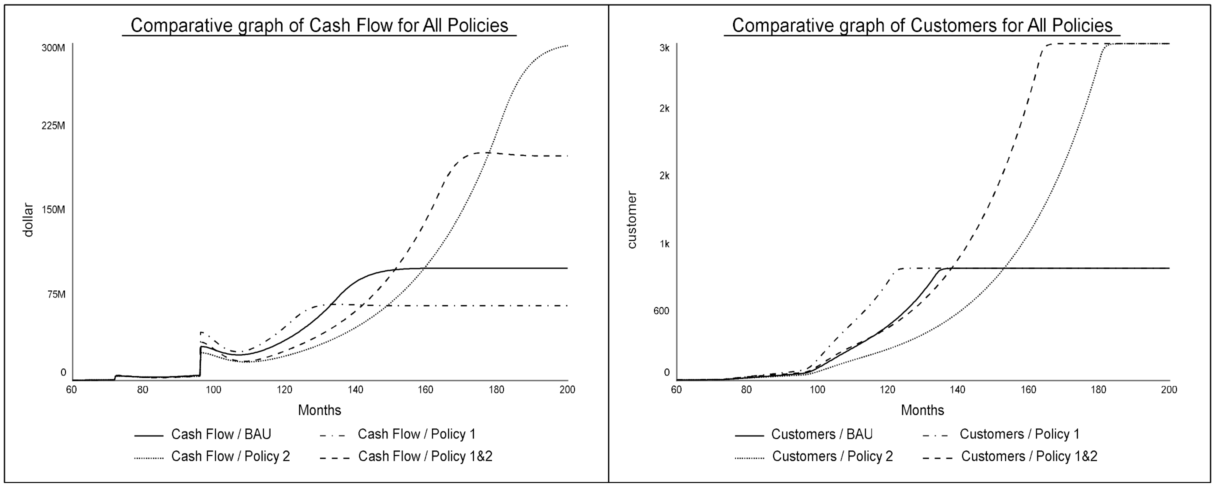

Figure 9. Comparative graphs showing results of combination of Policy 1 & 2 implementation alternatives against the business as usual (BAU) scenario on Cash Flow (left) and Customers (right) behavior over time.

4 CONCLUSION AND DISCUSSION

The study aimed to construct a system dynamics model that captures the structure and dynamic feedback involved in commercializing technology from the perspective of a deep tech startup firm. There can be various reasons why a deep tech firm fails in the VOD. This study focuses particularly on the funding gap, caused by a failure to raise venture capital funding. The modeling process incorporated a combination of literature review, data of deep tech startups and insights based on the professional experience of the authors. Stakeholder interviews with founders of a deep tech startup firm provided valuable insights into the decision-making involved in technology development, business development and management of financial resources. Furthermore, comprehensive structure validation tests were performed, building confidence in the model structure and simulation results.

The findings of the simulation experiments, which compared the undesired scenario of a firm failing in the VOD and the desired scenario of a firm successfully navigating the VOD, highlight the challenges that are caused by the firm failing to sufficiently and at the right timing, shift their focus from technology development to business development. Deep tech firms depend on venture capital investment to fuel their development through the innovation cycle. In both scenarios, the firm successfully raises venture capital funding at month 24. The desired scenario simulation shows a firm that shifts their budget wisely towards sourcing future customers, thus gaining market traction and as a result having a better risk profile in the assessment of venture capitalist investors in subsequent funding rounds. In addition, with this shift in budget the firm can effectively capitalize on the increased cash flow from venture capital funding by converting customers and thus strengthen the reinforcing revenue loop throughout the simulation. Conversely, the undesired scenario is characteristic of a deep tech firm which over-emphasizes technology development and fails to shift focus from R&D to sourcing and conversion. Thus, the firm does not capitalize on venture capital funding by converting customers. As highlighted above, the difference between the undesired scenario and desired scenario is the shift of budget allocation from technology development to business development. This non-linear relationship is captured by the graphical functions effect of technical maturity on percentage allocated to R&D, sourcing and conversion respectively.

Three total policies were tested for enhancing the development of key performance indicators (KPIs), specifically cash flow and customer base. The policies targeted two leverage points, (1) increasing the percentage of cash flow allocated to the monthly budget and (2) expanding market size, which were informed by the local and global sensitivity analysis. Comparing the simulation results, the most effective policy for capturing the market in the short term is a combination of increasing the percentage of cash flow allocated to monthly budget by 5% and expanding market size by 20% (combination of Policy 1 and 2). However, if maximization of cash flow in the long term is the goal, then expanding the market by 20% (Policy 2) is the most effective policy option.

There are several limitations and areas for improvement. Firstly, the model does not account for the dynamics of competition in the market, although customer retention costs and continued R&D costs could be viewed as proxies for the need to keep customers satisfied and technology up to date. Policy implications may be very different in a scenario where a firm must compete for customers in a finite market. In the real world we often observe technology-driven companies investing heavily in acquiring new customers before being profitable, precisely to beat out the competition. Secondly, the model does not account for the firm's sensitivity to low levels of cash flow. There is no structure in place that limits the operation of the firm, even though it holds a very low level of cash for extended periods. Moving forward, the model should consider the level of cash flow stock, as it could inform other parts of the model. The third limitation is that budget allocation was treated as an exogenous variable and calibrated based on the firms within the biomaterials sector. In reality, budget allocation is endogenously controlled by the firm's activities and results. It is also influenced by human factors and market developments. As we all know in the field of system dynamics, models are a simplified version of a real system, involving assumptions and simplification that often omit certain factors. Nonetheless, models remain useful, and valuable insights can be gained to understand the dynamics of complex and puzzling phenomena, such as the "valley of death".

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