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A System Dynamics Model for R&D Portfolio Management

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Abstract. The ability to continually innovate is widely recognized as one of the core capabilities for technology-based firms. One of the major challenges is how to allocate scarce resources among innovation initiatives in a portfolio. The aim of this paper is to develop a system dynamics (SD) simulation model that can help technology-based firms improve the effectiveness of their R&D portfolio decision making. The developed SD simulation model can be used to help R&D managers determine adequate policies to manage their R&D portfolio with adaptability accounting for uncertainty and competitive responsiveness. We found that superior technical product performance and product variety are both important to technology-based firms for sustainable market growth along the technology life cycle.

1. Introduction

The ability to continually innovate is widely recognized as one of the core capabilities for technology-based firms. Although the firms have recognized the importance of innovation, they often struggle to capture emerging market opportunities because their innovation behavior would highly influence their sustainable growth. One of the major challenges is how to allocate scarce resources among innovation programs in an R&D portfolio, where each program may have conflicting corporate strategic directions [1, 2]. Success requires an appropriate portfolio balance between short-term benefits through exploitative innovation and long-term benefits through exploratory innovation. Companies that make poor R&D portfolio decisions run the risk of losing their competitive advantage [3]. There are many product failure examples caused by inappropriate portfolio management in different industries: DuPont in the chemical industry, AstraZeneca in the pharmaceutical industry, Digital in the computer industry, Kodak in the digital imaging industry, and so on [4].

Many methodologies and tools have been developed in the literature of portfolio management [3-13]. However, companies still struggle with the portfolio management problems [9]. The reasons may be due to most of the developed methodologies assumed that the context is static and portfolio management is a rational decision process. In the high-tech industry, the context is not stable, but rather complex, uncertain and evolving. The success or failure of an innovation effort is the outcome of a complex dynamic process that contains numerous variables or factors interconnected into multiple feedback processes [14].

The aim of this paper is to use system dynamics (SD) [15] to capture crucial variables, their interactions, and feedback structure in R&D portfolio management and to develop a system dynamics (SD) simulation model that can help technology-based firms better understand the dynamics of R&D portfolio planning context and improve the effectiveness of their R&D portfolio decision making for sustain the growth and profitability in the long run. System dynamics is a method to enhance learning and understanding in complex systems through the use of feedback loops, stocks, and flows. This can help R&D managers determine adequate policies to manage their R&D portfolio with adaptability accounting for uncertainty and competitive responsiveness.

The paper is organized as follows. Section 2 presents the developed SD simulation model. The simulation result is presented in Section 3. Finally, Section 4 concludes this paper.

2. The R&D Portfolio Management Model Based on System Dynamics

This research considers the R&D portfolio management as a dynamic innovation system and is aimed to develop a new R&D portfolio planning framework based on system dynamics to analyze the dynamics of R&D portfolio management under different scenarios. System dynamics (SD) is a methodology for understanding complex problems where there is an underlying dynamic behavior affected by a certain set of feedback mechanisms. These methods have been used for over 30 years in various application domains, including: production management, project management, strategic management, education, energy and environmental planning, medical services, and public policy [16-18]. Much of the art of SD modeling lies in discovering and representing the feedback processes and other elements of complexity that determine the dynamics of a complex system. Two SD modeling tools, the causal loop diagram and the stock and flow diagram, are frequently used for qualitative and quantitative analysis of a dynamic systems.

The model assumptions are briefed as follows. First, exploration projects are intended to develop new technologies, knowledge, or skills for improving new product performance, while exploitation projects utilize existing technologies, knowledge, skills (generated from exploration projects) in developing and launching new products to the market. Second, each firm only has limited R&D capacity for executing exploration and exploitation activities. Therefore, we assume that each firm has the maximum number of exploration projects and exploitation projects every year. Third, products are introduced and launched to the market at fixed intervals. Many industries, such as electronics and auto industries, new products are typically introduced on any annual cycle. Finally, technology evolution is driven by the firms involved in the industry.

The availability of R&D resources for exploration and exploitation projects is a function of the market performance of new products launched to the market in the past. The available R&D investment (*ARDI*) in year t is dependent on the market performance of a company in the previous year and is defined as the maximum of available R&D investment, $AR(t-1) \times RDIP$, and the minimum annual R&D investment (*MRDI*), where *AR* is annual revenue from the previous year and *RDIP* is the percentage of R&D investment relative to annual revenue:

$$ARDI(t) = \mathrm{Min}(RDCap, \mathrm{Max}(AR(t-1) \times RDIP, MRDI)) \quad (1)$$

Furthermore, annual R&D investment should not exceed the limited R&D capacity (*RDCap*) for each technology-based firm. The investment ratio of exploration projects to available R&D investment, f_{RD}, is defined. Therefore, the annual investments on exploration projects (*AIRP*) and exploitation projects (*AIDP*) are defined, respectively:

$$AIRP(t) = f_{RD} \times ARDI(t) \quad (2)$$

$$AIDP(t) = (1- f_{RD}) \times ARDI(t) \quad (3)$$

We assume that if the cumulative investment is not enough to launch an exploration project, the funding will accumulated for the next year. New exploration projects (*ANRP*) ae created based on the annual investment on exploration projects and average resource requirement for each exploration project (*ARRP*):

$$ANRP(t) = AIRP(t) / ARRP \quad (4)$$

The completion rate of an exploration project (*RPCR*) is determined by the exploration project remaining (*RPRN*) multiplied by average failure rate of an exploration project (*RPFR*), and then divided by the lead-time of exploration project (*RPLT*):

$$RPCR(t) = RPRN(t) \times (1 - RPFR) / RPLT \quad (5)$$

We assume that each completed exploration project can improve product performance (*RPPI*) and the improvement rate is stochastic and is determined by the Pearl curve, a typical *S*-shape growth function which is often used to model the performance of technological improvement:

$$RPPI(x(t)) = \frac{L}{1+exp(-\alpha(x(t)-\beta))} \quad (6)$$

where $x(t)$ is product attribute level within a range [0, 1]. The product improvement of an exploration project is simulated as a random walk from 0 to 1, where the moving distance is dependent on the length of technology life cycle and drawn from a uniform distribution $[a, b]$, $a, b \in [0, 1]$ and $a \le b$. L is the asymptotic limit of technological performance growth, α is the growth rate parameter specifying the width or steepness of technological *S*-curve, and β specifies the time when the curve reaches the midpoint of the *S* curve.

Similarly, new exploitation projects (*ANDP*) are invested based on the annual investment on exploitation projects and average resource requirement for each exploitation project (*ARDP*):

$$ANDP(t) = AIDP(t) / ARDP \quad (7)$$

The completion rate of an exploitation project (*DPCR*) is determined by the exploitation project remaining (*DPRN*) multiplied by average failure rate of an exploitation project (*DPFR*), and then divided by the lead-time of exploitation project (*DPLT*):

$$DPCR(t) = DPRN(t) \times (1 - DPFR) / DPLT \quad (8)$$

The product performance (*DPPP*) developed by each exploitation project is mainly based on the technological performance achieved by the exploration project of technology-based firm *i*, modeled by the normal distribution [19]:

$$DPPP(t) = ND(RPPI(x(t)), \sigma_T) \quad (9)$$

where the mean of the product performance is determined by the current product performance achieved by the exploration projects invested by the technology-based firm, and σ_T is standard deviation of potential performance achievement.

When product *i* is launched at the end of year *t* with a realized product performance $DPPP(i, t)$, it will generate an expected market payoff in year t+1 based on its customer satisfaction relative to other products in the market:

$$PMP(i, t+1) = \frac{DPPP(i,t)}{\sum_{j\in P} DPPP(j,t)} M(t+1) \quad (10)$$

where $F(DPPP(i, t)) = Prob(D(t+1) \le DPPP(i, t))$ represents the probability that the realized product performance $DPPP(t)$ exceeds market requirement D, M is the maximum potential market value, and P is the set of all products in the market in year t+1, respectively.

The expected annual revenue of a firm in year t+1 can be calculate:

$$TAR(t+1) = \sum_{i\in E} PMP(i, t+1) \ , \quad (11)$$

where E is the set of products for the firm launched at the end of year t. The operating profit of a firm is:

$$TOP(t+1) = \frac{TAR(t+1)\times\ GPM\ \times\ (1\ -\ TR)\times\ RC(t)}{(1+r)^{t+1}} \quad (12)$$

where *GPM* is the gross profit margin, *TR* is the tax rate, *RC* is the R&D expense and r is the cost of capital.

3. Computational Experiments

This research classifies R&D portfolio strategies based on the investment ratio of exploration projects f_{RD}: extremely exploitation-focused (f_{RD} = 0.1), exploitation-focused (f_{RD} = 0.25), balanced exploitation-exploration (f_{RD} = 0.5), exploration-focused (f_{RD} = 0.75), and extremely exploration-focused (f_{RD} = 0.9). We assumed that five technology-based firms, C1-C5, compete for the same market, and each individual firm applied different exploration investment ratios, 0.1, 0.25, 0,5, 0.75, and 0.9, respectively. Market requirement uncertainty (σ_M) was set to 0.3 at the initial stage of technology lifecycle, gradually decreased to 0.15 at the growth stage, and then to 0.07 at the mature stage. The product performance uncertainty (σ_T) was set to 0.05 for all firms. Finally, we assumed that all firm had the same minimum amount of R&D investment (*MRDI* =30) and R&D capacity (RDCap = 250).

A scenario is assumed that market evolution is slow but technology evolves fast; for example, the electric vehicle industry. Since this scenario assumed low technological barriers, firms such as C4 and C5 with a higher investment on exploration investment for technological improvement had a slightly better technical performance at the initial stage (Figure 1(a)). At the growth stage, the technical performance of both firms quickly outperformed other firms. After the 337th period Firm C4, which offered additional product variety, surpassed firm C5 on the technical performance. Since market requirements were quite uncertain at the initial stage, firms offering extra product variety had better market performance. From Figure 1(b), 1(c), and 1(d), firm C1 (strong exploitation focused strategy) outperformed other firms until the 289th period. Due to weak technical performance, firm C1 could not sustain its market performance in the long run. Firm C4 with superior technical performance and various product variety became the market leader.

4. Conclusions

This research developed a new system dynamics model to analyze the dynamics of R&D portfolio management for determining how a technology-based firm choose between exploitation-focused innovation and exploration-focused innovation. We found that using the same exploration ratio for R&D investment may not obtain the best result for different stages of technology life cycle. In addition, superior technical product performance and product variety are both important to technology-based firms for sustainable market growth along the technology life cycle. In additional to improving technical performance, product variety offering is also important for technology-based firms. Technology-based firms can benefit from enhancing their product variety to increase the chance of satisfy uncertain customer requirements, as the there is no clear distinction of technology performance among different firms in the early stage of technology life cycle. Product variety can benefit market performance of firms, especially for all firms are struggle to improve technology performance.

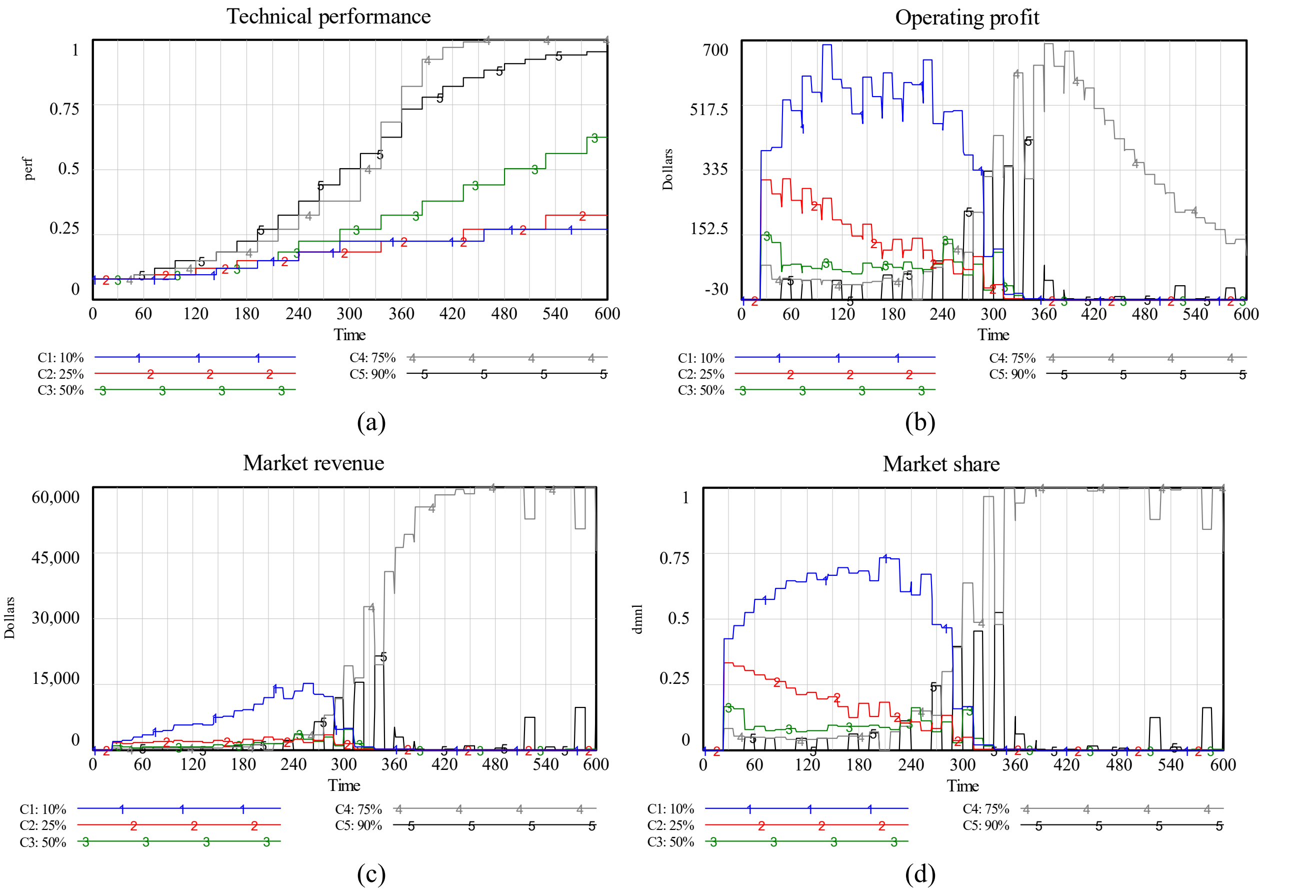

Fig. 1. Experimental results

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