A Risk-based Real Options Framework for Flexible Technology Planning

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Abstract: Although the importance of R&D is well understood by technology-based firms, with the increasing uncertainty in technology development and market trends in recent years, managing uncertain R&D projects to enhance competitive technological position is still a major challenge for those firms. This research develops a technology planning framework that integrates R&D risk management with real options analysis enables technology-based firms to allocate their limited R&D resources with managerial flexibility for maximizing the expected market value of R&D project under uncertainty. The proposed technology planning framework consists of four stages: technology roadmapping, risk identification, risk response planning, and flexible plan optimization. Since technology development usually involves great uncertainty at early R&D stages, the Monte-Carlo simulation optimization technique is applied to evaluate and select optimal technology plans under different scenarios. The developed methodology is illustrated with a case study of ASIC power module technology development project in Taiwan.

1 INTRODUCTION

Technology is an important asset that enables a technology-based firm to develop future products and the manufacturing processes supporting these products. It is very important for those firms to invest on adequate R&D projects to retain their competitive advantages. Although the importance of R&D is well understood by technology-based firms, with the increasing uncertainty in technology development and market trends in recent years, managing uncertain R&D projects to enhance competitive technological position is still a major challenge for those firms (Pich et al., 2002; Song et al., 2007). The presence of tremendous uncertainty leads to many failures in their R&D projects. Therefore, how to develop a technology plan and effectively manage uncertainty in an R&D project over time to enhance its success rate has become a very important issue for technology-based firms (Wang et al., 2015).

Traditionally, companies often use Net Present Value (NPV) as a method of evaluating R&D investments. However, the NPV approach neither takes risks into account, nor includes managerial flexibility in the investment decision-making process. It is assumed that investment decisions once determined at the initial stage, decision-maker will be unable to make any changes for the investment process. So the project has failed to effectively carry out risk control and flexibility planning (Trigeorgis, 1996). Real options analysis (ROA) is a good way to remedy these issues for R&D projects with great uncertainty and high risk. It incorporates managerial flexibility in the evaluation process in order to play the hedging role on R&D investment and find the adequate value for R&D project (Dixit and Pindyck, 1994; Trigeorgis, 1996; Huchzermeier and Loch, 2001).

This research develops a technology planning framework based on the real options theory that enables technology-based firms to allocate their limited R&D resources with managerial flexibility for maximizing the expected market value of R&D project under uncertainty. The proposed technology planning framework integrating R&D risk

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management with real options analysis consists of four stages: technology roadmapping, risk identification, risk response planning, and flexible plan optimization. Since technology development usually involves great uncertainty at early R&D stages, uncertain parameters involved in technology planning and development are characterized by appropriate probability distributions. The Monte-Carlo simulation optimization technique is applied to evaluate and select optimal technology plans under different scenarios. The developed methodology is illustrated with an ASIC technology development project in Taiwan's power module industry.

The structure of the paper is described below. Section 2 reviews the related literature for technical planning and real options analysis methods. The proposed risk-based real options framework for flexible technology planning is developed in Section 3. Section 4 presents the case study on the ASIC power module development. Section 5 concludes the paper and describes the future research.

2 THEORETICAL BACKGROUND

2.1 Technology Planning

Technology planning aims to planning the technical evolution of a technology or product to achieve the vision of a technology-based firm. Technology roadmapping is a technology planning tool, which is widely used in the industry for the development of long term technology plans (Petrick and Echols, 2004a). Kappel (2001) presented two types of technology roadmapping: scientific-oriented roadmapping which predict the direction and trend of technology from the industry point of view and product-oriented roadmapping which is a business perspective to assess the technology decision. Phaal et al., (2004) proposed the Fast-Start technology roadmapping method that provides a practical guide to a fast application of the technology roadmapping. Walsh (2004) modified the traditional technology roadmaps for disruptive technologies. Petrick and Echols (2004b) recommended that companies must share and extend the product and technology planning with their supply chain partners to make better planning and decision-making. In addition, technology roadmapping is able to integrate with other management tools, such as scenario planning (Saritas and Aylen, 2010), morphology analysis (Yoon et al., 2008), and patent analysis (Lee et al., 2009).

2.2 Real Options Analysis

Real option has been widely used in many different areas, such as operations management, supply chain management, R&D management, and strategy planning. There are two main evaluation methods in R&D project evaluation: the Black-Scholes method (Black and Scholes, 1973) and the binomial tree method (Cox et al., 1979) which improve restrictions of the Black-Scholes model that can only assess single option value with restricted time to maturity. Huchzermeier and Loch (2001) developed a real R&D options model that not only considered market uncertainty but also technological uncertainty. Brandao et al., (2005) proposed an approach that integrates the real options theory with decision tree to assess the value of R&D project. A dynamic programming model was applied for R&D project evaluation. Wang and Yang (2012) extend their model for flexible R&D planning of drug development project in the pharmaceutical industry.

Although there have been several real options research in R&D project valuation, few studies really consider risk management and real options analysis at the same time for technology planning. Linking risk management with real options analysis allows decision makers to select appropriate contingent actions and to respond effectively to the various risks faced by the project for maximize project value while reducing risks.

3 METHODOLOGY

In this study, a technology planning framework that integrates risk management with the real options analysis is proposed to help technology-based firms develop a new technology for maximizing the probability of positive return or expected project profitability (see Figure 1). The proposed framework consists of 4 stages presented as follows.

Step 1: Technology Roadmapping
Technology roadmapping is a systematic methodology that integrates the concepts of market pull and technology push, aligning target market requirements, products, technology capabilities, and R&D resources (see Figure 2). Its main advantage is to show the linkages of customer demands, products performances, technology capabilities, and R&D resources with timeframe to clearly present

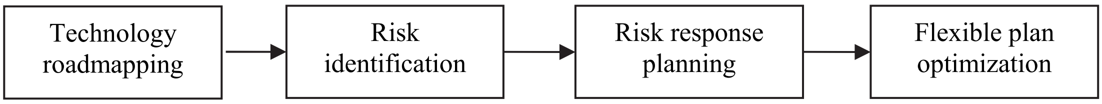


Figure 1: The framework of flexible technology planning.

and communicate and corporate strategic planning (Phaal et al., 2003).

Step 2: Risk Identification
The innovative R&D project usually has great market and technological uncertainties, which may lead to project failure. The purpose of this step is to identify and understand critical R&D risks that may affect the success rate of an R&D project. Risk identification distinguishes potential risks that may affect project goals and outcomes, and information about potential R&D risks may be collected from survey, interview, best practice, brainstorming, etc. (Chapman and Ward, 2003; Wang et al., 2010). Based on the information collected in development phases, different scenario alternatives are analyzed to identify potential risks for the R&D project.

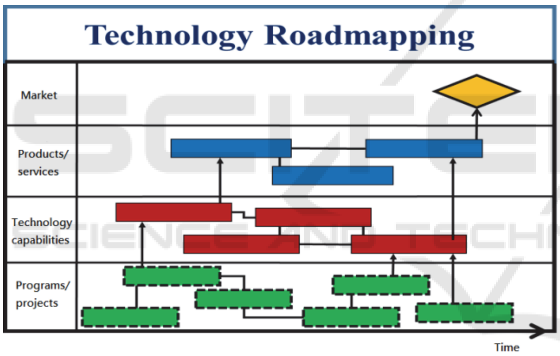


Figure 2: Example of technology roadmapping.

Step 3: Risk Response Planning
According to the critical risks identified in the second step, this step maps the risks that must be managed to appropriate managerial actions or options. This research summarizes the following R&D investment options that have been used to enhance managerial flexibility as follows (Trigeorgis, 1996; Huchzermeier and Loch, 2001):

Continue/Abandonment Option: This type of option is usually used in every stage of a R&D development project. A project may be abandoned because its performance can't be satisfied to the market requirement or it fails to obtain regulation approval.

Expansion/Contraction Option: This type of option represents the possibility of adjusting the amount of investment, depending on product performance and market conditions.

Deferral Option: The firm may invest in an R&D project until the market has emerged. Deferral option allows firms to wait for full investment commitment in more uncertain market situations until more useful information is available or market opportunity is clear.

Switching Option: A switching option provides the right and ability but not the obligation to switch among different sets of technologies, markets, or products based on the progress of technology development and market condition (Trigeorgis, 1996).

Outsourcing Option: The benefits of outsourcing include reducing cost, gaining extra capacity, and utilizing a vendor's special expertise to enhance the competitiveness of developing products. Alongside these benefits, however, this option also has the drawback that the output quality of the outsourcing partner might vary due to inappropriate process compatibility, coordination policy, and cultural fit between the two organizations (Piachaud, 2002).

License-in Option: This option provides a direct way to access the advanced technologies and methods of knowledge to get the ability. This option can provide immediate access to more advanced technologies that might enhance the technology capabilities of a firm, while saving R&D lead-time and cost. However, prior to the successful technology transfer into the firm, there might be higher uncertainty regarding the technology's achievable product performance in later R&D stages.

Improvement Option: The firm is allowed to invest more resources on an R&D project for improving product performance to meet higher market requirements and obtain greater market return (Huchzermeier and Loch, 2001).

Step 4: Flexible Planning Optimization
This research extends the real options model developed by Huchzermeier and Loch (2001) with Monte Carlo simulation to determine the best decision path that maximizes the expected project profitability or the probability of positive return. Assume that there are T review stages: t = 0, 1, 2,…T-1, and the new product is launched to the market at stage T. R&D uncertainty can be represented by performance improvement and

deterioration spread over possible performance states. The state of the project at review stage t is characterized by the expected product performance $X = (x_1, x_2, \ldots, x_n)$, where x_k is the individual product performance, $k = 1, \ldots, n$. Let d be the management decision (e.g., continuation, abandonment, etc.) at stage t. It is assumed that whenever the system is in state x_i and decision d is made at stage t, the system moves to a new state x_j with transition probability $p_{ij}^{t}(d)$, development cost $c_t(d)$, and development duration $h_t(d)$.

Let Y be the total product life cycle, S_t be the market size at year t, δ be the market share of a firm, α be the average contribution rate of the product using the technology, β be the product sharing ratio of the technology, and r be the discount rate. The potential profit margin M of the technology is calculated as:

$$M = \sum_{t=1}^{Y} \frac{S_t \times \delta \times \beta \times \alpha}{(1+r)^t} \tag{1}$$

When the project is launched at stage T with a performance state X, it will generate an expected market payoff $\Pi(X)$:

$$\Pi(X) = \underline{M} + F(X)(\overline{M} - \underline{M}) \tag{2}$$

where $F(X) = \text{Prob}(X \geq R)$ represents the probability that product performance X exceeds the market requirement R, $\overline{M}$ is a maximum profit margin as the realized product performance meets or exceeds R, and $\underline{M}$ is a minimum profit margin if the project misses the target market requirement R.

The total technology development project costs $C(D)$ is

$$C(D) = \sum_{t=1}^{T} \frac{c_t(d)}{(1+r)^t} \tag{3}$$

where D is the set of actions d selected at each stage to mitigate the risks encountered. Then the project profit can be calculated:

$$V(X) = \Pi(X) - C(D) \tag{4}$$

Given the required input data, the above model integrated with Monte Carlo simulation (Rubinstein and Kroese, 2007) can be used to estimate the probability distribution of R&D project profit for every candidate solution and to determine the optimal decision path using the simulation optimization technique (Fu, 2002).

4 CASE STUDY OF AN ASIC POWER MODULE DEVELOPMENT PROJECT

DC/DC converter module is an important element in power electronics and its purpose is to realize power conversion from an electrical source to an electrical load in an efficient, reliable, and cost-effective way (Owen et al., 2008). There has been a great and diverse demand for DC/DC converter modules, ranging from consumer electronics (such as laptop computers and cellular phones) requiring smaller size and lower-cost power converters to large industrial systems (e.g., telecommunication, medical, mass transportation, etc.) demanding highly reliable power converters. With growing demand of energy-efficiency and miniature size for electronic appliances in recent years, there has been an explosion in demand for smaller and lighter, more efficient, and less expensive power converters. Increasing power requirements on energy efficiency and need for reliable power drive demand for DC-DC converters. Innovations in segments such as telecommunications, medical, and technology promote demand for newer products. It was projected that the total worldwide revenue market for DC-DC converter modules will reach approximately \$5.0 billion in 2019, a compounded annual growth rate (CAGR) of 4.9%.

The case study was conducted at a leading power module company in Taiwan (called M company in this research). Facing the great competition challenges, Company M conducted technology roadmapping to identify market demands, product features, and required technologies to fulfill the market demands. The company decided to initiate the new R&D project to develop the ASIC technology that is able to integrate functional circuits into a chip for making the overall decrease in the number of components and increasing product life, stability, and power density as well as product size miniaturization, leading to better product differentiation and product niche. Meanwhile, ASIC technology can also improve manufacturing yield and reduce manufacturing costs, while greatly enhancing R&D of and product design quality. The linkage between market drivers, product features, and technologies are shown in Figure 3.

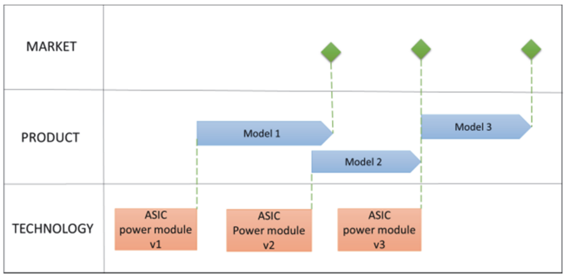


Figure 3: Technology roadmapping for Company M.

The ASIC power module R&D project can be divided into four stages: defining ASIC specification and identifying collaboration partners, collaborative design for ASIC architecture, ASIC testing and integration verification, and lot purchasing and production quality verification. The firm identified potential technical challenges and corresponding risk response actions for each stage of ASIC R&D project. The risks and corresponding options are identified in Figure 4.

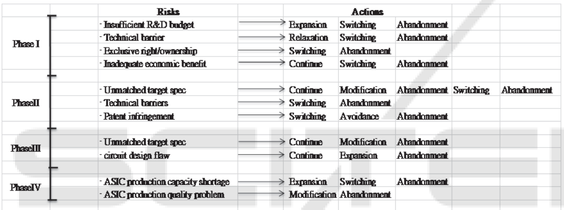


Figure 4: Risks and corresponding options for ASIC R&D project.

5 RESULTS AND DISCUSSIONS

5.1 Maximizing the Probability of Positive Investment Return

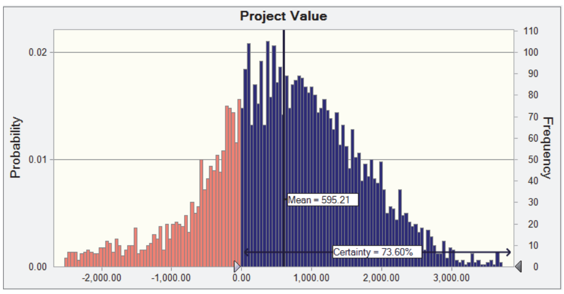
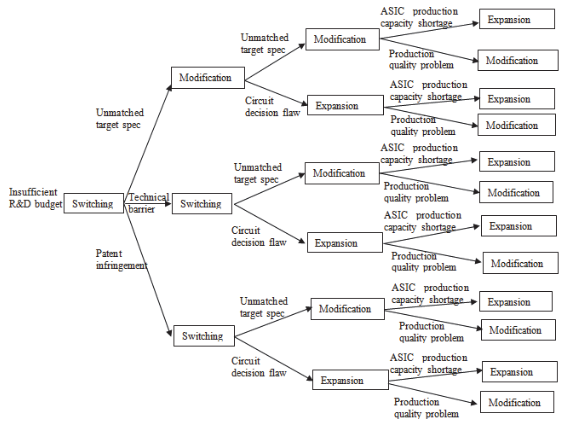
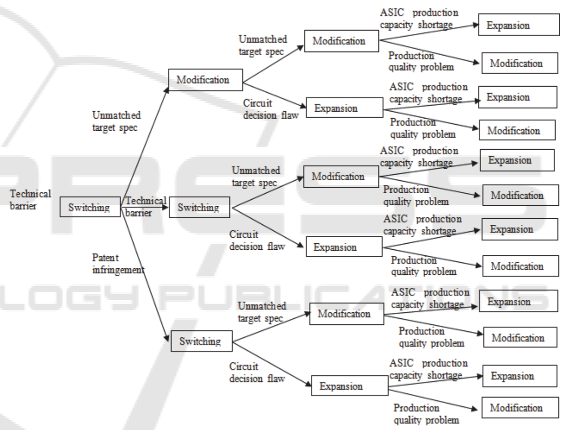


Figure 5: Probability distribution of project profit for ASIC R&D project.

The first scenario is to maximize the probability of positive investment return. Using the method developed in section 3, the optimal expected project profit was NTD$ 5.952 million and the probability of positive investment return was 73.6%. Please refer to Figure 5 for the probability distribution of project profit.



(a) Insufficient R&D risk



(b) Technical barrier risk

Figure 6: Optimal decision paths for maximizing the probability of positive investment return.

Figure 6 depicts the optimal decision paths that suggest an appropriate risk response action for every potential risk. For example, in the first stage of technology development project, if R&D budget is insufficient to pay to the collaborated firm, then the option of switching to alternative IC design firm is suggested. In the second stage, if the specification still cannot be satisfied, then the option to modify for improving the ASIC design is suggested. On the other hand, if technology barrier or IC design patent infringement is encountered, then the option of switching to alternative IC design firm is also recommended. Next, if the target design specification cannot be reached in the third stage, then the option to modify the original design is suggested. If a major design flaws has been found, then expanding R&D investment is suggested to improve the ASIC design. At the last stage, the option to expand the production capacity is suggested for the ASIC inventory shortage problem, while the option to modify design is recommended for the production quality problem. Please refer to Figure 6 for optimal decision paths regarding other potential risks such as technical barriers, patent infringement, and inappropriate economic benefits.

5.2 Maximizing R&D Project Profitability

The second scenario is to maximize the expected project profit and the optimal expected project profit is about TWD$ 12.335 million with a probability of 70.53% having a positive return on investment. The probability distribution of project profit is shown in Figure 7.

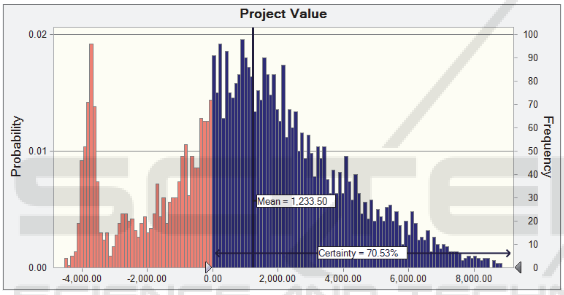


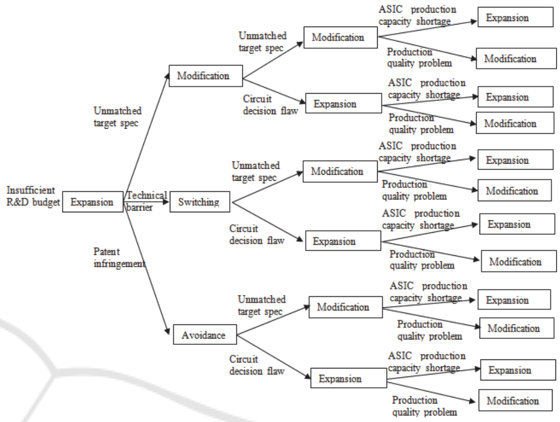
Figure 7: Probability distribution of project profit for ASIC R&D project.

The optimal decision paths are shown in Figure 8. For example, if technical barrier is encountered in the first stage of technology development project (such as the selected design firm cannot provide the ASIC design satisfying the specification required), the option of switching is suggested to be applied to find another IC design firm with better IC design competence.

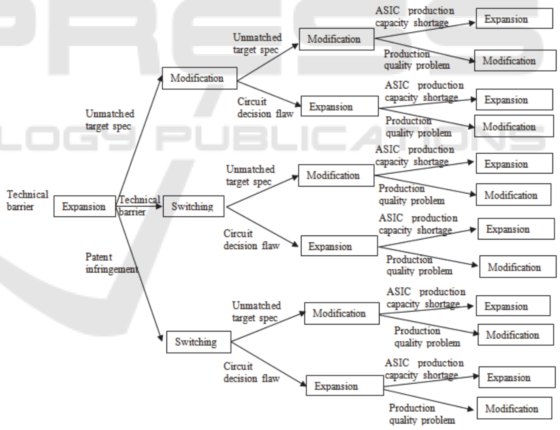
In the second stage, if the specification still cannot be satisfied, then the option to modify for improving the ASIC design is suggested. Next, if a design problem has been found in the third stage, then the option to expand R&D investment is suggested to improve the ASIC design. When there is an ASIC inventory shortage problem in the third stage, then the option to expand the production capacity is suggested.

5.3 The Value of Managerial Flexibility

From the above results, the first scenario has a higher probability of positive investment return, but the second scenario has much better investment profitability with a bit higher potential project failure. The final selection decision is dependent on the risk attitude of R&D manager. If R&D manager is risk averse, then the objective of maximizing the probability of positive return is recommended. On the other hand, if R&D manager is toward to risk-pro, then the objective of maximizing project profit is suggested.



(a) Insufficient R&D risk



(b) Technical barrier risk

Figure 8: Optimal decision paths for maximizing ASIC project prifitability.

We also applied the NPV method to calculate the project profit and the expected NPV project profit is TWD$ -49.527 million. The value of flexibility for the first scenario is TWD$ 55.479 million, while the first scenario is TWD$ 61.862 million. Therefore, it is necessary to include managerial flexibility in the process of project planning and valuation for managing project uncertainty and risks to improve the chance of project success. Failing to take managerial flexibility into account would under-estimate project value and potential feasibility. The probability distribution of three scenarios are shown in Figure 9.

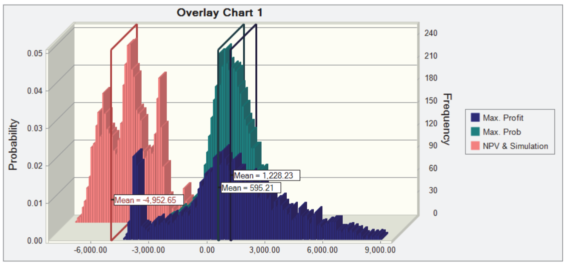


Figure 9: Comparison of three scenarios.

6 CONCLUSIONS AND FUTURE RESEARCH

Technology planning is significant for technology-based firms to enhance their competitive advantages in today's rapidly changing and highly competitive industry environment. This study developed a real-option framework integrating with risk management that helps R&D managers consider managerial flexibility in their technology planning to maximize project profitability, while enhancing project success rate. The first stage used technology roadmapping linking market requirements, product features, and technology capabilities. The second and third stage identified the risks and corresponding risk response actions, respectively. The final stage evaluated and constructed optional flexible technology plans. The case of power module ASIC R&D project was used to illustrate the developed methodology. The obtained results show that the developed methodology can not only mitigate the risks but also enhance the profitability of technology investment.

This paper only consider two key performance indicators: operating voltage and temperature for illustrative purposes. Since the power module ASIC is complex and has more than two critical performance indicators, future research will take full ASIC technology complexity into account for more practical validation.

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