Real Option Approach and Multi-Stage Fuzzy Decision-Making System for IP Valuation

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Abstract: This article delves into the pricing of intellectual property (IP) valuation and proposes the Real Option Approach (ROA) as a suitable method. Drawing on an overview of previous research on ROA, IP pricing, and fuzzy inference systems, a FIS approach is introduced to optimize real options. This approach utilizes a multi-stage fuzzy decision-making system comprising 15 variables and 11 fuzzy decision-making rules. The patent is considered as an asset that requires commercialization and generates positive cash flow after the development process. After establishing underlying distributions of parameters, simulation results suggest us to admit the system's stability and the pricing of intelligence property.

Keywords: Real Option Approach, Patent Valuation, Fuzzy Inference System

1 Introduction

With the enrichment of financial tools and the improvement of the financial market, an increasing number of types of assets are being securitized in order to enable owners to obtain greater returns and better utilize assets. In the past, the majority of securitized assets were tangible assets, such as securities and minerals. However, as technology plays an increasingly important role in production, the financial market has begun to focus on intangible assets such as intellectual property, trademarks, and patents.

However, the entire market resembles more of an OTC market, with most bonds not publicly issued and licensing transactions determined through one-on-one negotiations between companies. One possible reason is that the pricing methods used for intellectual property are not yet sophisticated enough. Currently, the mainstream pricing methods include the following, first, Cost method: based on the intention of establishing the value of an IP asset by calculating the cost of developing a similar (or exact) IP asset either internally or externally; second, Market method: based on comparison with the actual price paid for a similar IP asset under comparable circumstances; third, Income method: values the IP asset on the basis of the amount of economic income that the IP asset is expected to generate, adjusted to its present day value. This method is the most commonly used method for IP valuation; forth, Real-option method: treats an IP asset as a real option and pricing its NPV by considering its volatility and abandonment option.

Currently, the majority of intellectual property valuation use the second and third methods, whose advantages and limitations are evident. They are easy to calculate, but cannot reflect the

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costs of commercializing IP in the future, nor do they take into account the risks of intellectual property in the future. They can facilitate the conversion of intellectual property into bonds, but are not conducive to commoditized transactions. Therefore, this article will mainly focus on the Real Option Approach (ROA) method and its current research status, and propose possible solutions to several key issues.

2 Literature Review

2.1 Framework of Real Option Approach for Patents

One of the most important works in the ROA field is Schwartz's work [1], in which he constructs a complete framework. From the perspective of real options, the buyer is not buying the asset itself, but rather the right to develop the asset. After acquiring the asset, the buyer can choose whether or not to develop it, and during the development process, the buyer can stop development at any time based on their judgment of the future. The developer's cost during this process is considered a negative cash flow with uncertainty. Once development is completed, the asset will provide a positive cash flow with uncertainty. Furthermore, Cotropia [2] compares financial asset options with real options and concludes that the flexibility of real options gives them unique value in a wider range of fields. And some specific method are applied.

The first commonly used method is to directly replace the parameters in the Black-Scholes model or the binomial/trinomial tree model with statistical data. For example, Wu [3] provide a real option formula based on B-S Equations to calculate the patents. Hemantha [4] use Binomial Approach to simulate the value of a MACH3 R&D project and hence do some numerical analysis.

The second method is relatively more complex and comprehensive, which truly takes into account the fact that developers can choose to abandon the development. The process of development and commercialization is described as a time series process, and the expectations of developers are subject to random influences at each stage, and if developers believe that the costs outweigh the benefits, they will choose to stop the development. Scholars such as Hernandez-Garcia et al [5], Iazzolino and Migliano[6] have used this method for pricing.

2.2 Heuristic Algorithm and Fuzzy Inference System

In terms of implementation, heuristic algorithms and fuzzy inference systems are two major types of numerical methods that embody the heuristic approach. Heuristic algorithms are algorithms that seek approximate optimal solutions. They are often used to solve problems that are difficult to solve with exact algorithms. By inputting variables with stochastic properties, introducing certain decision rules and membership functions, a solution that is sufficiently logical can be produced, often based on some predetermined decision rules and variable distributions.

Regarding the pricing of intellectual property, as we have discussed previously, fuzzy inference systems are undoubtedly more suitable. This is because it is difficult to determine the "correct price" in advance, making it difficult to design the optimization direction of heuristic algorithms. At the same time, fuzzy inference systems can be flexibly modified according to the needs of the company and the judgment of actuaries in the business, and provide specific development recommendations.

Previous literature has already made significant progress in the design and application of fuzzy inference. Ojha et al [7]. reviewed 30 years of research on fuzzy inference and provided an in-depth overview of the best designs for using five famous fuzzy inference systems (FIS). Guillaume [8] discussed the design process and optimization methods of fuzzy inference systems. Firstly, the rules are generated based on the data set and expert knowledge, and then different rules are analyzed and optimized to improve the system performance.

3 Methodology and Results

3.1 Fuzzy Multi-State Decision Process

In short, the key to heuristic valuation is to handle information that is uncertain, so as to make the most robust and effective choices. In our case, such a heuristic should be reflected in a multi-stage decision-making process, where at each stage of patent development, the holder can consider the fuzzy information of benefits, expenses, and risks comprehensively and make decisions accordingly.

To conform to reality, we can consider patents as a combination of Abandon Option, Delay Option, and Expand Option, as the holder's decisions in the development process can be categorized into these three types. This type of real options is often applied in the development of production or inventory systems, and our modeling process also refers to literature in this area. For instance, Li et al [9].and Dettenbach and Thonemann [10] all discussed heuristic decision-making in uncertain inventory systems. Brandao and Dyer [11] discussed the use of multi-stage decision tree models to evaluate the value of physical options and provided properties of some variables in the development process.

Therefore, we have designed a multi-stage fuzzy decision model. At each stage, the owner of the intellectual property will make investment decisions based on fuzzy decision rules, including normal investment, increased investment in the stage, decreased investment in the stage (equivalent to delaying the option), or ending investment. After development is completed, the net income is discounted to the initial time as the option value. Figure 1 summarizes our process.

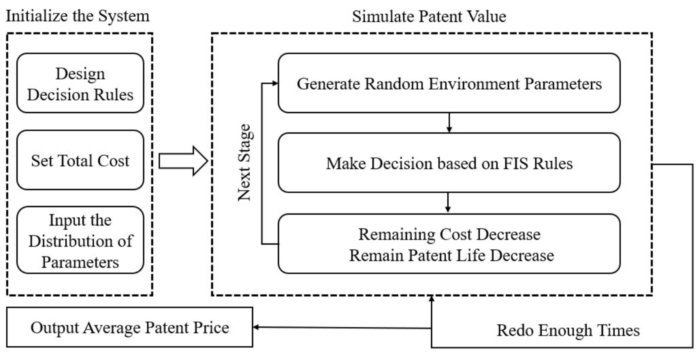

Figure 1: Valuing Process

3.2 Introduce the Parameters

During the initialization process of the system, two types of variables need to be inputted. The first type includes variables that depend on actual values, such as the initial expected cost, initial expected annual profit (based on an expected normal market share and sales volume), and expected average interest rate (used for discounting). The second type includes random variables that affect decision-making. In specific business logic, decision-makers adjust their decisions based on their “views”. In the FIS, we simulate this part of the decision-makers’ views and regard these variable to follow fixed distribution, and in reality, we simulate the real parameters that affect these views.

The second part consists of fuzzy variables, which need to take into account the range and distribution of values. The specific value itself is not of decisive importance, as it only describes the degree of importance of the event, which is more like a qualitative description. The range of values needs to be set because it is related to the membership functions that we will mention later, while the distribution affects the realism of the system. The table below describes the fuzzy variables that we have set. Of course, users of the system can design variables according to their needs. We especially recommend using distributions related to the Poisson distribution for variables involving risk, which is obviously more in line with reality than the uniform distribution.

We have defined three fuzzy categories, “High”, “Medium”, and “Low”, for each random variable. After using the membership function to complete the transformation, we decode the results back into decision categories. There are four decision categories, “Increase”, “Maintain”, “Decrease”, and “Abandon”, where the latter means to exit the entire development process, which usually happens when the risk is extremely high. The entire decision-making process is illustrated in Figure 2.

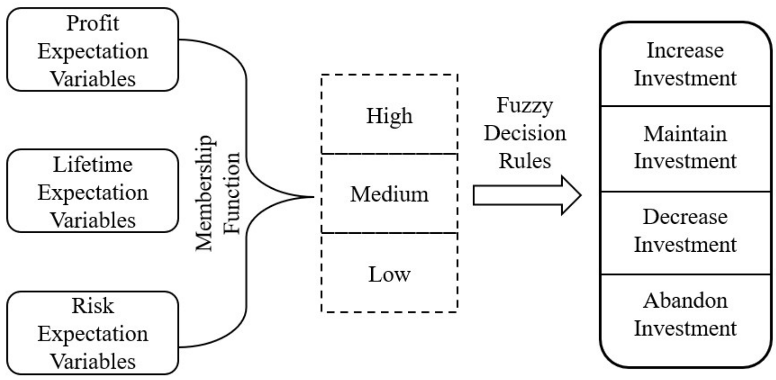

Figure 2: Logic of Fuzzy Inference

In terms of the design of specific decision rules, we developed 11 rules based on the potential concerns in the development process, guided by experiential thinking. These rules are presented in Table 1. It is worth noting that our rules are different from the quantitative descriptions used in heuristic algorithms and tend to be more qualitative. These rules cover the random variables to a large extent, but in reality, a more accurate fuzzy decision-making system may require more rules than this.

Table 1 Investment Decision Rules

Index	Rule Description
1	If sales volume and market share are high, development cost is low, and patent lifetime is long, then increase investment.
2	If sales volume or market share is medium, then maintain investment.
3	If policy risk, systemic risk or industry risk is high, then decrease investment.
4	If interest rate and company risk are low, and investor patience is high, increase investment.
5	If interest rate, company risk, or investor patience is medium, maintain investment.
6	If there is a risk of technological replacement, then decrease investment.
7	If development cost is high and company risk is low, then decrease investment.
8	If patent lifetime is short and there is a risk of being replacement, decrease investment.
9	If policy risk, systemic risk, and industry risk are all low, then increase investment.
10	If interest rate is high and investor patience is low, then decrease investment.
11	If sales volume and market share are low, company risk is high, then decrease investment.

3.3 Empirical Experiment

In this section, we conduct a case study using the set fuzzy variables and control rules. We set the initial cost to be 100,000, initial income to be 100, and the interest rate to be 0.05. The entire project is divided into 40 stages. We first conducted three valuations, with 5,000 path simulations conducted for each valuation. The simulation was performed using Python, and the pseudocode for the entire process is shown in Algorithm 1.

Algorithm 1 Multi-stage fuzzy decision system

Input: N stages, Init Cost, Init Annual Income, Interest Rate

Output: Exit Count, Average value

for *i inrange(5000)* **do**

  for *stage inrange(n stages)* **do**

    1: Generate random state values

    2: Apply fuzzy decision rules to determine investment decision

    3: Adjust investment based on decision

    4: Update remaining cost

    5: Check if development is complete

    6: Determine next stage based on decision

  end

  Calculate Net Profit at Time 0

  if *Development is exited earlier in stage* **then**

    ExitCount ← *ExitCount* +1 **end**

  Calculate average value;

  Output exit count and average value;

The two figures below show two different scenarios: in Figure 3 the decision maker chose to abandon the project midway, and the other where the project was completed in its entirety. In the abandonment scenario, we can see that the decision maker executed the abandon option in the eighth stage, resulting in no revenue generation and only sunk investment costs. By observing the graph, we can see that the Remaining Cost experienced an abnormal increase in the last stage, which may be the core reason for abandoning the development.

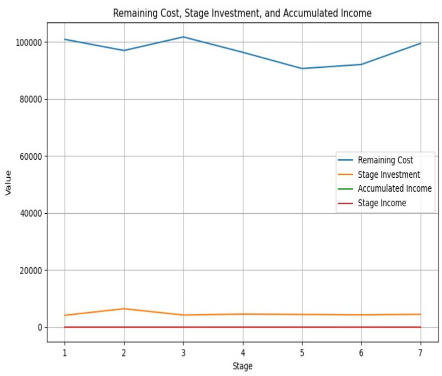

Figure 3: Abandon Investment Case

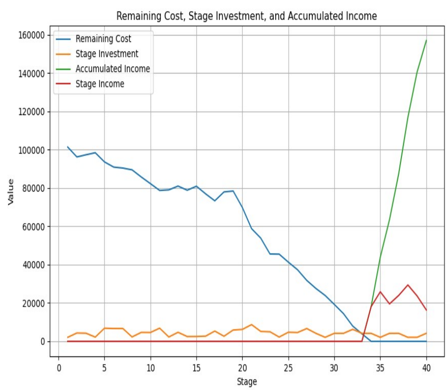

Figure 4: Successful Investment Case

In this second case which is shown in Figure 4, the investor completed the investment and started to earn profits in the 33rd stage, with the profits fluctuating around the initially set value. After all, 40 stages were completed, we calculated the present value of the net profit (revenue - development cost), which was -52865.51. This seems to deviate slightly from the result shown in the graph, but this is because we discounted the cash flows, and the further away the cash flow is from the initial time, the lower its present value. However, this is also related to our rough initial value settings, including the initial income, development cost, and interest rate. More accurate value estimation requires more precise initial estimates.

4 Conclusion

In summary, we have reviewed traditional approaches to pricing intellectual property and, based on the multiple options inherent in intellectual property, we believe that real options are the most suitable pricing method. Furthermore, we have examined the limitations of real options and introduced a Heuristic approach to optimize them. In practice, we used a multi-stage fuzzy decision-making system to simulate the development process of real options, with 11 fuzzy decision-making rules. Through multiple simulations, this system yielded relatively stable results for the given input values.

Certainly, whether this system can provide appropriate valuation in real-world situations requires empirical data verification. For some key variables, we have made assumptions about their distributions, and whether this set of assumptions is appropriate also warrants further testing.

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