Comparison of Real Asset Valuation Models: A Literature Review

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Abstract

NPV, decision trees, and real options have been prevalently practiced in real asset valuation and management. Complexities have been built on the basic frameworks in practice. In this paper, application values and limitations of real options, NPV, and decision trees in real asset valuation are illustrated with literature review. The pros and cons of each method shed light on future improvement of real asset investment evaluation and risk modeling.

Keywords: NPV, Decision trees, Real options, Real asset valuation, Complete market, Risk neutral probability

Introduction

According to Smith and Nau, NPV, decision trees, and real options modeling have been applied without a clear understanding of the strength and limitations of each model in many fields:

"In the usual MBA curriculum, students learn about decision trees and utility theory in their project management course. In financial management courses, they are taught about how the discounted cash flow and discounted rate are used to model risks. In advanced finance courses, they learn option valuations in the complete market using risk neutral probabilities. The result of all these trainings is the graduates who may understand each method but fail to appreciate the relationships between them and their relative strengths and weaknesses. A similar gap between the decision analysis and finance disciplines exists in the academic literature and professional practice. This gap has become increasingly apparent with the development of option pricing techniques for valuing projects in which managerial flexibility or 'real options' play an important role." ----- By Smith and Nau (1995)

1. Net Present Valuation (NPV)

Net present value (NPV) is a stereotyped methodology that firms have used for a long time to evaluate a project investment. However, Myers (1984), Brennan and Schwartz (1985a, 1985b), Kester (1984, 1993), McDonald and Siegel (1986), Pindyck (1991), and Trigeorgis (1993c) all pointed out that NPV modeling ignores the value of flexibility of real asset investment. Hence, the real asset investment is undervalued. More particularly, strategic value of a project is missing in NPV, as pointed by Myers (1984), Pinches and Lander (1997), Brennan and Schwartz (1985). Consequently, NPV kills many projects with strategic value with an expected NPV benchmark. They proposed that the true value of real asset investment should be adjusted by adding the values of all embedded real options to the net present value of the underlying asset.

In technology innovation investment, NPV holds back firms' effort in disruptive technology exploration. When a disruptive technology invented and introduced to the market, the new technology "S" curve starts below the one of its precursor. The financial criteria may disapprove the investment of the technology based on a small discernible market. However, the new products may accumulate its popularity with an accelerating rate. Therefore, sticking to NPV which does not tell the potential of a new technology may obstruct firm's technology competitiveness development.

Moreover, "the dynamic features of the market, industry, and technologies render the estimation of future cash flows and discount rates difficult if not possible" (Porter, 1996). The weighted average cost of capital (WACC) and the risk premium calculated according to the estimated beta are not reliable, since a proper beta is available for a disruptive technological innovation investment.

2. Decision Trees

Unlike NPV, decision trees focus on modeling various kinds of flexibilities during a life span of a technology project development. The discount rate, probabilities, and the expected value of each alternative are determined based on practitioners' knowledge of the investment. Decision trees enable the practitioners to "recognize the interdependencies of decisions made at different stages" of the project investment (Trigeorgis, 1996). It reflects synergies that NPV misses. What's more, decision trees calculate the "maximum expected NPV rather than just the expected NPV" based on a serial of optimum circumstances. (Galli &Armstrong, 1999)

Compared with real option pricing models, decision trees model flexibilities with unknown underlying asset distributions. In many publications, the distributions of real asset investments in real option pricing modeling have not been studied carefully. Rather, Geometric Brownian Motion or Arithmetic Brownian Motion was adopted for granted in calculation.

Moreover, since decision tree framework models reality without "no arbitrage" assumption, which is a must in option pricing models, it can be applied in all kinds of markets, complete or incomplete. Therefore, decision tree modeling provides an alternative to resolve the fundamental problem in real option pricing.

In spite of its superior features over NPV and real option pricing, decision trees have their fundamental discrepancies that are hard to be fixed.

First, "in complex investment circumstances, the more the layers are added to the decision tree, the more difficult it is to apply decision trees in real asset investments" (Baker & Pound, 1964). Decision tree modeling is no longer practical once the tree framework becomes complicating. "Decision tree analysis can easily become an unmanageable 'decision-bush analysis', as the number of different paths through the tree (or bush) to be evaluated expands geometrically with the number of decisions, outcome variables, or states considered for each variable."(Trigeorgis, 1996)

Second, the values of variables in decision trees are hard to estimate. Trigeorgis, (1996), Baker & Pound (1964), Cetron, Martino, and Roepcke (1967) pointed out "the over optimization and poor treatment of uncertainties were the limitations of decision trees application in real world practice". Further, "market demand does not have just 'high' or 'low' values; there are quite a few intermediate values." (Trigeorgis, 1996)

At last, "discount rate in decision tree is a big problem, since, among several reasons, it cannot be constant across the tree." (Trigeorgis, 1996). To simplify, some decision trees apply risk free rate according to risk neutral approach in financial models. However, this approach is flawed as pointed out by Trigeorgis (1996). "It is inconsistent to build the tree forward using the actual probabilities and expected rate of return but … move backward discounting at the risk-free rate (without using certainty-equivalent or risk-neutral probabilities)."

Binomial tree or lattice method is a discrete time option model employing decision tree format. The binomial tree modeling bases its framework on Brownian motion distribution of the underlying asset in a risk neutral world. Trigeorgis (1993) and Smith and Nau (1995) integrated the "paradigms of finance theory and decision analysis as applied to investment valuation" by assuming the traded and non-traded asset are in a same complete market. However, Adam Borison (2003) disagreed and proposed that risks with different characters should be measured differently. In his model of gas investment project, he decomposed the risks of the underlying asset into two categories: the "entirely market-dominated" and the "entirely private-dominated". He said if the investment falls into the former category, "risk neutral" valuation, i.e. the financial option pricing mechanism, should be used. If the investment falls into the latter, decision trees with the estimated real probabilities is proper. In his model, he claimed the amount of the gas discovered has private risk and the price of gas has market risk. To take advantage of the strength of both decision trees and option models, his hybrid model incorporates "this binomial model of gas prices in the tree together with the three-state model of gas amount and roll the tree back at the risk free rate." Integrating the risk neutral valuation and specific risk valuation, according to Borison (2003), is a "consistent and reasonably accurate world-view" to price option in the real asset investment. However, his approach became inconsistent when he applied real probabilities of gas amount and risk free rate of return simultaneously as pointed by Trigeorgis (1996). (Figure 1)

The binomial tree constructed by Borison demonstrated the challenges to integrate both with theoretical soundness and practical feasibility, as Boer (2002) stated in his "financial management o R&D 2002", "the distinction between unique and market risk is critical for sound decision-making in real business."

3. Real Options

Real options, of course, originated from financial options. A European call option gives holder the right, but not the obligation, to buy the underlying asset at the exercise price on a designated date. While the financial option concept was applied in real asset investment, the phrase “real options” was coined.

Real option modeling is a multi-disciplinary subject. It has been applied in almost every industry during past decade. Mitchell and Hamilton first proposed technology real options in 1988: “the firm purchases an R&D option by investing on new technology research and development.” Once the technology is developed, the firm has the right to introduce it to the market if the market condition is favorable. Real option valuation, compared with NPV, enabled the firms to recognize market flexibilities. With the real asset investments being divided into layers or stages the risk of the whole project is limited to the investments incurred. Firms accumulate market and technology knowledge through the process of investments at each stage and benefit from modifying their investments and technology strategy with learning. Tanguturi & Harmantzis (2005) valued the operation flexibility based on learning during the migration path from the second wireless technology to the third wireless technology with Real Options. Laate (2006) compared the valuation of a new biotechnology development and commercialization using NPV and RO. In his study, NPV valuation rejected the R&D project but Real Options approved it. Besides suggesting the value of flexibility, his study also proposed Real Option models should be adopted in public policy and R&D investment management. Li and Johnson (2002) build Real Option calculation based on technology switching costs and the nature of competition. MacMillan and McGrath (2002) propose Real Options portfolio for R&D project management.

Some literature suggests the time value is missing in NPV calculation. When technology project development horizon extends farther into future, the time value of real options drives the value. Hence, the NPV of a technology investment with high future uncertainties embedded renders wrong decisions.

Many researches suggested integration of Real Options and NPV for project valuation. According to MacMillan, & Putten (2006), the combination fixes the flaws of NPV analysis in practice. Trigeorgis (1993c) even quantified this approach by:

NPV of the real asset investment=NPV of estimated cash flows + option values. (Figure 2)

Comparing NPV and real options methodologies, the “potato garden” (Harvard Business School Case 295-074) provides a vivid analogy of the advantage of real options valuation over NPV as well as their relationship. With positive net present values and low volatilities, the projects are ripe for harvest. Projects with high volatilities are to be observed carefully, since high volatilities may imply high potentials. (Figure 3.)

In short, real option valuation is an effective strategic management tool for a firm to maneuver in market competition. Kumaraswamy compared the firms adopting real options with the firms sticking with NPV methodology:

“I test the core proposition using data collected through a mail survey of high-technology firms. Exploratory analyses indicated that the adoption of a real options perspective of R&D encourages investment in long-term R&D, and enhances certain aspects of R&D performance - particularly, the success rate of projects funded, the number of new products introduced and the performance improvements achieved in current products. Results also indicate that option-based project evaluation practices alone are not sufficient for enhanced R&D performance. Rather, options-based project evaluation practices yield desired results only when supported by the adoption of appropriate organizational structures/practices and a well-endowed R&D resource base.” (Kumaraswamy, 1996)

Although real options have advantage over NPV and decision trees in modeling real asset investment flexibilities, real option modeling assumptions are problematic in real option calculation, since real options have been valued with the framework of financial option modeling following the complete market assumption and Geometric Brownian Motion distribution of the underlying assets. These real option models must fail once the conditions are violated.

Trigeorgis is an advocate and a pioneer of real option modeling and practice. He has been leading the development of real options during last ten years. He extended financial option applications and proposed the fundament theoretical framework for real option pricing:

“Cox and Ross’s (1976) recognition that an option can be replicated from an equivalent portfolio of traded securities. Being independent of risk attitudes and of considerations of capital-market equilibrium, such risk-neutral valuation enables present value discounting, at the risk free interest rate, a fundamental characteristic of ‘arbitrage-free’ price systems involving traded securities….According to Mason and Merton (1985) and

Kasanen and Trigeorgis (1994), 'real option may, in principle, be valued similar to financial options, even though they may not be traded, since in capital budgeting we are interested in determining what the project cash flows would be worth if they were traded in the market (that is, their contribution to the market value of a publicly traded firm)."(Trigeorgis, 1996)

Hull's book on derivative pricing has been highly recognized and accepted as a classical textbook for derivatives over years. He added a new chapter of real options in the new version (2003) textbook, in which the theoretical framework of real option modeling is described as:

"…We find that an asset can always be valued as if the world were risk neutral, provided that the expected growth rate of each underlying variable is assumed to be risk free rate. The volatility of the variables and the coefficient of correlation between variables are not changed. The result was first developed by Cox, Ingersoll, and Ross and represents an important extension to the basic risk-neutral valuation argument (Cox, Ingersoll, and Ross, 1985)."(Hull, 2002)

As in these real option theories as well as many other real option models, the authors' efforts have focused on forcing the factors of real asset investments into the financial option models; the suitability for applying these financial models in empirical projects, however, needs to be examined.

Among many real assets valued by option models, technology R&D is new and exciting for people in the fields of real option model development and technology innovation and adoption management. According to Trigeorgis,

"For traded assets in equilibrium or for real assets with no systematic risk (e.g. R&D and exploration or drilling for certain precious metals or natural resources), the certainty-equivalent or risk-neutral growth rate just equals the risk-free interest rate (minus any 'dividends')" (Trigeorgis, 1996)

In a book edited by Paxon published in year 2003, 14 papers with 14 real R&D option models are presented. All of them are built on complete market assumption applying risk free rate of return for the future cash inflows as proposed by Trigeorgis. For instance, assuming the R&D revenue and R&D development cost both follow geometric Brownian Motion, Lee and Paxson (2001) studied E-Commerce R&D investment based on financial compound option valuation in a risk neutral world. No justification of the assumption of the distributions was given. This real R&D option models must lead to a question we have to confront: is the no arbitrage condition true for technology investment as it is true for a stock?

Trigeorgis provided almost all available rationales to support real option pricing models in a risk free world under no arbitrage assumption:

"The existence of a traded 'twin security' (or a dynamic portfolio of traded securities) that has the same risk characteristics (i.e., is perfectly correlated) with the non-traded real asset in complete markets is sufficient for real-option valuation. More generally, Constantinides (1978), Cox, Ingersoll, and Ross (1985, lemma 4) Garman (1976), and Harrison and Kreps (1979), among others, have suggested that any contingent claim on an asset, traded or not, can be priced in a world with systematic risk by replacing its expectation of the cash flow (or actual growth rate) with a certainty-equivalent growth rate (by subtracting a risk premium that would be appropriate in market equilibrium) and then behaving as if the world were risk neutral. For traded assets in equilibrium or for real assets with no systematic risk (e.g. R&D and exploration or drilling for certain precious metals or natural resources), the certainty-equivalent or risk-neutral growth rate just equals the risk-free interest rate (minus any 'dividends')" (Trigeorgis, 1996).

In summary of his opinions, one of the following rationales must be true in order to support the validity of the extensively used 'risk neutrality' approach in real option pricing:

a, the "portfolio matching" or "twin portfolio", i.e. the underlying asset distribution can be "perfectly" mimicked by a financial security;

b, the complete market theory, which includes the real asset investment into the financial asset market. Therefore, any real asset can be replicated "from an equivalent portfolio of traded securities". Once the market of financial assets and real assets is a complete one, i.e. a unique market price of risk applies to both the financial assets and real assets, "no arbitrage" assumption and risk neutral approach are valid in pricing any asset within this complete market.

Even though the risk neutral approach has dominated real option modeling development for over 20 years, doubts on the theoretical framework have been lingered since late 90s:

"Brennan and Schwartz assume that the spot price (here the oil price) obeys this (B-S) model. Paddock, Smith and Siegel, Trigeorgis and Kemma have taken a radically different approach; they base their analysis on the hypothesis that the project value itself obeys the model. The difference is important because the theory of option pricing requires that there is a liquid market for the underlying commodity and that there are no transaction costs and no arbitrage. While this is probably true of oil prices, it is doubtful whether there is a large enough market for oil projects….. The hypothesis of a twin security is extremely strong. This can be seen quite clearly in academic examples…; it is less obvious in practical case studies." (Galli, &. Armstrong, 1999)

Since real options frontiers are mainly from fields of finance and mathematics, the suitability of these assumptions of financial option pricing in other industry sectors has been ignored in many published researches. First and foremost, the risk of real asset investment cannot be quantified the same way as the risk for stock investment that is based on the standard deviation of the periodical returns.

In this paper, we are going to challenge the two schools of ideas in support of risk neutral approach in real option pricing suggested by Trigeorgis.

3.1 "Matching Portfolios"

To find the "matching portfolios", some real option models start with regressing the real project investment returns against some stock returns before applying the available financial option models. This cannot be a proper approach to validate the application of financial option models in real option scenarios. The reason is the same as why we cannot replace the Standard & Poor 500 with the butter production in Bangladesh although Leinweber (1997) "searched through a United Nations database and discovered that, historically, the single best predictor of the S&P 500 was butter production in Bangladesh".

A firm's common stock value is determined by the market judgment of a firm's overall competitiveness. A firm's management, organization, technology and products, strategies, and its competitors all contribute to its stock price fluctuations. On the contrary, the return of a project depends on many specific industry and project factors. Further, projects are usually short lived compared with firms' common stocks. The relationships between the factors determining the real investment returns and the factors influencing the firm's stock prices cannot be clear-cut explained except that they are different. Therefore, the perfect correlation suggested by Trigeorgis does not exist if the period of the series data is extended long enough.

Although the capital market is so efficient "that any economic rents which can be earned by powerful firms are fully reflected in the value of their securities"(Sullivan, 1982), we cannot decompose the stock pricing fluctuations into different projects earnings, so we cannot rely on a stock return to value a project as an option, for almost all firms invest in more than one project during their entire lives. Therefore, the statistical correlation between a project return and a stock return cannot justify the "no arbitrage" assumption in real option modeling.

3.2 Is the Market Complete for Real Option Pricing?

In order to use risk neutral measurement in real option pricing, we have to include the non-tradable asset such as R&D in the complete capital market, where we defined the "no arbitrage" earning of risk free rate and developed the financial option models. This forces us to confront a question: is the market outside the financial market arbitrage free? If it is, we can extend CAPM to include the real asset investment. Linking the market price of risk for any real asset investment with β in CAPM, we have:

$$\mu - r = \sigma\lambda = \beta(R_m - r)$$

According to Trigeorgis, a complete market should include both financial assets and real assets:

"For traded assets in equilibrium or for real assets with no systematic risk (e.g. R&D and exploration or drilling for certain precious metals or natural resources), the certainty-equivalent or risk-neutral growth rate just equals the risk-free interest rate (minus any 'dividends')" (Trigeorgis ,1996)

However, the tests of market efficiency based on CAPM rely mainly on the financial security investments with historical returns providing consistent volatilities. People even disagree with capital market efficiency and completeness. All kinds of anomalies, e.g. January effect, small firm effect, even weather effect and political party effect, have been identified. Controversy began before any real option model was built.

Regarding the real asset investments ranging from any small retail businesses to high scale projects like oil exploration and R&D on AIDS and new genes, an agreement reached by majority of investment experts is that "there are monopoly elements in some product markets which enable some firms to earn excess returns (i.e., returns above the opportunity costs of the resources utilized)" (Sullivan, 1999). It means the high investment barriers of some real assets enable the few to earn excessive returns. Not many investors have the luxury to satisfy the capital and policy requirements for the above-normal-profit investment.

What's more, the unclear volatilities of various kinds of real asset projects prevent these real asset investments from fitting into the complete market that requires an equal return per unit risk across any asset such as a T-Bill and a stock. The risk of financial investment is measured by the standard deviation of the historical returns. However, the risk of a disruptive technology does not have a historical data to trace. Thus, the border of the complete market cannot be extended to include both financial and real asset investments without careful considerations. Therefore, the theoretical foundation of real option pricing models applying risk neutral methodology is flawed.

In conclusion, "no arbitrage" valuation in real option pricing is acceptable while the underlying investment falls into the test scope of CAPM and other capital market models, based on which the capital market has been proved to be practically complete and efficient. The real options that fall into this category are mainly those with underlying asset being commodities such as oil, copper, which are sold in the future market. However, the investments like R&D on disruptive technology and projects of technology innovation possess high investment barriers and unknown volatilities so are not arbitrage free. Complete market theory does not apply. Neither do the financial risk neutral measurement and the existent financial option models.

4. Conclusion

This research summarizes the advantage and disadvantage of applications of NPV, decision trees, and real options in practice with literature review. By integrating theoretical requirements and applications of major quantitative models in real asset management, this research calls for caution for real option modeling and sheds light for improvement of real asset valuation and risk modeling.

This research suggests the path from financial option to real option pricing should to be adjusted. The risks of real asset investment include political, economic, industrial, technological uncertainties. Their features are different from the financial security risks measured by fluctuations of the trading prices. The risk of these two groups cannot be measured in a same complete market.

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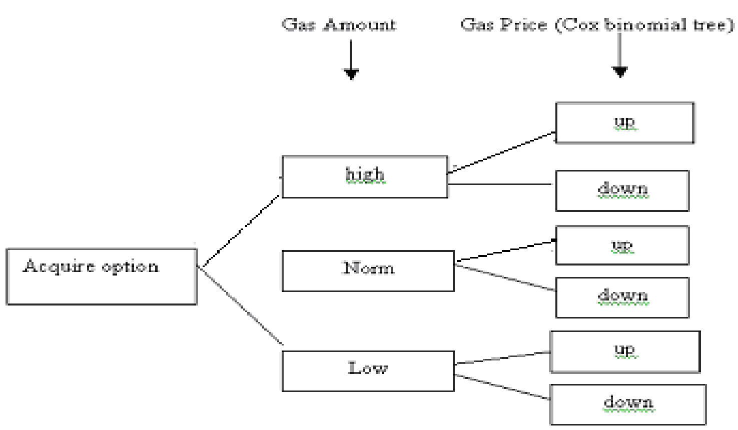

Fig. 1. A Hybrid Model

(Adam Borison, “Real Option Analysis: Where are the Emperor’s Clothes?”)

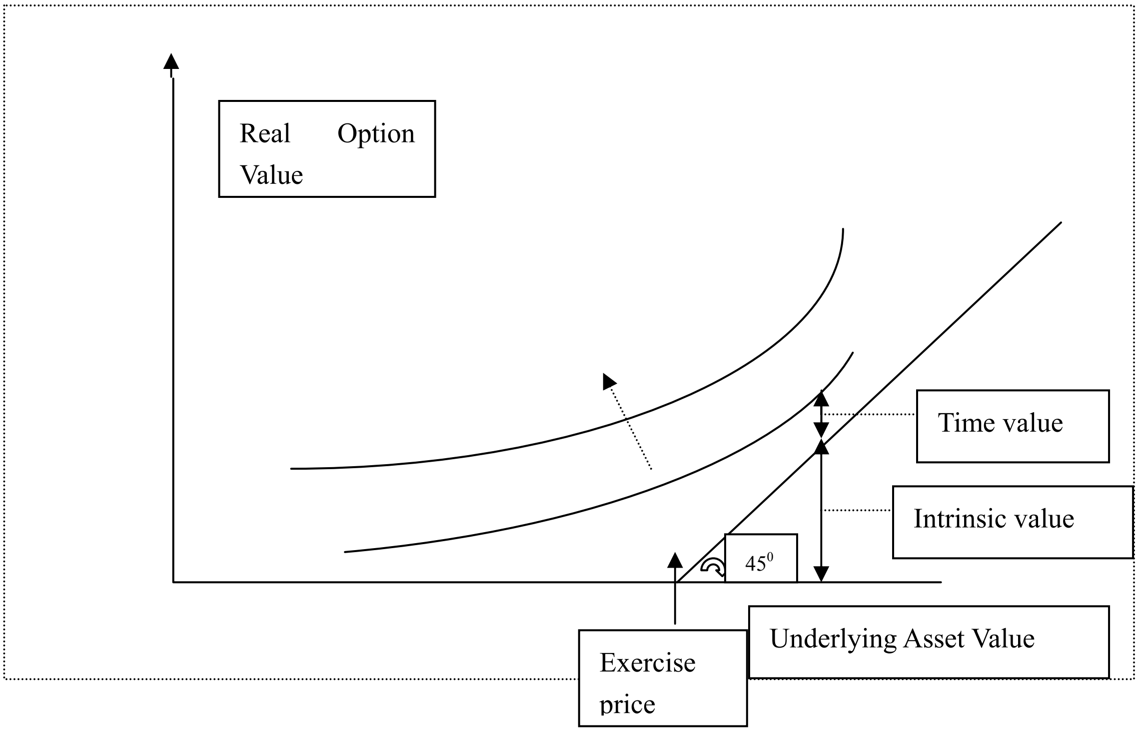

Fig. 2. Time Value & Intrinsic Value (Trigeorgis, 1993c)

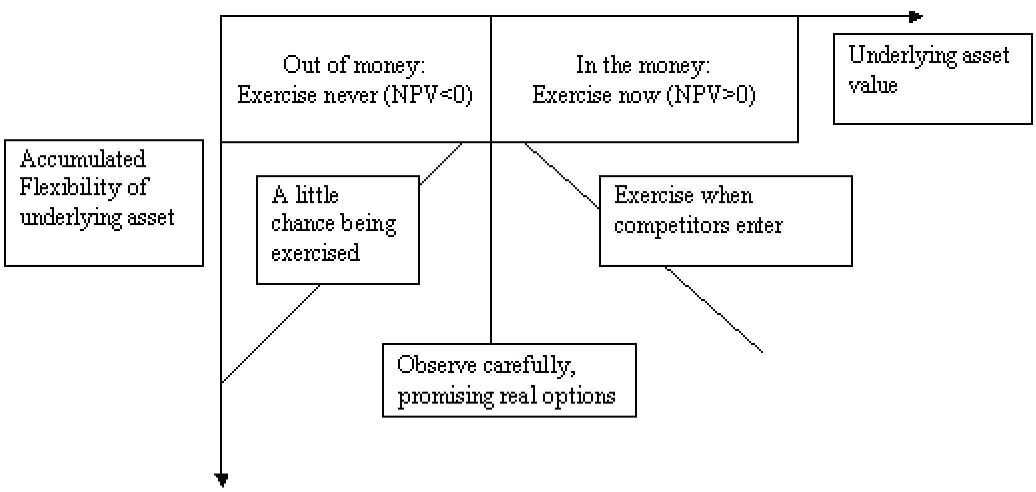

Fig. 3. Potato Garden (Harvard Business School Case 295-074)