REAL OPTIONS: EXAMPLES AND PRINCIPLES
OF VALUATION AND STRATEGY

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Abstract

The paper illustrates the use of real options and game theory principles to value prototypical investment projects and capture important competitive/strategic dimensions in a step-by-step analysis of investment decisions (options) under uncertainty. It first illustrates the application of real options principles to a mining concession and to an R&D program. It then provides examples from innovation cases and uses basic game theory principles to discuss other strategic and competitive aspects, especially applicable to oligopolistic industries like consumer electronics. The issue of whether (and when) it is optimal to compete independently or coordinate/collaborate (e.g., via joint R&D ventures or strategic alliances) is given particular attention.

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1. INTRODUCTION

This paper provides an overview of the basic principles of quantifying the value of corporate real options and of capturing important strategic dimensions, which are at the core of strategic planning and investing under uncertainty. In the current, highly volatile and competitive landscape, the horizon over which cash flows can be estimated confidently is shrinking, making it essential for firms to be flexible in their investment programs. The future is uncertain and as the dynamic investment path unfolds the firm's management learns, adapts and revises investment decisions in response to unexpected market developments. An analysis of projects in a dynamic environment is often more complex than the standard (DCF) approaches may suggest, since they implicitly assume a static view of investment decisions and projected cash flow scenarios.[1] The real options approach is more dynamic than the traditional approaches since it is capable of incorporating not only the value of flexibility and growth opportunities but also of competitive strategies in an uncertain environment.[2]

It is well accepted by now that the value of many strategic investments does not derive so much from direct cash inflows, as it does from the options to invest in future growth. Indeed, strategic plans often encompass projects which, if measured by cash flows alone, typically appear to have a negative net present value (NPV), when in fact they may have a positive total strategic value. An early investment in research and

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[1] The standard NPV methodology has obvious shortcomings in analyzing investment opportunities whose value derives from future growth options. NPV implicitly assumes such investment decisions are a "now or never" proposition; it does not take into account the value to "wait and see" and alter planned investment decisions as uncertainty gets resolved over time.

[2] A number of papers have addressed the importance of managerial flexibility. Baldwin (1982) examines sequential investment strategies and interdependencies with future investment opportunities. She observes that if firms with market power wish to compensate for the loss in the value of future opportunities that result from undertaking a project now, they must require a positive premium over NPV. Myers (1987) suggests considering strategic investment opportunities as growth options, while Kester (1984) discusses qualitatively strategic and competitive aspects of growth opportunities. Dixit and Pindyck (1994), Trigeorgis (1988, 1995, 1996a), Kemna (1988), Sick (1989), Smit (1996), and others, discuss many corporate options and provide various expositions of the real options approach to investment.

development (R&D), for instance, may seem unattractive if its direct measurable cash flows are considered in isolation. However, the potential profits from commercialization that may result from the research (and related spin-off applications) must be properly captured by determining the value of the underlying research program. Such a strategic R&D investment should not be seen as a one-time investment at the outset; proper analysis requires explicit consideration of its follow-on commercial options (i.e., to commercialize the end product of the R&D program) and related applications. The option perspective suggests that, as information over the success of R&D is revealed, management has flexibility to proceed with, terminate or otherwise alter its future investment plans.

The new view of investment that treats opportunities as corporate real options has enriched modern corporate resource allocation and planning. The *opportunity* to invest can be seen as a call option, involving the right to acquire an asset for a specified price (investment outlay) at some future time. The underlying asset may be a package consisting of the project plus the value of other embedded corporate real options (e.g., to later expand production scale, abandon the project for its salvage value etc.). The techniques derived from option pricing can help quantify management's ability to adapt its future plans to capitalize on favorable investment opportunities or to respond to undesirable developments in a dynamic environment by cutting losses.

"Wait-and-see" flexibility is clearly important in the evaluation of many investment opportunities under uncertainty. By delaying an investment decision, new information can be revealed that might affect the desirability of the investment, while management has the option to discontinue the project if market conditions turn out to be unfavorable. From this perspective, management should wait until a project is clearly desirable, requiring a premium over the zero-NPV value, reflecting the option value of deferment. Of course, from a strategic perspective it is not always advisable to defer investment. Besides the learning advantages of postponement, waiting may involve serious disadvantages. For example, management could lose early operating cash inflows when a fixed-life project is delayed, or miss out on a competitive first-mover advantage. An earlier (or heavier) strategic investment (say, to develop a new technology) may confer upon the pioneer firm a cost or timing advantage and influence the competitor's behavior and the resulting equilibrium in a way that

strengthens the pioneer's competitive position and long-term value. In other words, early investment *commitment* may have strategic benefits that must be weighted against the lost flexibility value component. These benefits and the resulting implications for competitive strategy can be captured with the help of basic game theory principles in combination with option valuation.

In the organization of this paper we find it instructive to follow a step-by-step exposition. To introduce different aspects into the analysis one at a time we start with examples of proprietary investment decisions (options) under uncertainty, and later introduce the strategic dimension of competitive reactions. The next section uses two basic numerical examples to illustrate the application of real options valuation principles to mining and to R&D programs. Section 3 extends the analysis using basic game theory principles to discuss other strategic and competitive aspects, especially applicable to oligopolistic, innovative (high-tech) industries like consumer electronics. Section 4 examines the issue of competition vs. coordination/collaboration. Section 5 concludes.

2. BASIC VALUATION EXAMPLES: MINING AND R&D

This section presents two prototypical applications. The first example considers the valuation of a gold mine concession, where the current project value can be estimated using a traded financial instrument (gold futures) whose probabilistic behavior is close to that of a producing mine. The valuation of a license to develop the mine is treated analogous to the valuation of a simple call option. In the second example, we consider whether to invest in R&D and subsequent stages of commercialization. The multi-stage R&D investment decision can be viewed as a compound option (or option on an option).

2.1 VALUING A MINE CONCESSION (LICENSE)

Following Brennan and Schwartz (1985), consider a firm that must decide whether to invest in a gold mine. The decision to develop the mine is irreversible, in that after development management cannot disinvest and recover the expenditure. To keep matters simple, suppose that development and extraction can be started immediately, requiring an investment outlay, I, of \$4.5 million (m). There are no variable extraction costs. The gold reserves and the production profile, Q_t, over time t,

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is known ahead of time: production in year 1, Q_1, is expected to be 4,000 ounces, and production in year 2, Q_2, 10,000 ounces.

Uncertainty over the value of the project is closely related to the dynamics in gold prices. Currently, gold is priced at $300 per troy ounce; next year, the price will change. For simplicity, we assume two possible end-of-period prices after one period: price increasing (with a multiplicative factor $u = 1.5$) to $S^+ = \$450$, or price decreasing (with a multiplicative factor $d = 0.67$) to a value of $S^- = \$200$. Both prices are equally likely. In the subsequent year ($t = 2$), prices may rise or decrease again, and the same multiplicative factors will apply. Table 1 summarizes the possible gold prices (S), extraction quantities (Q), and the resulting operating cash flows, $CF = Q.S.$[3] Suppose further that the risk-free interest rate r is 4% per year.

TABLE 1. Quantities, Prices and Operating Cash Inflows of a Mine in Various States

Period	State (Nature)	Probability q	Gold price per ounce, S	Quantity Q	Cash inflow (Q'S) CF (m)
0	current		$300		
1	high	0.5	$450	4,000	$1.80
1	low	0.5	$200	4,000	$0.80
2	high, high	0.25	$675	10,000	$6.75
2	high, low / low, high	0.5	$300	10,000	$3.00
2	low, low	0.25	$133	10,000	$1.33

Given the value of the investment outlay, the current gold price, and the dynamics in gold prices, is this a good investment? Should management invest now, or should it wait and see how the gold prices will develop? For an immediate investment decision, we need to determine the opportunity cost of capital and the net present value (NPV). The required return can be estimated from a traded financial instrument (gold) whose probabilistic behavior is close to that of the completed project. With a spot gold price of $300, the implied market-required return, k, for this risk can be derived from the expected gold prices over the next one-year period, or it can be derived from the expected gold prices over a two-year period:

$$300 = \frac{0.5 \times \$450 + 0.5 \times \$200}{1+k} = \frac{0.25 \times \$675 + 0.5 \times \$300 + 0.25 \times \$133}{(1+k)^2}$$

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[3] Some of the numbers in Table 1 are rounded.

The expectation of future gold prices presented above has an implied required rate of return equal to $k = 8.33\%$. The NPV computation below shows that the present value of the expected cash inflows equals \$4.2m. The NPV of the gold mine is \$4.2m - \$4.5m = -\$0.3m; therefore, management would not invest in such a value-destructive project.

$$\text{NPV} = \frac{0.5 \times \$1.80\text{m} + 0.5 \times \$0.80\text{m}}{1.0833} + \frac{0.25 \times \$6.75\text{m} + 0.5 \times \$3.00\text{m} + 0.25 \times 1.33\text{m}}{(1.0833)^2} - \$4.5\text{m}$$
$$= \$4.2\text{m} - \$4.5\text{m} = -\$0.3\text{m}$$

Another approach to valuing the mine is to replicate the cash flows with an equivalent "twin" security rather than estimating the twin security's required return. Consider the position of the company that owns the producing mine. The company's position is long in gold. The company could offset this position and realize the value of the field today if management could sell short gold futures that exactly match the mine's production over time. This particular project is lucrative for the corporation's shareholders if the value of the covered position exceeds the investment outlay required for the project.

Consider, for instance, the dollar revenue of the mine at $t = 2$ equal to the production times the market price over two years, $10,000S_2$. The company can offset the price risk of this cash flow by selling future contracts short for 10,000 ounces of gold, with a futures price $_0F_2$ and a dollar revenue $(10,000)_0F_2$ at $t = 2$. Since it can offset the risk of gold prices, this hedged position, $Q_2(_0F_2)$, can be seen as a certainty equivalent, CEQ_2, of the uncertain operating cash flow at $t = 2$. In Equation (3) the present value of the certainty-equivalent cash flows is calculated using the risk-free rate, r, as the appropriate discount-rate:

$$\text{NPV} = \frac{Q_1F_1}{1+r} + \frac{Q_2F_2}{(1+r)^2} - I \qquad (3)$$

What is the price of long-term contracts if they are traded in an arbitrage-free financial market? In arbitrage-free markets the expected future price, $_0F_T$, equals the current spot price of gold, S_0, plus the interest accrued until maturity T of this

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position, i.e., $_0F_T = (1 + r)^{T-0} S_0$.[4] Equations (4) and (5) calculate the present value of the certainty-equivalent cash flows using the theoretical futures prices, $_tF_T = (1 + r)^{T-t} S_t$, where T - t is the time to maturity of the contract.

$$\text{NPV} = \frac{Q_1 S_0 (1+r)}{1+r} + \frac{Q_2 S_0 (1+r)^2}{(1+r)^2} - I \tag{4}$$

$$= (Q_1 + Q_2)S_0 - I = 14{,}000 \times \$300 - \$4.5m = -\$0.3m \tag{5}$$

Equation (5) illustrates that we can replicate the cash flows of the mine with a gold "cash-and-carry" strategy. In other words, owning the mine is equivalent to owning a portfolio of gold. We are able to replicate the cash flows directly if we buy 14,000 ounces of gold (the total amount of the reserves) today and sell 4,000 ounces at t = 1 and 10,000 ounces at t = 2. The current market value of this strategy and the value of the mine, therefore, equals 14,000($300) = $4.2m, and the NPV of the mine equals $4.2m - $4.5m = -$0.3m.

Not surprisingly, the NPV and the certainty-equivalent valuation approaches both result in the same answer (-$0.3m). In the NPV method, the risk adjustment was carried out in the denominator through an appropriate risk-adjusted discount rate, k. In the certainty-equivalent method, the adjustment for risk is in the numerator, allowing the certainty-equivalent cash inflows to be discounted at the risk-free rate, r. Equation (4) reflects this relation.

As a third variation, we could also calculate an (artificial) risk-neutral probability, p, of possible gold price up (and down) movements, which would allow us to calculate the CEQ from the possible gold prices.[5] The risk-neutral probability is the one that would prevail if the underlying asset (in a risk-neutral world) were expected to earn the risk-free return ($pS^+ + (1 - p)S^- = (1 + r)S$). The risk-neutral probability, p, differs from the actual (true) probability, q. The risk-neutral probability

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[4] This assumes no convenience or dividend-like yield. Suppose that this relation does not hold and that the futures price is higher. Should this happen, a "cash-and-carry" arbitrage opportunity is available if traders short the contract and simultaneously buy the gold. At maturity, the gold is delivered, covering the short position in the futures contract. Hence, traders are unlikely to be willing to serve this "free lunch" for the company by selling futures.

[5] Because of the ability to replicate the mine with a specific gold position, its value is independent of investor risk attitudes and hence it is the same if investors were risk neutral.

is given by Equation (7) (see Trigeorgis and Mason, 1987), where S^+ and S^- are the possible gold prices in the up and down states next period, and r is the risk-free interest rate.

$$S = \frac{q \times S^+ + (1-q)S^-}{1+k} = \frac{p \times S^+ + (1-p)S^-}{1+r} = \frac{CEQ}{1+r} \qquad (6)$$

where:

$$p \equiv \frac{(1+r)S - S^-}{S^+ - S^-} \qquad (7)$$

In the computation below we apply the risk-neutral valuation of Equation (6) to the above mine, using the risk neutral probability from (7):

$$p = \frac{(1+0.04)300 - 200}{450 - 200} = 0.45$$

The resulting valuation again gives the same project value of -$0.3m:

$$\begin{aligned} NPV = {} & \frac{0.45 \times \$1.80m + (1-0.45) \times \$0.80m}{1.04} + \\ & \frac{0.45^2 \times \$6.75m + 2(0.45 \times 0.55)\$3.00m + (1-0.45)^2 \times \$1.33m}{1.04^2} - \$4.5m \\ = {} & \$4.2m - \$4.5m = -\$0.3m \end{aligned}$$

So far, replication of cash flows or properly discounting them at the required return has resulted in the same answer. We next examine situations in which NPV does not give the right answer. Capital investments are not usually a "now or never" proposition. Suppose that management can buy a one-year license that enables it to wait for a year and see how gold prices develop before making an investment in the project. If gold prices drop and the value of the mine declines below the required investment outlay, management can allow the license to expire. Figure 1 illustrates how this option to defer alters the shape (distribution) of the value of the mine. At a high gold price, the value of the mine equals $6.3m (Q x S = 14,000 x $450). At that value, management would invest $4.5m and the NPV would equal $6.3 m - $4.5m = $1.8m. At a low price, management would decide not to invest, as the value of the

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project would be only $2.8m (< $4.5m). In this case, management would allow the license to expire and the value would be truncated to zero.

FIGURE 1. Asymmetry in the Distribution of Project Value due to Flexibility
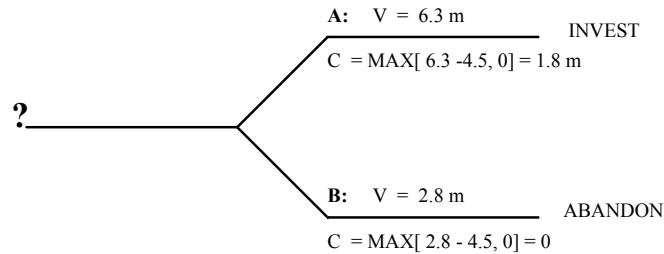
The standard NPV framework, which determines the present value of the *expected* cash inflows and the present value of *expected* outlays, does not give the right answer in this case. Under uncertainty, management has the flexibility to revise the investment decision as uncertainty over the value of the project gets resolved. The future investment decision is based on future gold prices, information that is not yet known. Decision tree analysis (DTA) can in principle capture this decision flexibility that cannot be handled well by static NPV. However, to find the appropriate discount rate (cost of capital) along each branch (gold price state) is not an easy task. As in a call option, the risk of the license changes each time its underlying value changes; the risk of the license is reduced if the price of gold --and the value of the mine-- increases. An option-based approach uses decision nodes (rather than passive event nodes) in modeling flexibility, with risk-neutral valuation capturing changes in risk in an appropriate manner. As with DTA, the valuation problem can be solved recursively, starting with future values and working backward along the tree. The resulting "certainty-equivalent" values can then be consistently discounted at the risk-free rate, r. The value of the license in this way can be seen to equal:

$$V_0 = \frac{p \times C^+ + (1-p)C^-}{1+r} = \frac{0.45 \times \$1.8m + (1-0.45) \times 0}{1.04} = \$0.78m \qquad (8)$$

where C^+ and C^- denote the values of the option in the up (+) and down (-) states next period. Based on the expanded NPV criterion, the value of the license to invest has the following components:

$$\text{Expanded NPV} = \text{(static) NPV} + \text{flexibility (or option) value}$$
$$\$0.78m = -\$0.3m + \$1.08m$$

The risk-neutral valuation method used above is based on an underlying ability to replicate the value of the cash flows. In this case, management can create a gold portfolio in the financial markets that replicates the future payoff of the license. In order to truncate the resulting payoff, it can combine this gold portfolio with the risk-free asset. The position in gold in the replicating portfolio, N (the option *delta* or hedge ratio), would equal the spread in the value of the license ($1.8m - 0) divided by the spread in gold prices ($450 - $200). Table 2 shows that the synthetic license consists of a position of N = 7200 ounces in gold and a risk-free payment of $1.44m that exactly replicates the future truncated payoff of the mine (zero, $1.8m). If the gold price is low ($200), the value of this replicating portfolio equals 7200($200) - $1.44m = 0. If the price is high ($450), the value of the synthetic license equals 7200($450) - $1.44m = $1.8m.

TABLE 2. Replication of Mine Project Value (License) with a Gold Position

	Low price ($200)	High price ($450)
7200 ounces gold	$1.44m	$3.24m
Loan repayment (risk free)	($1.44m)	($1.44m)
Project value (license)	0	$1.8m

Since the license and the replicating portfolio have the same future payoff in each gold price state, the value of the license today must be the current cost of constructing this replicating portfolio. Equation (9) estimates the value of the license using the position in gold (7200) multiplied by the current gold price ($300) and the present value of the risk-free loan ($1.44m/1.04). This results in a $0.78m value, exactly the same as found earlier when using the risk-neutral probabilities under the risk-neutral binomial valuation method:

$$N \, S_0 + B = 7200 \text{ x } \$300 - \$1.38m = \$0.78m \tag{9}$$

It is worth noting that in the valuation of the above gold mine we can use directly the principle of replicating future project cash flows. In R&D, however, an implementation problem with carrying out the replication argument of standard option pricing arises because a correlated financial instrument is non-existent. Nevertheless, the methodology can still be applied for valuing the contingent claim (investment opportunity) provided there is a corresponding valuation for the underlying asset (relative valuation). In this case the issue is to determine the market value of the project to a firm *if it were traded* in the financial markets, which is a standard assumption in traditional capital budgeting (see Mason and Merton, 1985).

2.2 VALUING RESEARCH & DEVELOPMENT

Our second example concerns how to analyze an R&D program available to a high-tech company, and which technology strategy to pursue. As noted, R&D programs involve multiple contingent stages and thus should not be treated as isolated projects. The value of potential profits from follow-on commercial projects that may result from the research stage must be properly captured in determining the value of the underlying research program. Hence, the analysis requires explicit consideration of the project's various stages: research & product development, and future commercialization.

Figure 2 shows the estimated cash flows of an R&D project available to a high-technology company. Suppose the project involves a two-year upfront R&D phase, followed by expected cash inflows over a four-year period of commercialization. The R&D phase requires an immediate capital outlay of $15m, and an outlay of $50m as of year 1. The follow-on commercial project has expected cash inflows over the four-year period of $CF_3 = \$200m$, $CF_4 = \$500m$, $CF_5 = \$700m$ and $CF_6 = \$200m$, and requires an outlay of $I_2 = \$1,200m$ as of year 2. Even though the program appears to have a low return on investment, it may be profitable to develop the new technology to enhance the company's future market position.

FIGURE 2. Capital Outlays (↓) and Expected Cash Inflows (↑) for the R&D Project to Develop a New Technology, and the Potential Follow-on Commercial Project
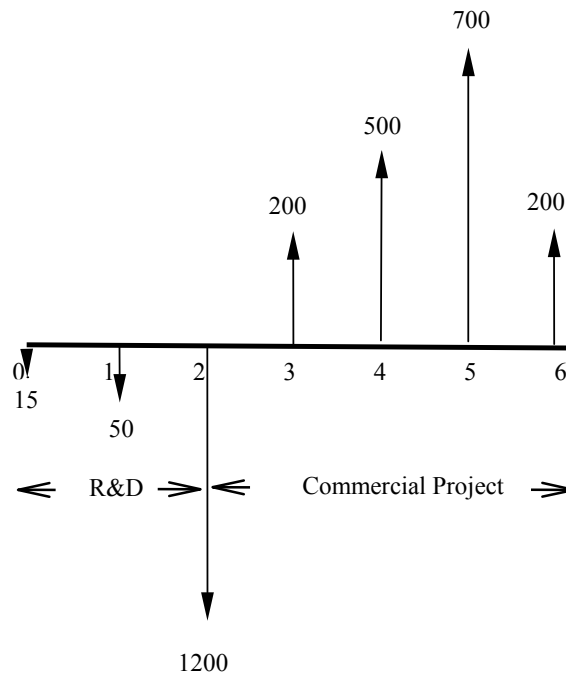

What is the value of the R&D program if management were to commit to both stages immediately? Its value at the beginning of commercial phase, V_2, discounted at an opportunity cost of capital $k = 15\%$, is \$1127m, and its NPV_2 therefore equals \$1127m - \$1200m = -\$73m. Based on the expected scenario of a static NPV analysis, the commercialization project itself does not appear to be profitable. Calculating the present value as of $t = 0$, using an opportunity cost of 15%, results in a \$852m value for the technology. The present value of the (certain) investment outlays for the entire program, discounted at the risk-free rate of 4%, equals \$1109m for the commercial stage and \$63m for the R&D stage. Thus, if the firm were to commit to both stages of the program right now, the total expected net value loss would amount to $NPV = V_0 - I_0 = \$852m - (\$1109m + \$63m) = -\$320m$.

However, the firm does not have to commit to both stages immediately. Investing in R&D derives strategic value from generating the opportunity to commercialize later on, but implies no obligation to invest in the future commercial project. In other words, R&D is analogous to an option, in the sense that it creates a valuable future opportunity without committing the company to making the full investment.

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Is this technology strategy worth pursuing? To answer this question, we must consider two decisions: Should the R&D be undertaken, and if so, should the technology be implemented after R&D results are known?[6] The opportunity to invest in the commercialization is like a call option with time to maturity of $t = 2$ years, and an exercise price of $1,200m. The underlying asset is the current (time zero) value of a claim on the commercial project's expected future cash inflows of $852m. Suppose that uncertainty during the R&D phase results in a yearly increase or decline with multiplicative up and down factors, $u = 1.5$ or $d = 0.67$. The dynamics in the time series of commercial project values (V) are illustrated in the event tree of Figure 3 below.

FIGURE 3. Dynamics in the Value of the Commercial Project (in millions)
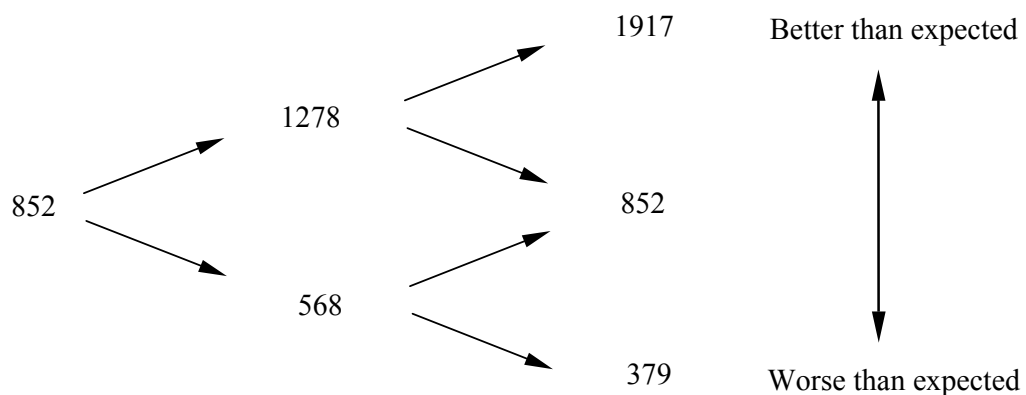

As with decision tree analysis (DTA), we can value the option at the end of the tree, starting at year 2 and working backward, using risk-neutral binomial option valuation. At the end of the R&D phase, management must decide whether to implement the technology. Consequently, the worst possible outcome for the implementation stage will be zero if the new technology is not used. Thus, at year two, the value of the option equals the highest of: The NPV of commercialization (V^{++} - $1,200m); or abandoning the technology (zero). As of year two this results in a net commercialization value of $717m [= 1917 – 1200] in the case events turn out better than expected, or a zero net value in the case of abandonment of the program (see the

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[6] See Kolbe et al. (1991).

end nodes of the option valuation tree of Figure 4). Under risk-neutral valuation, the current value of this claim can be determined from its expected future up and down values discounted at the risk-free interest rate (r = 4%), with expectations taken over the risk-neutral probabilities (p = 0.45). Stepping back in time (to t = 1) results in a zero value in the low state and a (0.45 × \$717m + 0.55 × 0)/1.04 = \$310m option value in the high state. Finally, as of year zero, the value of this growth option equals (0.45 × \$310m + 0.55 × 0)/1.04 = \$134m.

FIGURE 4. Net Value of the Option to Invest in the Commercial Project (in millions)
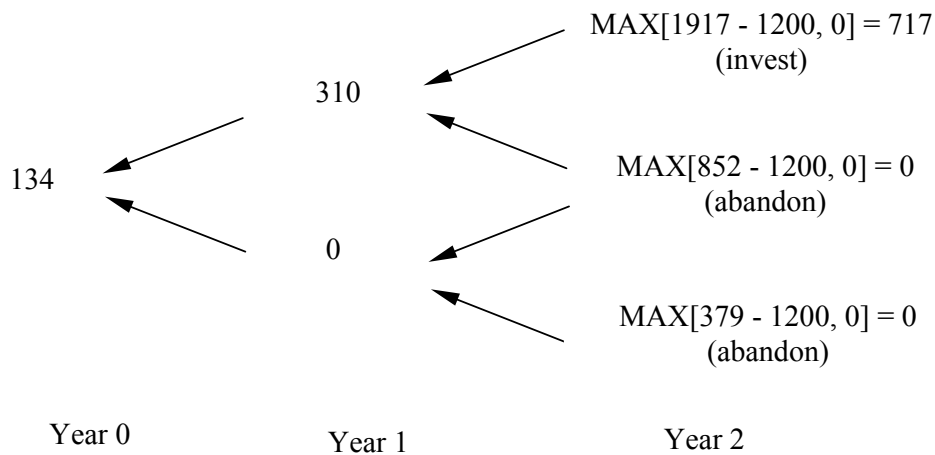
After having estimated the option of investing in commercialization, we can now consider our first question: should the R&D program be undertaken in the first place? Investment in the R&D project can be viewed as exercising a compound option. The underlying value of the R&D option is the subsequent commercialization option, which has a value of \$134m. The exercise price of the R&D compound option is the present value of the R&D outlays, which equal \$63m. The worst possible outcome will be zero if management decides not to develop the new technology in the first place. The value of the R&D program therefore equals MAX[0, \$134m - \$63m] = \$71m.

$$\text{Expanded NPV} = -\$320m + \$391m = +\$71m$$

In this case, management is justified to invest in R&D to prove the new technology and position itself to take advantage of a future growth option, despite the negative NPV of its expected cash flows (-$320m). Management should recognize that a wider range of possible outcomes would in fact increase the option value of commercialization.

Both of the above examples where analyzed assuming the project is proprietary and its value is essentially unaffected by competitive moves. The next section considers situations prevailing in oligopolistic markets where a strategic investment by a firm has a direct impact on (and/or is affected by) competitors' behavior. An expanded or strategic analysis (often relying on game theory principles) is then called for.

3. STRATEGIC (EXPANDED-NPV) ANALYSIS

As noted, a strategic investment entails "commitment value" by virtue of influencing the investment decisions of competitors (e.g., see Dixit (1979, 1980)). Consider a pioneer firm that invests early and aggressively on a large scale in a new geographic market. Competitors may view this strategic investment as a threat to their future profit base in this market, and in certain states (e.g., low demand) may choose to stay out altogether or enter later at a reduced scale to avoid a market-share battle. By reducing the likelihood of competitive intrusion, the strategic project can lead to higher long-term profits for the pioneer firm.

Shared investment opportunities in oligopolistic markets are exercised with the explicit recognition that they may invite competitive reaction, which in turn can impact the value of the investment opportunity for the incumbent. Under such conditions, a strategic investment no longer represents an internal value-optimization problem under uncertainty (i.e., against nature) as in standard option models that assume an exclusive opportunity. Rather, the shared investment now involves a *strategic game against both nature and competition.* Such a strategic investment plan should be based on an expanded or strategic NPV criterion that incorporates not only the passive (or direct) NPV of expected cash flows from investing immediately and the flexibility value from active management (of the firm's portfolio of operating real

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options), but also the strategic (game-theoretic) value from competitive interactions. That is,

Expanded (strategic) NPV = direct (passive) NPV + strategic (commitment) value +
flexibility value   (10)

The box insert (Table 3) exhibits the strategic contexts of these basic game metaphors with an illustration using investment examples. In the classic "prisoner's dilemma context," firms have an incentive to invest immediately to avoid being pre-empted, which results in an erosion of flexibility value. The payoff of this competitive game may be positive, but less than had they followed a coordinated wait-and–see strategy. A similar strategic context can be found in the "Grab the Dollar" game, but here firms obtain a negative payoff when they end up investing simultaneously. The "grab the dollar" game illustrates the situation where the current market prospects are only favorable if one of the players invests but simultaneous investment results in a battle with a expected negative payoff. Only the first player captures the dollar (e.g., patent), but when they both enter the market, they both end up loosing in a battle. A dominant firm has an advantage to win this simultaneous game. The "burning the bridges" game explains that a firm can use the threat of a battle if it has a first-mover advantage and can make the first investment commitment to capture a large portion of the market. Of course, instead of fighting for a leading position in the market, firms may sometimes find it beneficial to follow an accommodating strategy to avoid a market battle. The "battle of the sexes" game shows that in certain cases firms have an incentive to align their strategies and cooperate.

TABLE 3. Taxonomy of Game-theory Metaphors and Investment Applications

Game-theory Metaphor	Description (Investment Analogy)	Examples/Applications
"Prisoners' Dilemma" (Figure 5) Two people are arrested as suspects for a crime. The police puts the suspects in different cells to avoid communication. Each suspect is to be released if he testifies against the other. If neither confesses, both will get a lower punishment. The paradox is that the equilibrium outcome where both confess is worse for both prisoners, compared to the situation where neither confesses.	Innovation Race Each of two innovative firms (players) faces two possible actions: invest early or wait. Competitive pressure to be the first (e.g., to acquire a patent) induces firms to invest early; each firm has a dominant strategy to invest due to the high value of commitment, triggering a situation where both firms invest receiving their second-worst payoff. If the two firms could coordinate their investment strategy they could share the flexibility benefits of the wait-and-see option, avoiding the inferior panic equilibrium where they rush to invest prematurely.	In high-tech industries like consumer electronics, we often see firms getting into innovation races, even forming strategic partnerships to acquire a first-mover or time-to-market advantage that erode the value of wait-and-see flexibility from deferring investment. A noted example is the intensely competitive race in memory chip development. In February 1997 Hitachi, Mitsubishi Electric and Texas Instruments announced they would jointly develop a one-gigabyte DRAM. NEC, which has been co-operating loosely with ATT-spin-off Lucent Technologies and Samsung, announced in June 1997 that it had developed a 4-Gb DRAM.
"Grab the Dollar" (Figure 6)Each of two players has two possible actions: grab the dollar or wait. In the complete information (symmetric) version of the game, a player wins the dollar if he is the only one who grabs, but loses if both players try to grab the dollar. The pay off of this Grab the Dollar variant is similar to the Prisoner's dilemma game, but both players recognize that they have negative pay off if they both play tough.	Innovation Race In the strategic context the market prospects are only favorable if one of the players invests, whereas simultaneous investment results in a battle with a negative expected payoff. Either one player captures the dollar (market) or the other, but when they both enter, they both loose in the resulting battle. In many emerging, high growth industries, the possibility of each firm pursuing independent R&D activities to capture the product standard may trigger a simultaneous similar investment by competitors that results in such a market battle.	Under competitive pressure to be the first (e.g., in a patent race) competitors may rush to make parallel innovation investments simultaneously, with one or both sides potentially getting hurt. For instance, Novell got hurt due to competition in networking products, Apple lost its lead as a user-friendly computer with the development of Microsoft's Windows, while in the 1980's Philips got hurt from losing the race against Matsushita over the VCR standard.
"Burning the Bridge" (Figure 7) Two opposing armies are asked to occupy an island in-between their countries, connected by bridges to both. Each army would prefer to let the island go to its opponent than fight. Army 1, who moves first, occupies the island and burns the bridge behind it (signaling	Product Standard/Preemption Each firm (player) has two possible actions: high irreversible investment commitment or more flexible, low-effort investment. The value of early/heavy commitment is that it may set the product standard or signal to competing firms about the reduced future profitability of their options in this market. Consider a	Being the first in the market enables a firm to capture a larger share of the market and put followers on a strategic disadvantage. For instance, in cellular phones the early introduction of new models of a relatively small company like NOKIA, preempted a significant market share (compared to larger competitors). Competitors like Philips (who formed a partnership with Lucent Technologies) could not catch up and left this market. In an extreme case, the pioneer can

its commitment to fight). Thus army 2 has no option but let Army 1 keep the island, because it knows that Army 1 has no choice but fight back if they attack. The paradox of commitment is winning the game by reducing your options (burning the bridge).	pioneer firm that makes an early, large-scale irreversible R&D investment in a new market. The firm's competitors could view this as a threat to their future profit base in the market, thus deciding to stay out or entering the market later on a reduced scale to avoid a market share battle.	capture the product standard early on. For instance, Intel preempted 80% of the microprocessor market with its Pentium microchip that became the product standard, forcing competitors like Digital to retreat from the market, even though Digital's Alpha chip was three to four times as powerful as the Pentium chip at a fraction of the cost.
"Battle of the Sexes" (Figure 8) A couple must choose between going to a movie or to a play. The couple prefers going somewhere together that separately, one prefers the movie and the other the play. The couple would be better of to collaborate, sometimes going to a movie and other times to a play.	Standardization Game Two (alliances of) firms must choose between standard A or standard B. Everyone would be better off with one standard (avoiding a "war of attrition"), but for one firm standard A would be the best, while for the other firm it is standard B.	In the standardization game of the high density disk, on one side was an alliance between Toshiba and Time Warner who had jointly developed a super density disk (SDD); on the other side was an alliance among Philips and Sony with their multimedia compact disk (MMCD). In this high-density CD battle, both sides recognized that the launch of more than one system would result in confusion and major capital waste, particularly for the losing company as well as the consumers. A standardization agreement resulted in increased productivity and expanded markets for both.

The following sections illustrate these ideas with a series of examples, ranging from a symmetric decision to launch an R&D project (faced by two comparable competitors), to an asymmetric game involving different degrees of R&D effort and the possibility of complete preemption, to a game of R&D competition versus collaboration via joint R&D ventures or strategic alliances.[7]

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[7] See Dixit and Nalebuff (1993) for various applications of games.

3.1 TIME TO LAUNCH UNDER COMPETITION (SYMMETRIC INNOVATION RACE)

Consider first the example of an innovation race involving a shared R&D option among two consumer electronics firms, P (Philips) and S (Sony).[8] Both firms plan to develop an interactive CD technology and expect subsequent commercialization applications. The total market value (NPV-pie) from immediate investment (whether by a single firm or shared equally among the two firms) is $400m. The additional value of the flexibility to "wait and see" under demand uncertainty (had there been no competition) is $200m. This results in a total (shared) opportunity value (option pie or expanded-NPV) of $600m if the two firms could fully appropriate the flexibility value of waiting.

The 2 x 2 table in Figure 5 summarizes the payoffs (firm P, firm S) in four investment-timing scenarios: (*i*) when both firms invest immediately (simultaneously) they share equally the total NPV (½ × 400), resulting in a (200, 200) value payoff for each firm; (*ii*)/(*iii*) when one firm (P or S) invests first while the other waits it preempts its competitor and captures the full NPV value (400) for itself, resulting in a payoff of (400, 0) or (0, 400), respectively; and (*iv*) when both firms decide to wait they share equally the value of the investment option (½ × 600), resulting in a (300, 300) payoff.

FIGURE 5. Innovation Race: Competitive Pressure to be First Induces Firms to Invest Prematurely, even though they Could Both be Better off to Wait ("Prisoners' Dilemma")

| | | Firm S | |
		Wait	Invest
Firm P	**Wait**	(300, 300)	(0, 400)
	Invest	(400, 0)	**(200, 200)***

Note: Payoff in each cell is for (firm P, firm S).
Strategies of firm P: wait (upper row) or invest (lower row)
Strategies of firm S: wait (left column) or invest (right column)

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[8] This prototypical example uses hypothetical numbers.

The above value-payoff structure results in a Nash-equilibrium outcome where both firms invest (200, 200). Firm P's payoff from immediate investment (lower row) exceeds its payoff from a wait-and-see strategy (upper row), regardless of which strategy firm S chooses (400 > 300 in left "wait" column, 200 > 0 in right "invest" column); that is, firm P has a dominant strategy to invest, regardless of the timing decision of its competitor. Firm S also has a dominant strategy to invest regardless of P's decision, resulting in a Nash equilibrium (*) outcome in the lower right cell, from which neither firm can improve by making a unilateral move; thus, both firms receive their second-worst payoff of (200, 200), an example of the well-known *prisoners' dilemma*.[9] Obviously, here both firms would be better off to collaborate or coordinate and fully appropriate the option value of waiting (300, 300).

3.2 ASYMMETRIC INNOVATION RACE AND PREEMPTION

Let us revisit the above innovation race among the two firms, P and S, but in another strategic context. If both firms invest they end up in a market share battle with a negative payoff. Suppose now that firm P has an edge in developing the technology, although it has limited (financial or other necessary) recourses at the time. Competitor S may take advantage of this resource weakness and try to win the race to the market. Following Dixit and Nalebuff (1993), each firm can choose how intense an effort to make in developing this innovative technology. Less effort is consistent with a (technological) follower strategy involving lower development costs but is more flexible (safe) in case of unfavorable developments. More effort corresponds to a (technological) leader strategy involving higher development costs that could result in earlier product launch and a first-mover cost advantage.

Figure 6 illustrates the payoffs resulting if the competitors follow a (technological) leader or follower strategy (high or low R&D effort) when they are in an asymmetric power position. In this payoff table, both sides regard a high-effort R&D battle as their worst scenario: for firm S because it is likely to loose an all-out

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[9] In the classic prisoners' dilemma, two prisoners accused of a crime would be worse off if they both confess (200, 200) than if they do not (300, 300), but the fear of the other prisoner confessing (0, 400) puts pressure for both to do so even though not confessing would have been preferable for both.

race, and for firm P because it would incur large costs. Suppose that this situation results in a (-$100m, -$100m) payoff.

The next-worst scenario for each competitor is to exert low effort while its competitor chooses a high-effort R&D strategy. This entails spending money with little chance of success, resulting in a payoff of only $10m. Under firm S's technological leader strategy, it develops its interactive CD technology by exerting high effort ($200m), while firm P follows with a low-effort follower strategy. In the best scenario for firm P, both firms avoid an intense innovation race and make a low-effort investment, with firm P more likely to win due to its technological edge and lower cost (resulting in a payoff of $200m for P, $100m for S).

FIGURE 6. (Simultaneous) Innovation Race with High vs. Low R&D Effort (Asymmetric "Grab the Dollar" Game)

Firm S

		Low	High
Firm P	Low	($200m, $100m)	($10m, $200m)*
	High	($100m, $10m)	(-$100m, -$100m)

Note: Payoff in each cell is for (firm P, firm S).
Strategies of firm P: low-effort R&D (upper row) or high-effort R&D (lower row)
Strategies of firm S: low-effort R&D (left column) or high-effort R&D (right column)

Consider the equilibrium implications of an asymmetric payoff structure as that of the "Grab the Dollar" game in Figure 6 above.[10] Firm P's payoff for pursuing a low-effort R&D strategy (upper row) exceeds the payoff of a high-effort strategy

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[10] This is an asymmetrical variant of the "Grab the Dollar" game, in that both firms have a negative payoff if they both make a high R&D effort, and there is a positive payoff if only one of them follows a high-effort strategy. Only Firm S has a dominant position in playing this game, reflected in its higher pay off.

(lower row), no matter which strategy firm S chooses ($200m > $100m and $10m > -$100m). Thus, firm P has a dominant strategy to pursue low-effort R&D. Given this, firm S will pursue a high-effort R&D strategy (since $200m > $100m). The Nash equilibrium (*) outcome of this R&D rivalry game is given by the top right cell ($10, $200), where P receives its second worst payoff. P would follow a flexible, low-effort strategy, while S would follow the high-effort R&D strategy.

Consider next a similar situation (as the simultaneous innovation race of Figure 6 above), but with the difference that firm P can make the R&D investment before firm S can decide which strategy to follow. Which R&D strategy should firm P follow? Management must now recognize that its investment decisions will directly influence competitive reaction, as illustrated in the sequential game of Figure 7. The threat of a market battle could actually work in firm P's favor.

FIGURE 7. Sequential Investment Game with High vs. Low R&D Effort ("Burning the Bridges")
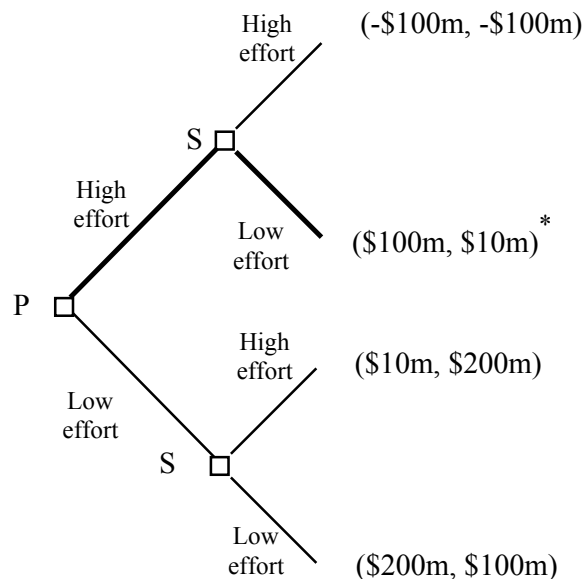
If firm P pursues a flexible low-effort strategy (making a small R&D investment), firm S will respond with high effort, and firm P's payoff will be $10m. However, if P pursues a high-effort R&D strategy, firm S can be expected to respond with low effort (since $10m > -$100m), in which case P's payoff will be $100m. Therefore, firm P would invest heavily in R&D, signaling a credible commitment to

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the high-effort R&D strategy (with the competitor responding with a low-effort strategy). With such a strategic timing move, the equilibrium results in a more desirable payoff for firm P ($100m) than that of the earlier (simultaneous) game ($10m).

This strategy represents an early exercise of a shared multistage R&D option and it explicitly influences both competitive behavior and the firms' future profit base. In our strategic (expanded-NPV) framework, an immediate high-effort R&D strategy (technological leadership) has two main effects on value, with opposite sign:

(*i*) *A standard option-value or flexibility effect*. This reflects management's ability to wait to invest in the business under uncertain conditions. The large (early) investment implicit in the high-effort R&D strategy, although enhancing the value of future growth opportunities, sacrifices this flexibility value compared to a more flexible low-effort strategy.

(*ii) A strategic commitment effect.* A large (early) R&D investment consistent with technological leadership and a high-effort strategy can influence competitors' investment decisions and the equilibrium outcome favorably for the pioneer firm (P), giving it an asymmetric competitive edge. This must be weighted against the loss of flexibility value.

In certain cases, however, efforts to create asymmetric power positions vis-à-vis a competitor must be given up in favor of more fully appropriating the option value of a coordinated wait-and-see strategy under demand uncertainty.

4. COMPETITION VS. COORDINATION/ STRATEGIC ALLIANCES

In an oligopolistic industry, firms can make prior investments in R&D to increase their ability to capture the growth opportunities in the industry. This section considers the issue of whether (and when) it is optimal to compete independently or coordinate (e.g., via standardization agreements) and otherwise collaborate (e.g., via joint R&D ventures or strategic alliances) in the innovation phase, to increase the total value of growth opportunities in the industry under uncertainty. Section 4.1 examines the competition vs. coordination (standardization) game in the high-density disk market, while section 4.2 discusses learning and across-time evolution in a given

industry (consumer electronics) from a competitive mode (in VCRs) to one of strategic alliances (in the launch of the CD).

4.1 STANDARDIZATION IN THE HIGH-DENSITY DISK

Consider the innovation battle for the development of the high-density disk. Initially, it might seem as if this effort would end up in a technological war. Instead, it ended up in a coordination game. On one side was an alliance between Toshiba and Time Warner who had jointly developed a super density disk (SDD). On the other side were Philips and Sony with their multimedia compact disk (MMCD). The storage capacity of the old CD (70 minutes for a movie) had become insufficient; with new compression techniques and the use of two layers, the storage capabilities of the new-generation disk could increase ten times to 7.4 gigabytes, and even more for the Toshiba disk.[11] The new technology was expected to result in valuable growth opportunities in audio CD, CD-ROM (information storage), digital video disc (DVD), and other CD applications.

Both sides claimed victory in advance, hoping to enhance the "commitment value" of their technology by influencing competitive behavior. For instance, both firms made strategic moves by making advance announcements of the launch of their high density players and disk, listing the computer producers who had chosen their systems, emphasizing the success of their R&D efforts, even providing misleading information about the capabilities of each other's systems.[12]

The game below describes the strategic context of the dilemma faced by the two parties (alliances). Each side would prefer to launch their own standard but clearly would be better off to avoid a market battle. Figure 8 describes the four outcomes in a 2×2 game. The worst payoffs for both parties, (2, 1) and (1, 2), are for the situation in which both pursue exclusionary (adversarial) technological strategies and develop competing product standards. This would result in intense competition, but eventually uncertainty will get resolved over which one will be the winning system. The two parties would clearly be better off with a single standard to avoid a

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[11] Toshiba's disk, however, had the disadvantage of being double sided.

[12] For example, Toshiba announced that its competitor, Philips, would not develop a rewritable CD version. Philips called this untrue: "Of course we are working on that. However, we have to protect the copyright first before we launch the product." In this aggressive strategic context, the competitor's managers made threatening statements at that time, e.g., "We are in a state of war" (NRC 5-7-95).

war of attrition, but each alliance would prefer their own standard to prevail. This results in payoffs of (3, 4) or (4, 3) when both choose a standard based on SSD or on MMCD, respectively.

FIGURE 8. The 2 × 2 Competition vs. Coordination Game ("Battle of the Sexes")

Competition

	Standard based on MMCD	Standard based on SDD
Standard based on MMCD	(4, 3)	(2, 1)
Standard based on SDD	(1, 2)	(3, 4)

Philips (row label)

By recognizing the above strategic context, however, both firms will have an incentive to coordinate their product strategy to avoid a market battle. Standardization agreements may result in increased productivity and expanded markets for both. In the high-density CD battle, both sides recognized that the launch of more than one system would result in confusion and major capital waste, particularly for the losing company and the consumers. A "technical working group" representing the leading firms in the computer industry investigated the competing systems and found that both the MMCD of Philips and Sony as well as the SDCD of Toshiba fulfilled the requirements. The computer industry, which would benefit if the two alliances would agree on one standard, encouraged the two sides to negotiate and coordinate.[13]

4.2 LEARNING: FROM COMPETITION IN VCRS TO STRATEGIC ALLIANCES IN THE LAUNCH OF CDS

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[13] Subsequently, the strategic moves of these firms (as reported in the press) changed from tough to accommodating. The vice president of Philips made accommodating statements about coming to one standard. The outcome would be a new standard for the next twenty years. The expectations were that over five years 200 million pieces of CD-carrying equipment would be sold yearly. Multimedia sales would represent 10% of total sales.

In consumer electronics, firms like Philips, Sony, Matsushita, and Toshiba have a history of competing in the development of technologically innovative products, such as CD players, CDi, walkman, 100 Hz TV, and the high density disk. Innovative strategies are often accompanied by high commercial and technological risk. Such strategies may also require close contact with customers and careful monitoring of competition. It is possible that firms may compete in one product and cooperate on another. As noted, strategic alliances with some competitors that use mutual standardization agreements can help win the battle in the competition between different systems.

Consider the battle for developing a technology standard in the video recorder market. In the late seventies, the introduction of three types of video recorders resulted in intense rivalry. Philips launched the V2000 system to compete with Sony's Betamax and JVC's VHS system. Instead of following a single standard, Philips decided to make the V2000 system incompatible with VHS tapes, claiming that the advantage of reversible tapes and better slow-motion pictures was sufficient to win adequate market share. The aggressive position by these companies resulted in an intense market share battle in the video recorder market.

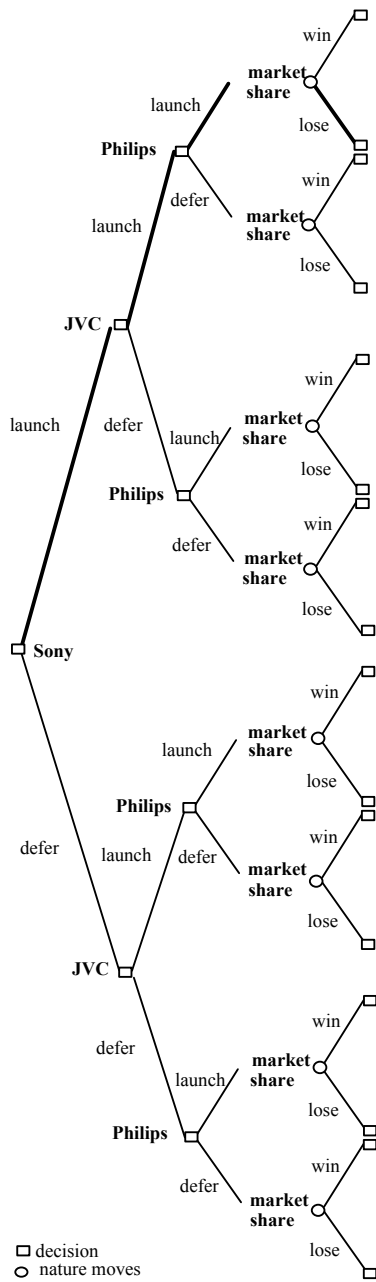**FIGURE 9.** Timing Product Launch with Multiple Competitors

Figure 9 illustrates the market share battle between Sony, JVC, and Philips. Uncertainty concerning Philips´ market share compared to the other systems is reflected by the states of nature (O). The branches in bolded type in the upper part of the tree illustrate the historic path of actions actually taken by the players involved and the resolution of uncertainty.

The market for consumer video recorders increased rapidly. Sony (with its Betamax system) and JVC (with VHS) were already involved in a market share battle before Philips introduced the V2000. Philips decided not to make its system compatible with the existing VHS system, but unfortunately its claimed technical advantage was not reflected commercially in a larger market share. The existing systems had already developed a large captive market and were supported with software (movies).

It should have been clear from the beginning that only one of the systems could win, and that in the end only one could become the standard in the market. The other firms eventually would have to switch to this system. Hence, each player must have believed they had at least a good chance of winning in order to be willing to participate in this battle.

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FIGURE 10. The "War of Attrition" Game
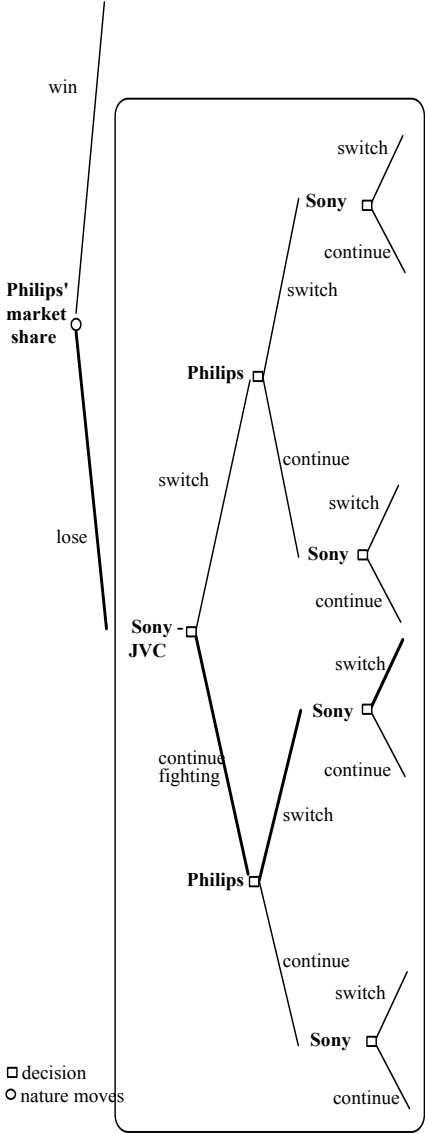
The above situation could be viewed as an optimal stopping problem against competition with uncertainty over the future value of the project. In a "war of attrition" game such as this, the winner takes all. This is more likely to occur in an industry in which economies of scale are important (see Tirole, 1990, pp. 311). Fighting is costly because it may lead to low or negative profits and R&D outlays may not be recovered. The object of the fight is to induce the rival to give up. The winning firm acquires the standard, and the losers are left wishing they had never entered the fight. Figure 10 illustrates the "war of attrition" game for the video recorder market. The game ends when it becomes clear that one of the players has either quit, or switched to another system. The historic path of this game is represented by the bolded-type branches. Philips suffered intense competition as unfavorable information was revealed (low market share), and in the end it switched to the VHS system. The VHS system by JVC (Matsushita) became the market standard.

By contrast, in the subsequent development of the CD technology, Philips recognized that the CD player would be a success only if other firms would be willing to produce CDs and CD players. Philips and Sony exchanged licenses to acquire an install-base for the CD player. The joint development of the CD turned out to be a success, resulting in a range of subsequent growth opportunities.[14]

The above examples from the launching of video recorders and the development of the CD technology clearly illustrate the potential use of options concepts and game theory principles in understanding competitive behavior under uncertainty in such oligopolistic markets. The commitment value of a firm's strategy can be enhanced by outsmarting competition under conditions of asymmetrical information or power, as well as and of technical and commercial uncertainty. Under other circumstances, however, market characteristics, demand uncertainty and competitive moves may change a firm's aggressive strategy to a collaborative one.

5. IMPLICATIONS AND CONCLUSIONS

This paper has reviewed some basic valuation principles involving real options and competitive strategy analysis. Numerical examples from valuation of a license on a mine concession and an R&D program illustrated the shortcomings of traditional NPV when management has flexibility to adapt its future contingent decisions based on the evolution of major uncertainties. In oligopolistic industries, we discussed (using basic game theory) a number of examples involving innovation races and other competitive games where the impact of a firm's decision on competitors is important in determining equilibrium outcomes and competitive strategies. A number of insights and implementation issues are summarized below.

We have shown why risk-neutral option valuation or a certainty equivalent-based approach is superior to traditional DCF or decision tree analysis, since it combines the use of decision nodes (rather than passive event nodes) to model

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[14] A couple of decades later, it appears that the development of the CD has been a far greater success than initially expected. In 1995, total sales for the entire market using this technology came to about $50 billion. Three billion CD's and about 110 million pieces of CD-carrying equipment have been sold annually.

flexibility choices while being more careful to price risk correctly in each branch (state) of the tree. In the implementation in natural resources, management can use directly the concept of replicating future cash flows. The estimated value of a producing field can be directly linked to oil futures. An insufficient set of market quotes of a correlated financial instrument (e.g., futures or forward contracts) is a general implementation problem of the option pricing methodology (and it is non-existent in the valuation of R&D programs). However, the methodology can still be applied provided there exists a corresponding valuation for the underlying asset.

The combined options and game theory perspective is particularly relevant for oligopolistic and innovative industries (e.g., pharmaceuticals or consumer electronics) facing high research and development costs in several phases in a technologically uncertain and competitive setting. The war of attrition in video systems, the coordination game of the CD technology, and the adversarial and accommodating strategies for the high density disk are just a few examples of games that corporations face in real life. Firms can make prior investments in R&D to improve their competitive position and their ability to capture the growth opportunities in the industry. Patents and proprietary use of information can prevent the creation of valuable opportunities for competition. In cases of differentiated products under contrarian, quantity-type competition (e.g., in pharmaceuticals), opposition is more likely to retreat. However, it not always wise to compete aggressively. An important aspect in corporate strategy is knowing when to coordinate strategies with competition and support rivals. When the product is homogeneous and competitive response is reciprocating, as in price competition (e.g., in the airline, the tobacco or the food industries), adversarial strategies may result in price wars and erosion of profit margins for all sides.[15]

While adversarial strategies and a lack of coordination may result in shrinking markets, the gains from sharing information and the benefits of innovation may result in higher productivity and profits for all under certain circumstances. With an accommodating strategy, firms can work closely together (e.g., appropriating the option value of waiting more fully as well as sharing costs) and may achieve more innovation and growth. Firms often co-operate in R&D via standardization

agreements, joint R&D ventures or create other forms of strategic alliances. Philips formed several joint ventures, such as with Matsushita Electronics. A potential downside is that while these ventures may strengthen the firm's position, they may also be helping build up new competitors.

The combined option pricing and game theory approach, when properly applied, can be a valuable tool of analysis in support of the overall corporate strategy. These quantitative tools are meant to complement the strategic thinking process and executive intuition and experience, not to replace them. Overly complicated methods are not easily adopted and face managerial resistance. Complex real-life investment problems often have to be simplified to their basic components to make the analysis more feasible. Real options valuation helps do that. To make the model easier to understand, it is more useful to use a discrete-time binomial process. Working backward in the option-game tree, decision-makers can trace the equilibrium project values and intuit from the model the relative magnitude of values in the different project phases. To use the model as a practical aid to corporate planners, appropriate user-friendly software will be useful. Real options concepts and tools are being increasingly used by consulting firms and leading corporations around the world in a variety of industries. The practical use of real option analysis looks quite promising.

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[15] As a result firms may try to differentiate their products with marketing expenses to avoid pure competition in prices.

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