A Real Options and Game-Theoretic Approach to Corporate Investment Strategy Under Competition

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■ An investment strategy encompasses a sequence of tactical investment projects, of which several may yield a low return when considered in isolation. Often the value of such an investment consists of the option to invest in the future growth of the firm. For example, the value of a pilot project or an R&D investment does not derive so much from the expected cash inflows, but rather from the option to invest in future commercial exploitation. Standard forecasting of the expected cash inflows implicitly assumes investing in the follow-up project. Therefore, the traditional discounted cash flow (DCF) method has serious shortcomings in analyzing projects when information concerning future investment decisions is not yet known. The application of option theory can be used as an analytical tool to evaluate such projects and to support the overall operating and investment strategy. Brennan and Schwartz [1] examine the operational policy of a copper mine. Myers [9], Trigeorgis [12], McDonald and Siegel [8], Majd and Pindyck [10], and Myers and Majd [10] provide other examples of flexible investment strategies.

We consider the option to defer investment in production facilities analogous to a call option on a dividend-paying stock. In this investment strategy, decisions involving the creation of capacity may be postponed so that management can decide not to invest if market demand turns out to be unfavorable. On the other hand, deferral also has disadvantages since during the postponement period the firm misses the net operating cash inflows. The analogy with a call option, of course, is not exact. One difference between financial call options and future investment possibilities is the exclusiveness of the latter. Kester [5] and Trigeorgis [12] have shown that competition in the

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market may force the company to invest early, which may erode the flexibility value of a deferred investment strategy.

This paper casts the real options approach for project timing in a microeconomic framework. We use microeconomic tools to analyze aspects of competition in the investment strategy in forecasting the cash inflows. In this connection, we focus particularly on the concept of economic rents, i.e., the excess profit above the opportunity cost of capital. Economic rents attract new entrants to the market so that if the investment opportunity is not exclusive new entrants will diminish returns until expected and required returns are equal. Under rivalry, economic rents only exist if the firm has a specific competitive advantage in the realization of the project. The firm, therefore, needs to identify those markets in which it has a temporary or permanent competitive advantage and concentrate investment in these areas. If the competitive advantage is temporary, expected economic rents will decline over time and postponement will erode the value of the project. Based on the firm's strength in relation to its competitors and the value of the project in relation to market uncertainty, we develop various investment tactics.

The paper is organized as follows. Section I discusses the options approach to investment timing. Section II studies the concept of economic rents for strategic planning purposes, as well as the influence of competition on the expected economic rents over time. In Section III, we use an options approach for timing investment strategy in different microeconomic market contexts. Finally, Section IV provides some concluding remarks and directions for further research.

I. The Option to Defer Investment

Some investment projects can actually be seen as the first links in a chain of subsequent investment decisions. With projects of this type, the firm essentially acquires an option to invest in a potential follow-up project. For example, an R&D project, the development of a new technology, or entry into a new geographical market may create future investment opportunities. In strategy, these projects are often compared with options for future company growth (e.g., see Myers [9]). We consider the option to defer a project (see Kester [5] for a qualitative approach, and Trigeorgis [12] or Kemna and Vorst [4] for a quantitative treatment). The deferment of a capacity expansion program caused by uncertain market demand is seen to create flexibility for management. The timing of investment in a production facility is analogous to the timing of exercising of a call option on a dividend-paying stock.

Exhibit 1. Analogy of a Deferred Project With a Call Option

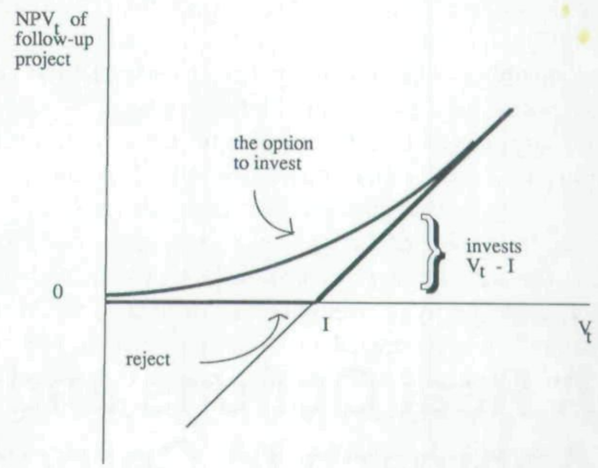


Exhibit 1 illustrates this analogy. The underlying value is the present value of the net operating cash inflows, V_t. The (present value of the) investment outlay in the plant, I, is equivalent to the exercise price. If, in time, market demand develops favorably, the firm would invest and the net value of the project would equal its $NPV = V_t - I$. If the project does not prove to be lucrative and the net present value turns out to be negative, management may decide not to invest and the value is zero. Besides this advantage to wait and see, deferment also has disadvantages. For example, if we consider a project with an infinite life, management misses the net operating cash inflows when the plant is not operative. The missed net operating cash inflow during the deferment period is equivalent to a dividend.

Based on this analogy, we can use option valuation techniques to value a deferred project and support the investment strategy. The binomial option valuation method of Cox, Ross, and Rubinstein [2] is a useful tool in this regard. We subsequently express the missed cash inflow during the postponement period as a constant proportion of the state project value. The dynamics of market demand for the product result in a series of possible project values, $V_{t,s}$, in each state (s) over time (t). The investment timing problem is solved recursively, starting with future values and working backward. The investment opportunity value is equal to the maximum of $V_{t,s} - I$ when management invests, zero when management decides not to invest, and the option value when management defers the project. The essence of the investment timing strategy is to find for every decision moment a critical project value V_t^*. At this critical value, the missed net operating cash inflow equals the flexibility value from postponing one more period. As long as the value of the project is below this critical value, the project will be deferred. Should the project value exceed the critical value, management would invest.

In asset valuation, we create shareholders' value by investing in projects for which the financial market value (of the cash inflows) exceeds the investment outlays. Therefore, we try to determine what the project would be worth if it were traded in a financial market. Option valuation models are often based on arbitrage arguments with an option equivalent. An equivalent portfolio strategy, consisting of a position in the underlying asset partly financed with a risk-free loan, is constructed so that it has in every state the same payoff as the option, and should therefore have the same value. In the real options case, the financial market valuation of the postponed project is determined by a project equivalent in the financial market. We could justify the portfolio equivalent approach if a financial instrument is traded with exactly the same risk characteristics as the project. If the underlying state variable is taken to be the price of a commodity, for example, an equivalent portfolio could be constructed with futures in the commodity (e.g., see Brennan and Schwartz [1] for the valuation of a copper mine). In the case of postponing a plant for consumer products, however, the underlying asset is an aggregate variable. If an identical plant is not explicitly traded, application of the option valuation method seems questionable. However, if the financial markets are complete, in that the securities traded are sufficient for dynamic spanning of the underlying asset, the option valuation method can still be applied (see Mason and Merton [7]). In complete financial markets, there would exist portfolios of securities that replicate the dynamics of the present value of the project caused by the rate of change of prices and market demand.

As noted, the analogy between a call option and a deferred project is not exact. A major difference is the degree of exclusiveness of the latter, so the call option analogy must be seen in the context of market structure (e.g., see Kester [5] and Trigeorgis [12]). A project in a monopoly situation is more analogous to a call option, since it involves an exclusive right to invest. A project under perfect competition, on the other hand, is like a "public good" of the whole industry. In this case, there is a loss in value from postponement caused by the entry of competitors. Emerging competition or rivalry may thus create an incentive to invest early, as postponement of the project may result in project value erosion. This is particularly so if early investment would preempt competitive entry (e.g., Kester [5], Trigeorgis [13]).

II. Corporate Strategy and Economic Rents

In an efficient financial market, the prices of all traded securities adjust rapidly to reflect all currently available information. If information about a firm's profits or new projects arrives in the financial market, investors bid up the prices until the return equals that on investments with comparable risk. Real markets are often less than perfectly competitive, so it is possible for a firm to consistently earn excess returns that exceed the opportunity cost of capital (see Shapiro [11]). We estimate the expected net operating cash inflow as the opportunity cost of capital plus the expected economic rent:

$$\overline{CF}_t = (I)i + \overline{ER}_t, \qquad t = 1, 2, 3, \ldots \infty. \qquad (1)$$

$\overline{CF}_t$ = the expected net operating cash inflow.
I = the investment cash outflow.
i = the opportunity cost of capital.
$\overline{ER}_t$ = the expected economic rent.

In Equation (1), $(I)i$ reflects the yearly opportunity cost of capital invested in a project with an infinite life.

Various microeconomic models can help in forecasting the excess economic rents or expected profit. In a competitive market characterized by costless entry and exit and homogeneous products, an early investment can produce only temporary economic rents. The expected economic rents can have several sources; for example, they can result from a new product introduction. Eventually, however, potential competitors will catch up and enter the industry. When the industry settles into long-run competitive equilibrium, all projects are expected to just earn their opportunity cost of capital and their expected net present value will just be zero. Economic rents are not always temporary. If, for example, the firm has a proprietary technology protected by enforceable patents, the economic rents could be persistent. As long as barriers to entry remain, the firm has an exclusive or proprietary investment opportunity. Appendix A describes the modelling of economic rents under perfect competition, monopoly and oligopoly.

Under rivalry, economic rents would exist if the firm has a competitive advantage in realizing the project. Barriers to entry or a distinct competitive advantage over existing competitors (e.g., economies of scale and scope, absolute cost advantages or product differentiation) are the real source of economic rents. The firm therefore needs to identify those markets in which it has a temporary or permanent competitive advantage, and concentrate investment in these areas. Understanding potential barriers to entry helps identify these markets and potential value-creating investment opportunities. One strategy, for example, will be directed towards increasing volume because of economies of scale or broadening when economies of scope are important in the market (see Hall [3]).

The present value of a project with an infinite life and constant expected cash inflows, when the cost of capital is i, equals $\overline{V}_t = \overline{CF}_t / i$. At the end of the period, the present value equals $\overline{V}_t^{inc} = (1 + i)(\overline{CF}_t / i)$. The difference between these present values reflects the net operating cash inflow during the deferment period, $CF_{t,s}$. We subsequently express this cash inflow as a proportion of the state project value in the binomial option model, $\delta_{t,s} V_{t,s}^{inc}$, so the present value, $V_{t,s}$, of the project equals $(1 - \delta_{t,s}) V_{t,s}^{inc}$. Since there is no decline in expected economic rent and expected cash inflow under monopoly, a postponed project in monopoly is analogous to a call option on a stock with a constant dividend payout ratio, $\delta_{t,s}$:

$$\delta_t = \frac{\overline{CF}_t}{\overline{V}_t^{inc}} = \frac{i}{(1+i)}, \qquad t = 1, 2, 3, \ldots \infty. \quad (2)$$

Under perfect competition, the expected net operational cash inflows will change over time until the project earns just the opportunity cost of capital.[1] The deferred project under perfect competition is thus analogous to a call option on stock with a changing dividend payout ratio:

$$\delta_{t,s} = \frac{CF_{t,s}}{V_{t,s}^{inc}} = \frac{(I)i + \left\{1 - \frac{1}{(1+i)} e^{-d}\right\}\left\{V_{t,s}^{inc} - (1+i)I\right\}}{V_{t,s}^{inc}}, \quad t = 1, 2, 3, \ldots \infty. \qquad (3)$$

In Equation (3), $(I)i$ reflects the yearly opportunity cost of capital, while $\left\{1 - (1/(1+i))e^{-d}\right\}\left\{V_{t,s}^{inc} - (1+i)I\right\}$ reflects the economic rent in each state of nature. Note that when the industry settles into competitive long-run equilibrium, the net present value of the project becomes zero

[1]Assuming that an individual competitor does not take the value of waiting into account.

Exhibit 2. Simultaneous Investment Subgame

		Firm B: Invest	Firm B: Defer
Firm A	Invest	I $V_{t,s} - I$ $V_{t,s} - I$	II $V_{t,s}^{leader} - I$ $C_{t,s}^{follower}$
	Defer	III $C_{t,s}^{follower}$ $V_{t,s}^{leader} - I$	IV $C_{t,s}$ $C_{t,s}$

$(V_{t,s}^{inc}/(1 + i) = I)$, and $\delta_{t,s}$ equals $i/(1 + i)$ as with constant expected cash inflows. If the projects have a positive net present value, competitors will enter and $\delta_{t,s} > i/(1 + i)$. If instead projects have negative net present values, competitors will exit and $\delta_{t,s} < i/(1 + i)$.

The number of firms active in an industry characterizes the intensity of competition. In monopoly, only one firm operates in the market, whereas in perfect competition, the number of firms is very large. Oligopoly is between these two extremes. In the case of duopoly, two firms are operating so that the behavior of each individual competitor directly influences the value of the project. The investment timing strategy of an incumbent firm in duopoly is coupled to the timing tactics of the rival. In the case of an early investment, it is sometimes possible to avoid a decrease in value by preempting the competitor. The threat of preemption is primarily determined by the strength of the firm and the intensity of competition in the industry (e.g., see Tirole [14]).

Applying basic principles from game theory, we can develop different investment tactics under each market structure. In duopoly, the timing of a project will be influenced by the development of market demand and the behavior of the competitor. Instead of the maximum of $(V_{t,s} - I, 0)$ and the deferment value in the binomial option model, the state value would now be equal to the (Nash equilibrium) outcome of a simultaneous investment subgame. Exhibit 2 presents an example of this subgame in the normal form (see Exhibit 6 for the option pricing model in extensive form). There are four possible situations: (*i*) both firm A and firm B decide to invest; (*ii*) A decides to invest but B waits; (*iii*) A waits but B invests; and (*iv*) both

A and B wait. The first number in each cell indicates the investment opportunity value for firm A, while the second number is the value of a competing project of firm B. The investment opportunity net value is estimated as the net present value, $V_{t,s} - I$, for a direct investment, or the option value, $C_{t,s}$, for a postponed investment. Note that each value depends on the tactic of the other firm (wait or invest), particularly if an early investment preempts a competitor or leads to a cost advantage:

$$(V_{t,s}^{leader} > V_{t,s}, \text{ or } C_{t,s}^{follower} < C_{t,s}).$$

III. Investment Timing Strategy and Economic Rents

A crucial strategic choice for competing in emerging industries is the timing of investment in capacity. We next utilize a simple numerical example to illustrate the timing strategy, first under perfect competition, and then under monopoly. The firm in this example has invested in a pilot project to get an early foothold in the market. If the market opens up and creates expansion opportunities, the firm will increase capacity significantly by investing in a follow-up project. This pioneering strategy involves high risk, but also involves low competition in the early stage of the market leading to substantial expected economic rents. Here we assume:

(*i*) An industry portfolio is traded in the financial market with exactly the same risk characteristics as the project, yielding an expected return of 16%. The dynamics in the present value of the follow-up project imply a 25% increase ($u = 1.25$) or a 20% decline ($d = 0.8$) per year. This represents a standard deviation in project present value of 22.315% per year. The real rate of interest is five percent per year ($r = 1.05$).

(*ii*) The expected economic rent of the follow-up project in the first year is 10. Due to anticipated entry, the cash inflows will decline exponentially at a 30% annual rate until the project earns the opportunity cost of capital of 16%.

(*iii*) The production facility has an infinite physical life. The required investment outlay is 500.

Given the declining expected economic rents and the opportunity cost of capital of 16%, the present value of the expected operating cash inflows from the production facilities is estimated to be 524.[2] The net present value (NPV) therefore is 524 - 500 = 24. Based on the net present value rule, management should invest immediately.

However, when we consider the option to defer capacity expansion and wait to see how the market develops further, management should postpone. The dynamics of market demand for the product result in a series of possible project values over time. Based on the binomial option pricing model, the value of the deferred project may increase by a factor of $u(1 - \delta_{t,s})$ per period if market demand turns out to be favorable, or it may decrease by a factor of $d(1 - \delta_{t,s})$ per period if market demand turns out to be unfavorable, i.e.,

$$\begin{tikzcd}[row sep=small]
 & & \begin{array}{c}567\\ \text{invest } (67)\end{array} \\
 & \begin{array}{c}548\\ \text{invest } (48)\end{array} \arrow[ur] \arrow[dr] & \\
\begin{array}{c}524\\ \text{defer } (28)\end{array} \arrow[ur] \arrow[dr] & & \begin{array}{c}409\\ \text{defer } (7)\\ 447\\ \text{defer } (10)\end{array} \\
 & \begin{array}{c}397\\ \text{defer } (7)\end{array} \arrow[ur] \arrow[dr] & \\
 & & \begin{array}{c}332\\ \text{defer } (5)\end{array}
\end{tikzcd}$$

The net value (inside the parentheses) at each state is equal to the maximum of:

$$\begin{array}{ll}
V_{t,s} - I & \text{invest} \\
0 & \text{stop} \\
C_{t,s} = \dfrac{pC_{t+1,u} + (1-p)C_{t+1,d}}{r} & \text{defer}
\end{array}$$

where $p = \dfrac{r-d}{u-d}$ is the risk-neutral probability.[3]

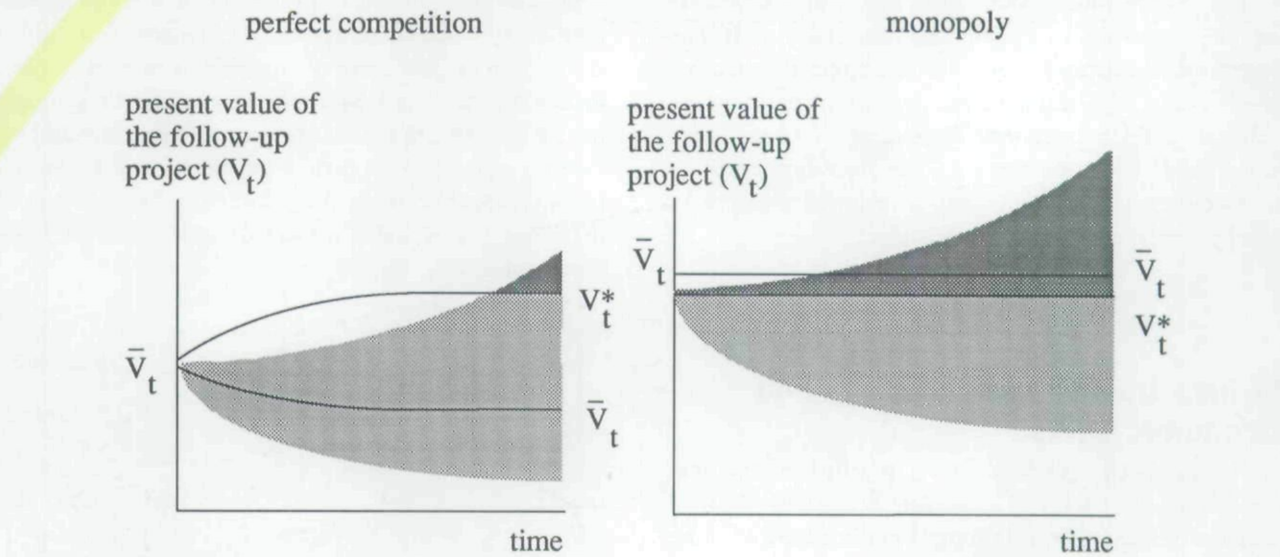
The value of the option to invest in the follow-up project is 28, which is greater than the net present value of 24. The optimal strategy, therefore, is to defer the follow-up project until the market develops favorably.

If we consider a project with the same economic rent, ER_1, in a monopoly, the expected net operating cash inflows are constant. The present value of the production facilities is now 563, and the NPV equals 563 - 500 = 63. When we consider the option to defer capacity expansion, management should invest immediately:

[2] $$524 = \frac{10 + 0.16(500)}{1.16} + \frac{7.4 + 0.16(500)}{(1.16)^2} + \frac{5.5 + 0.16(500)}{(1.16)^3} + \ldots \frac{0 + 0.16(500)}{(1.16)^{\infty}}.$$

[3] p is the probability that would prevail if investors were risk-neutral. This valuation principle is based on arbitrage arguments with a replicating portfolio.

Exhibit 3. Investment Timing Strategy Under Perfect Competition and Monopoly



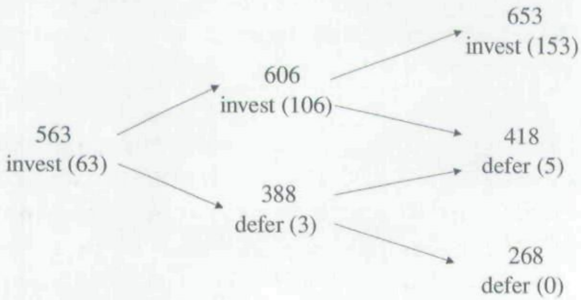


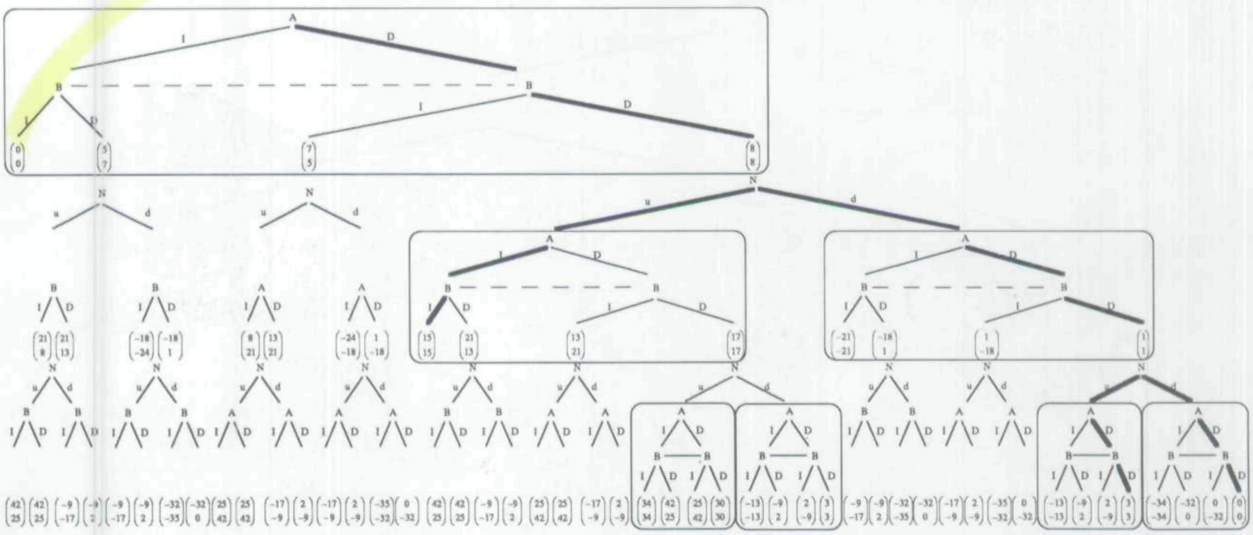
Exhibit 3 illustrates how the dynamics in present value, V_t, and the critical value above which it becomes optimal to invest, V_t^*, relate to each other. In the case in which the firm shares the investment opportunity with competitors, anticipated entry causes a decline in the expected present value of the project, V_t, and a low critical value, V_t^*. The absence of a structural competitive advantage may result in a tendency to invest early to preclude erosion in the value of the project. The figure on the righthand side of Exhibit 3 shows how the dynamics in present value and the critical value relate to each other in the case of an exclusive investment opportunity. Under monopoly, postponement of the project does not necessarily imply a decrease in expected value. Assuming the project has an infinite life, the critical value would be constant over time. In comparison to perfect competition, there is a stronger tendency to postpone projects under monopoly with relatively low net present values. However, if the project has a relatively high NPV due to permanent economic rents, there would be an incentive to invest early.

Now consider the timing of the follow-up project in a duopoly market. The expected net operating cash inflows are constant until a competitor invests in a competing project. However, in the case of an early investment, it is sometimes possible to avoid a decrease in value by preempting the market. Instead of the maximum of $(V_{t,s} - I, 0)$ or the deferment value in the binomial option model, the state value would now equal the (subgame perfect equilibrium) outcome of a simultaneous investment subgame.

Consider an example with two identical firms pursuing similar tactics for investment in the follow-up project.[4] Exhibit 4 illustrates the net values of a two-period game in extensive form. The actions to invest (*I*) or defer (*D*) are reflected by the branches. When both firms A and B invest, the game ends; when both firms defer, nature (*N*) moves and the game is repeated; and when one firm invests first, nature moves and the follower may then decide to invest later. The strategy of each firm consists of mapping the information set about the competitor's actions and the development of market demand (*N* moves) to an action by the firm. The subgame perfect equilibrium set of strategies can be found by backward induction, starting from the future project values for both firms and working back along the tree. The bold branches along the tree reflect the optimal actions along the equilibrium path. In this exam-

[4]In the symmetrical duopoly example, we use $u = 1.5$, $d = 0.66$, $r = 1.1$, $p = 0.52$, $\theta = 0.55$, $\nu = 0.5$, $V_0 = 100$, and $I = 50$. The values in Exhibit 4 are rounded and based on more periods.

Exhibit 4. Project Value Outcomes of a Game in Extensive Form When Two Competitors Have Symmetrical Market Power



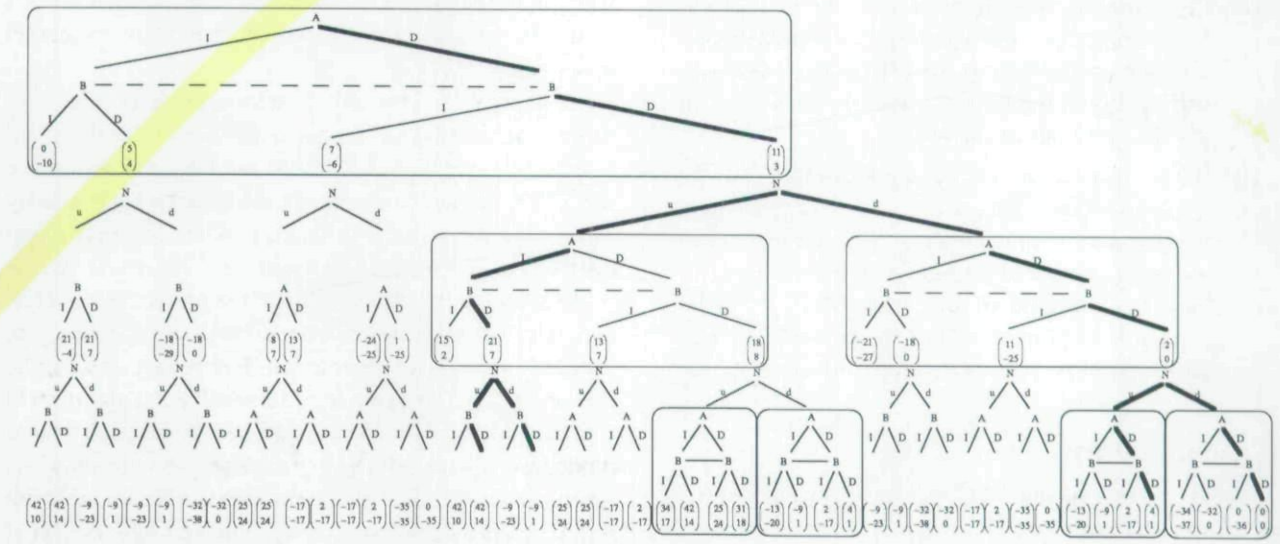
ple, both firms have an identical strategy, i.e., deferring (*D*) the follow-up project and investing (*I*) if, in the early stage, market demand turns out to be favorable (i.e., *N* moves up); or deferring the project further if market demand turns out to be unfavorable (i.e., *N* moves down) and continuing deferment in the later stage of the market (*N* moves down, up or down, down).

Consider next the subgame following initial deferral (*D*) by both firms and favorable demand (*N* moves up) in which both firms follow a strategy to defer (*D*) and market demand turns out to be favorable (*N* moves up). In this case, a decision to invest has a higher net value for the follow-up project, compared to deferral, regardless of whether the competitor decides to invest or not (34 > 25 and 42 > 30). Both firms have a strictly dominant strategy to invest, resulting in net present values of (34, 34) for both follow-up projects. If the market develops unfavorably in the last stage (*N* moves down), the dominant strategy for both firms is to defer, leading to (3, 3) values. Calculating the state values recursively along the nodes results in (17, 17) option values of the investment opportunities when both defer (*D*) in the earlier stage of the market.[5] The dilemma of this subgame (A, B defer, *N* moves up) is known as the prisoner's dilemma. Firm A's dominant strategy is to invest whether the competitor decides to invest or not. The dominant strategy for firm B is also to invest immediately (15 > 13 and 21 > 17). Thus, both firms will choose to invest. The paradox is that the outcome (15, 15) is worse for both, compared with the situation when both defer (17, 17). If both firms coordinated their investment strategies, they would be better off in the latter situation. If market demand develops favorably (*N* moves up), both firms would invest and the NPV of the projects are (15, 15), whereas, if the market develops unfavorably (*N* moves down), both firms would defer and the option values of the investment opportunities are (1, 1). Using these outcomes in the backward valuation process results in (8, 8) option values for the investment opportunities when both firms defer in the first stage.

In the previous example, we assumed identical tactics and equal market power for the two competitors. Of course, the strengths of each firm in an industry are not always identical. Subsequently, we focus on the influence of asymmetrical market power on a firm's investment tactics. A dominant position in the industry may give a competitive advantage to the firm in the realization of project value. Consider, for example, the case where back-

[5] $\frac{p(34)+(1-p)(3)}{r} = 17$.

Exhibit 5. Project Value Outcomes of a Game in Extensive Form When Two Competitors Have Asymmetrical Market Power



ward induction leads to the asymmetrical game between a dominant and a weak firm shown in Exhibit 5.[6]

When both firms defer in the early stage (*D*) and market demand develops favorably (*N* moves up), the competitive advantage of firm A results in a higher net present value from immediately investing in the project and a lower value of waiting. Thus, for firm A, the dominant strategy is to invest early, irrespective of the strategy of competitor B (15 > 13 and 21 > 18). Because a comparable project will have a lower value for the weaker competitor, the competitor will not invest first. Knowing that firm A will invest, the dominant strategy for firm B is to defer (7 > 2). In this example, the two firms pursue different strategies. Dominant firm A invests and preempts the market (receiving 21) if, in the early stage, market demand turns out to be favorable, or further defers if market demand turns out to be unfavorable. The preferred strategy for the weak firm is in each case to defer the project, waiting until the market develops sufficiently before entering with its project.

In general, market power can influence the threat of preemption. Typically, projects with low present value from immediate investment would be postponed. The low project value of weaker competitors gives them little ability to preempt a stronger competitor with high project value. The market power of a firm may also influence the value erosion associated with preemption of a competitor. By investing early, a weak competitor may only gain a small share of the total market, but the potential loss in the value of the project would be minimal. The loss in value, if the firm becomes a follower, will be larger as the market power of the leader grows, because then an early investment can take significant market share away.

Based on the market strength of a firm in relation to its competitors and the value of the project in relation to market uncertainty, we can distinguish the following investment tactics:

(*i*) Projects with relatively small net present values from immediate investment in uncertain markets have relatively larger decision flexibility value favoring postponement. If the firm has a dominant position in the industry, there is little threat of complete preemption by competitors. The firm can safely postpone the project, and invest only if the market develops favorably or if the weaker competitor invests first. It is even possible that a dominant firm can delay investing even when a weaker competitor invests. This could be the case if the competitor can test the market without taking away a significant market share.

(*ii*) Projects with relatively large net present values in stable market environments have relatively small flexibility values. The opportunity cost of deferment in the form of missed cash inflows during the

[6]In the asymmetrical duopoly example, we use the same input variables as in the symmetrical game, except for the present value of the investment opportunity of the weak firm B. For firm B's project, we use $V_0 = 80$ and $I = 50$ instead.

deferment period is high, and so the dominant firm (firm A in the previous example) will invest early.

(*iii*) If the firm has a weak position in the market and the project does not have a large net present value, it may be better to wait until the market develops sufficiently in the future to start the project (firm B in the previous example).

(*iv*) If the firm has a weak market position but the project appears to have a positive net present value, it would invest immediately if early investment can preempt a competitor or create a cost advantage. However, because of the weak position of the company, a stronger competitor may come in and erode its net present value (even turn it negative).

IV. Conclusions

The net present value (NPV) method has serious shortcomings in analyzing projects when future decisions are contingent on intermediate developments in an uncertain environment. Option theory provides a better analytical tool to evaluate such projects. One important difference between a real investment opportunity and a call option is the exclusiveness of the latter. If we use the analogy with a call option to value an investment opportunity, we have to take this difference into account.

Using simple numerical examples, we have illustrated the influence of competition on project value and investment timing. Postponement under perfect competition implies a loss in the expected value of the project due to anticipated competitive entry. Absence of a structural competitive advantage may thus result in a tendency to invest early if the firm can preclude this erosion of value. An investment opportunity in a monopoly is exclusive, so during the postponement period there is no expected loss in value due to competition. In comparison with perfect competition, there is a stronger tendency under monopoly to postpone projects with relatively low net present values. On the other hand, an exclusive project with large present value creates a tendency to invest early.

Oligopoly lies between these two extremes. Here, a few firms are operating in the industry with individual market power. In duopoly, it may be attractive for both firms to defer investment when there is low project value and uncertain market demand. If the firms can coordinate their investment, both will postpone. However, as soon as one of the firms invests, the other firm will follow suit with a similar project. If competitive rivalry is intense and there is no coordination, both firms will invest immediately, which may be suboptimal. In the case where firms in the industry have asymmetric market power, we have distinguished various investment tactics based on the firm's strength in relation to its competitors, and the net present value from immediate investment in relation to market uncertainty.

In general, a firm will postpone projects when net present value is low, market demand is uncertain, and interest rates are high. In contrast to a financial option, the degree of nonexclusiveness of the investment opportunity influences the investment strategy. When there are many competitors, each with a negligible market power, anticipated entry can erode the value of the project. With a few competitors having individual market power, there may be a threat of complete preemption. Future research can be directed toward applying the option valuation approach in real cases. Extension of the theory can be directed toward modelling option pricing in combination with dynamic game theory and incomplete information. However, with higher mathematical complexity, much of the intuition of viewing projects as real options may be sacrificed.

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Appendix A. Forecasting Cash Inflows in Different Market Structures

This appendix relates cash inflows to economic rents. We estimate the expected net operating cash inflow as the opportunity cost of capital plus the expected economic rent, according to Equation (1). We assume that (*i*) the financial market is efficient; and (*ii*) the project has an infinite physical life.

I. Perfect Competition

In perfect competition, economic rents are expected to decline exponentially, as follows:

$$\overline{ER}_t = (\overline{ER}_0)e^{-dt}, \qquad t = 1, 2, 3, \ldots \infty. \qquad (A1)$$

II. Monopoly

In monopoly, the expected economic rents are constant.

$$\overline{ER}_t = \overline{ER}_1, \qquad t = 1, 2, 3, \ldots \infty. \qquad (A2)$$

III. Duopoly

In oligopoly, the timing of a project will be influenced by the behavior of a competitor. Instead of the maximum of ($V_{t,s} - I$, 0) and the deferment value in the original version of the binomial model, a state value equals the outcome of a simultaneous subgame. The investment timing problem is then solved by backward induction leading to a subgame perfect equilibrium. The details are shown in Exhibit 6.

$V_{t,s}$ = present value of operating cash inflows as if there is no competition.

θ = proportion of value left when the firm preempts the market.

ν = proportion of value left when both firms invest simultaneously.

δ_t = proportion of value expressing net operating cash inflow.

p = risk-neutral probability.

Exhibit 6. The Game in Extensive Form