

To factor real-world uncertainties into your decisions, look beyond net present value.

The Options Approach to Capital Investment



Companies make capital investments in order to create and exploit profit opportunities. Investments in research and development, for example, can lead to patents and new technologies that open up those opportunities. The commercialization of patents and technologies through construction of new plants and expenditures for marketing can allow companies to take advantage of profit opportunities. Somewhat less obviously, companies that shut down money-losing operations are also investing: The payments they make to extract themselves from contractual agreements, such as severance pay for employees, are the initial expenditure. The payoff is the reduction of future losses.

Opportunities are *options*—rights but not obligations to take some action in the future. Capital investments, then, are essentially about options. Over the past several years, economists including ourselves have explored that basic insight and found that thinking of investments as options substantially changes the theory and practice of decision making about capital investment. Traditionally, business schools have taught managers to operate on the premise that investment decisions can be reversed if conditions change or, if they cannot be reversed, that they are now-or-never propositions. But as soon as you begin thinking of invest-

ment opportunities as options, the premise changes. Irreversibility, uncertainty, and the choice of timing alter the investment decision in critical ways.

The purpose of our article is to examine the shortcomings of the conventional approaches to decision making about investment and to present a better framework for thinking about capital investment decisions. Any theory of investment needs to address the following question: How should a corporate manager facing uncertainty over future market conditions decide whether to invest in a new project? Most business schools

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teach future managers a simple rule to apply to such problems. First, calculate the present value of the expected stream of cash that the investment will generate. Then, calculate the present value of the stream of expenditures required to undertake the project. And, finally, determine the difference between the two—the net present value (NPV) of

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the investment. If it's greater than zero, the rule tells the manager to go ahead and invest.

Of course, putting NPV into practice requires managers to resolve some key issues early on. How should you estimate the expected stream of operating profits from the investment? How do you factor in taxes and inflation? And, perhaps most critical, what discount rate or rates should you use? In working out those issues, managers sometimes run into complications. But the basic approach is fairly straightforward: calculating the net present value of an investment project and determining whether it is positive or negative.

Unfortunately, this basic principle is often wrong. Although the NPV rule is relatively easy to apply, it is built on faulty assumptions. It assumes one of two things: either that the investment is reversible (in other words, that it can somehow be undone and the expenditures recovered should market conditions turn out to be worse than anticipated); or that, if the investment is irreversible, it is a now-or-never proposition (if the company does not make the investment now, it will lose the opportunity forever).

Although it is true that some investment decisions fall into those categories, most don't. In most cases, investments are irreversible and, in reality, capable of being delayed. A growing body of research shows that the ability to delay an irreversible investment expenditure can profoundly affect the decision to invest. Ability to delay also undermines the validity of the net present value rule. Thus, for analyzing investment decisions, we need to establish a richer framework, one that enables managers to address the issues of irreversibility, uncertainty, and timing more directly.

Instead of assuming that investments are either reversible or that they cannot be delayed, the recent research on investment stresses the fact that companies have *opportunities* to invest and that they must decide how to exploit those opportunities most effectively. The research is based on an important analogy with financial options. A company with an opportunity to invest is holding something much like a financial call option: It has the right but not the obligation to buy an asset (namely, the entitlement to the stream of profits from the

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project) at a future time of its choosing. When a company makes an irreversible investment expenditure, it "exercises," in effect, its call option. So the problem of how to exploit an investment opportunity boils down to this: How does the company exercise that option optimally? Academics and financial professionals have been studying the valuation and optimal exercising of financial options for the past two decades.¹ Thus we can draw from a large body of knowledge about financial options.

The recent research on investment offers a number of valuable insights into how managers can evaluate opportunities, and it highlights a basic weakness of the NPV rule. When a company exercises its option by making an irreversible investment, it effectively "kills" the option. In other words, by deciding to go ahead with an expenditure, the company gives up the possibility of waiting for new information that might affect the desirability or timing of the investment; it cannot disinvest should market conditions change adversely. The lost option value is an opportunity cost that must be included as part of the cost of the investment. Thus the simple NPV rule needs to be modified: Instead of just being positive, the present value of the expected stream of cash from a project must exceed the cost of the project by an amount equal to the value of keeping the investment option alive.²

Numerous studies have shown that the cost of investing in an opportunity can be large and that investment rules that ignore the expense can lead the investor astray. The opportunity cost is highly sensitive to uncertainty over the future value of the project; as a result, new economic conditions that may affect the perceived riskiness of future cash flows can have a large impact on investment spend-

1. For an overview of financial options and their valuation, see John C. Cox and Mark Rubinstein, *Options Markets* (Englewood Cliffs, N.J.: Prentice-Hall, 1985); John C. Hull, *Options, Futures, and Other Derivative Securities* (Englewood, Cliffs, N.J.: Prentice-Hall, 1989); or Hans R. Stoll and Robert E. Whaley, *Futures and Options: Theory and Applications* (Cincinnati, Ohio: South-Western Publishing Co., 1993).

2. Of course, one can always redefine NPV by subtracting from the conventional calculation the opportunity cost of exercising the option to invest and then saying that the rule "invest if NPV is positive" holds. But to do so is to accept our criticism. To highlight the importance of valuing the option, we prefer to keep it separate from the conventional NPV. But if others prefer to continue to use positive NPV terminology, they should be careful to include all relevant option values in their definition of NPV.

ing – much larger than, say, a change in interest rates. Viewing investment as an option puts greater emphasis on the role of risk and less emphasis on interest rates and other financial variables.

Another problem with the conventional NPV rule is that it ignores the value of creating options. Sometimes an investment that appears uneconomical when viewed in isolation may, in fact, create options that enable the company to undertake other investments in the future should market conditions turn favorable. An example is research and development. By not accounting properly for the options that R&D investments may yield, naïve NPV analyses lead companies to invest too little.

Option value has important implications for managers as they think about their investment decisions. For example, it is often highly desirable to delay an investment decision and wait for more information about market conditions, even though a standard analysis indicates that the investment is economical right now. On the other hand, there may be situations in which uncertainty over future market conditions should prompt a company to speed up certain investments. Such is the case when the investments create additional options that give a company the ability (although not the obligation) to do additional future investing. R&D could lead to patents, for example; land purchases could lead to development of mineral reserves. A company might also choose to speed up investments that would yield information and thereby reduce uncertainty.

As a practical matter, many managers seem to understand already that there is something wrong with the simple NPV rule as it is taught—that there is a value to waiting for more information and that this value is not reflected in the standard calculation. In fact, managers often require that an NPV be more than merely positive. In many cases, they insist that it be positive even when it is calculated using a discount rate that is much higher than their company's cost of capital. Some people have argued that when managers insist on extremely high rates of return they are being myopic. But we think there is another explanation. It may be that managers understand a company's options are valuable and that it is often desirable to keep those options open.

In order to understand the thought processes such managers may be using, it is useful to step back and examine the NPV rule and how it is used. For anyone analyzing an investment decision using NPV, two basic issues need to be addressed: first, how to determine the expected stream of profits

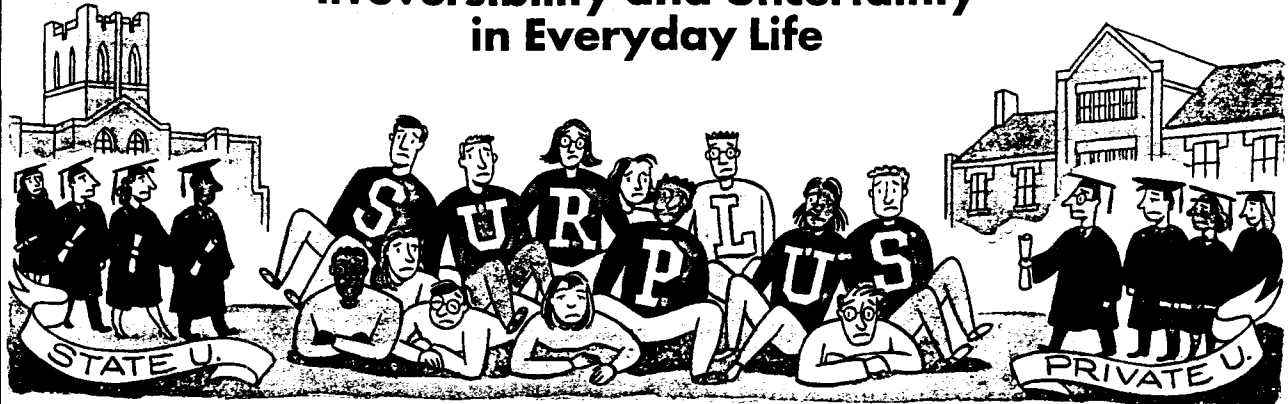
that the proposed project will generate and the expected stream of costs required to implement the project; and, second, how to choose the discount rate for the purpose of calculating net present value. Textbooks don't have a lot to say about the best way to calculate the profit and cost streams. In practice, managers often seek a *consensus* projection or use an average of high, medium, and low estimates. But however they determine the expected streams of profits and costs, managers are often unaware of making an implicit faulty assumption. The assumption is that the construction or development will begin at a fixed point in time, usually the present. In effect, the NPV rule assumes a fixed scenario in which a company starts and completes a project, which then generates a cash flow during some expected lifetime – without *any* contingencies. Most important, the rule anticipates no contingency for delaying the project or abandoning it if market conditions turn sour. Instead, the NPV rule compares investing today with *never* investing. A more useful comparison, however, would examine a range of possibilities: investing today, or waiting and perhaps investing next year, or waiting longer and perhaps investing in two years, and so on.

As for selecting the discount rate, a low discount rate gives more weight to cash flows that a project is expected to earn in the distant future. On the other hand, a high discount rate gives distant cash flows much less weight and hence makes the company appear more myopic in its evaluation of potential investment projects.

Introductory corporate-finance courses give the subject of selecting discount rates considerable attention. Students are generally taught that the correct discount rate is simply the opportunity cost of capital for the particular project—that is, the expected rate of return that could be earned from an investment of similar risk. In principle, the opportunity cost would reflect the nondiversifiable, or *systematic*, risk that is associated with the particular project. That risk might have characteristics that differ from those of the company's other individual projects or from its average investment activity. In practice, however, the opportunity cost of a specific project may be hard to measure. As a result, students learn that a company's weighted average cost of capital (WACC) is a reasonable substitute. The WACC offers a good approximation as long as the company's projects do not differ greatly from one another in their nondiversifiable risk.³

3. For a more comprehensive discussion of the standard techniques of capital budgeting, see a corporate finance textbook such as Richard A. Brealey and Stewart C. Myers, *Principles of Corporate Finance* (New York: McGraw-Hill, 1991).

Irreversibility and Uncertainty in Everyday Life



The decisions that individuals face in their personal lives do not typically involve billions of dollars. In many cases, the highest costs and the biggest benefits are emotional. However, we have found that the option view of investment can be applied fruitfully to all sorts of personal choices and that presenting examples that are "closer to home" can help individuals get a firmer grasp of the central ideas.

For example, one's career choice is a major and largely irreversible decision, which is made in the face of considerable uncertainty about the future prospects of one's chosen sector, one's skill in it, one's future enjoyment of it, and so on. Examples of large-scale mistakes are legendary. In the 1950s, many bright students chose physics as an exciting and rewarding career, only to find that a surplus of physicists developed in the 1970s. There are signs that the same may happen to today's medical students during the next two decades.

The option view suggests appropriate caution. First, it suggests proceeding in steps. For example, instead of committing oneself in the freshman year of college to a specialized program that leads only to medical school, one should follow a more general program to

acquire a more flexible set of skills and find out more about one's own tastes. As one acquires that information and gathers more data about the likely career prospects in medicine versus, say, chemical engineering, one can gradually fine-tune decisions about the appropriate direction. Second, one should not take the final and irreversible plunge into a very specialized line unless the rate of return to the investment is sufficiently greater than the cost, with high enough rewards to justify killing the option of flexibility.

Marriage is another decision that can be analyzed in the same manner. It is costly to reverse, and there is significant uncertainty about future happiness or misery. Therefore, one should enter into it with due caution and only when the expected return is sufficiently high. The criteria should become stiffer as the social costs of separation increase: for example, in some religions or cultures. Courtship is the equivalent of exploratory or R&D investment. Even if the expected return is not very high, one should be willing to undertake courtship because it creates a valuable option — namely the opportunity but not the obligation to follow up or not to, according to the information revealed by the initial steps.

Most students leave business school with what appears to be a simple and powerful tool for making investment decisions: Estimate the expected cash flows for a project; use the company's weighted average cost of capital (perhaps adjusted up or down to reflect the risk characteristics of the particular project) to calculate the project's NPV; and then, if the result is positive, proceed with the investment.

But both academic research and anecdotal evidence bear out time and again the hesitancy of managers to apply NPV in the manner they have been taught. For example, in a 1987 study, Harvard economist Lawrence Summers found that companies were using hurdle rates ranging from 8% to 30%, with a median of 15% and a mean of 17%. Al-

lowing for the deductibility of interest expenses, the nominal interest rate during the period in question was only 4%, and the real rate was close to zero. Although the hurdle rate appropriate for investment with a nondiversifiable risk usually exceeds the riskless rate, it is not enough to justify the large discrepancies found. More recent studies have confirmed that managers regularly and consciously set hurdle rates that are often three or four times their weighted average cost of capital.⁴

Evidence from corporate *disinvestment* decisions is also consistent with that analysis. In many industries, companies stay in business and absorb large operating losses for long periods, even though a conventional NPV analysis would indicate that it

makes sense to close down a factory or go out of business. Prices can fall far below average variable cost without inducing significant disinvestment or exit from the business. In the mid-1980s, for example, many U.S. farmers saw prices drop drastically, as did producers of copper, aluminum, and other metals. Most did not disinvest, and their behavior can be explained easily once irreversibility and option value are taken into account. Closing a plant or going out of business would have meant an irreversible loss of tangible and intangible capital: The specialized skills that workers had developed would have disappeared as they dispersed to different industries and localities, brand name recognition would have faded, and so on. If market conditions had improved soon after and operations could have resumed profitably, the cost of reassembling the capital would have been high. Continuing to operate keeps the capital intact and preserves the option to resume profitable production later. The option is valuable, and, therefore, companies may quite rationally choose to retain it, even at the cost of losing money in the meantime.

The slow response of U.S. imports to changes in the exchange rate during the early 1980s is another example of how managers deviate from the NPV rule. From mid-1980 to the end of 1984, the real value of the U.S. dollar increased by about 50%. As a result, the ability of foreign companies to compete in the U.S. market soared. But the volume of imports did not begin to rise substantially until the beginning of 1983, when the stronger dollar was already well established. In the first quarter of 1985, the dollar began to weaken; by the end of 1987, it had almost declined to its 1978 level. However, import volume did not decline for another two years; in fact, it rose a little. Once established in the U.S. market, foreign companies were slow to scale back or close their export operations when the exchange rate moved unfavorably. That behavior might seem inconsistent with traditional investment theory, but it is easy to understand in the light of irreversibility and option value: The companies were willing to suffer temporary losses to retain their foothold in the U.S. market and keep alive their option to operate profitably in the future if the value of the dollar rose.

4. See Lawrence H. Summers, "Investment Incentives and the Discounting of Depreciation Allowances," in *The Effects of Taxation on Capital Accumulation*, ed. Martin Feldstein (University of Chicago Press, 1987) p. 300; James M. Poterba and Lawrence H. Summers, "Time Horizons of American Firms: New Evidence from a Survey of CEOs" (MIT Working Paper, October 1991); Michael L. Dertouzos, Richard K. Lester, Robert M. Solow, and the MIT Commission on Industrial Productivity, *Made in America* (Harper Paperback, 1990) p. 61; and Robert H. Hayes and David A. Garvin, "Managing As If Tomorrow Mattered," *HBR* May-June 1982, pp. 70-9.

So far, we have focused on managers who seem shortsighted when they make investment decisions, and we have offered an explanation based on the value of the option for waiting and investing later. But some managers appear to override the NPV rule in the opposite direction. For example, entrepreneurs sometimes invest in seemingly risky projects that would be difficult to justify by a conventional NPV calculation using an appropriately risk-adjusted cost of capital. Such projects generally involve R&D or some other type of exploratory investment. Again, we suggest that option theory provides a helpful explanation because the goal of the investments is to reveal information about technological possibilities, production costs, or market potential. Armed with this new information, entrepreneurs can decide whether to proceed with production. In other words, the exploratory investment creates a valuable option. Once the value of the option is reflected in the returns from the initial investment, it may turn out to have been justified, even though a conventional NPV calculation would not have found it attractive.

Before proceeding, we should elaborate on what we mean by the notions of irreversibility, ability to delay an investment, and option to invest. What makes an investment expenditure irreversible? And how do companies obtain their options to invest?

Investment expenditures are irreversible when they are specific to a company or to an industry. For example, most investments in marketing and advertising are company specific and cannot be recovered. They are sunk costs. A steel plant, on the other hand, is industry specific in that it cannot be used to produce anything but steel. One might think that, because in principle the plant could be sold to another steel producer, investment in a plant is recoverable and is not a sunk cost. But that is not necessarily true. If the industry is reasonably competitive, then the value of the plant will be approximately the same for all steel companies, so there is little to be gained from selling it. The potential purchaser of the steel plant will realize that the seller has been unable to make money at current prices and considers the plant a bad investment. If the potential buyer agrees that it's a bad investment, the owner's ability to sell the plant will not be worth much. Therefore, an investment in a steel plant (or any other industry-specific capital project) should be viewed largely as a sunk cost: that is, irreversible.

Even investments that are not company or industry specific are often partly irreversible because

buyers of used equipment, unable to evaluate the quality of an item, will generally offer to pay a price that corresponds to the average quality in the market. Sellers who know the quality of the item they are selling will resist unloading above-average merchandise at a reduced price. The average quality of used equipment available in the market will go down and, therefore, so will the market price. Thus cars, trucks, office equipment, and computers (items that are not industry specific and can be sold to buyers in other industries) are apt to have resale values that are well below their original purchase costs, even if they are almost new.

Irreversibility can also arise because of government regulations, institutional arrangements, or differences in corporate culture. For example, capital controls may make it impossible for foreign (or domestic) investors to sell their assets and reallocate their funds. By the same token, investments in new workers may be partly irreversible because of the high costs of hiring, training, and firing. Hence most major investments are to a large extent irreversible.

The recognition that capital investment decisions can be irreversible gives the ability to delay investments added significance. In reality, companies do not always have the opportunity to delay their investments. For example, strategic considerations can make it imperative for a business to invest quickly in order to preempt investment by existing or potential competitors. In most cases, though, it is at least feasible to delay. There may be a cost—the risk of entry by other companies or the loss of cash flows—but the cost can be weighed against the benefits of waiting for new information. And those benefits are often substantial.

We have argued that an irreversible investment opportunity is like a financial call option. The holder of the call option has the right, for a specified period, to pay an exercise price and to receive in return an asset—for example, a share of stock—that has some value. Exercising the option is irreversible; although the asset can be sold to another investor, one cannot retrieve the option or the money that was paid to exercise it. Similarly, a company with an investment opportunity has the option to spend money now or in the future (the exercise

Recognizing that an investment opportunity is like a financial call option clarifies the role of uncertainty.



price) in return for an asset of some value (the project). Again, the asset can be sold to another company, but the investment itself is irreversible. As with the financial call option, the option to make a capital investment is valuable in part because it is impossible to know the future value of the asset obtained by investing. If the asset rises in value, the net payoff from investing increases. If the value declines, the company can decide not to invest and will lose only what it has spent to obtain the investment opportunity. As long as there are *some* contingencies under which the company would prefer not to invest, that is, when there is some probability that the investment would result in a loss, the opportunity to delay the decision—and thus to keep the option alive—has value. The question, then, is when to exercise the option. The choice of the most appropriate time is the essence of the optimal investment decision.

Recognizing that an investment opportunity is like a financial call option can help managers understand the crucial role uncertainty plays in the timing of capital investment decisions. With a financial call option, the more volatile the price of the stock on which the option is written, the more valuable the option and the greater the incentive to wait and keep the option alive rather than exercise it. This is true because of the asymmetry in the option's net payoffs: The higher the stock price rises, the greater the net payoff from exercising the option; however, if the stock price falls, one can lose only what one paid for the option.

The same goes for capital investment opportunities. The greater the uncertainty over the potential profitability of the investment, the greater the value of the opportunity and the greater the incentive to wait and to keep the opportunity alive rather than exercise it by investing at once. Of course, uncertainty also plays a role in the conventional NPV rule—the fact that a risk is nondiversifiable creates an uncertainty that is added on to the discount rate used to compute present values. But in the option view of investment, uncertainty is far more important and fundamental. A small increase in uncertainty (nondiversifiable or otherwise) can lead managers to delay some investments (those that involve the exercising of options, such as the construction

of a factory). At the same time, uncertainty can prompt managers to accelerate other investments (those that generate options or reveal information, such as R&D programs).

In addition to understanding the role of irreversibility and uncertainty, it is also important to understand how companies obtain their investment opportunities (their options to invest) in the first place. Sometimes investment opportunities result from patents or from ownership of land or natural resources. In such cases, the opportunities are probably the result of earlier investments. Generally, however, investment opportunities flow from a company's managerial resources, technological knowledge, reputation, market position, and possible scale, each of which may have been built up gradually. Such resources enable the company to undertake in a productive way investments that individuals or other companies cannot undertake.

Regardless of where a company gets its options to invest, the options are valuable. Indeed, a substantial part of the market value of most companies can be attributed to their options to invest and grow in the future, as opposed to the capital they already have in place. That is particularly true for companies in very volatile and unpredictable industries, such as electronics, telecommunications, and biotechnology. Most of the economic and financial theory of investment has focused on how companies should (and do) exercise their options to invest. But managers also need to understand how their companies can obtain investment opportunities in the first place. The knowledge will help them devise better long-term competitive strategies to determine how to focus and direct their R&D, how much to bid for mineral rights, how early to stake out competitive positions, and so on.

To illustrate the implications of the option theory of investment and the problems inherent in the traditional net present value rule, let us work through the process of making a capital investment decision at a hypothetical pharmaceutical company.

Suppose that you are the CEO of a company considering the development and production of a new drug. Both the costs and the revenues from the venture are highly uncertain. The costs will depend on, among other things, the purity of the output of the chemical process and the compound's overall effectiveness. The revenues will depend on the company's ability to find a principal market for the compound (and for whatever secondary uses might be discovered) and the time frame within which rival companies are able to introduce similar products.

Suppose that you must decide whether to make an initial investment of \$15 million in R&D. You realize that later, if you decide to continue the project, additional money will have to be invested in a production facility. There are three possible scenarios for the cost of production: low (\$40 million), middle (\$80 million), and high (\$120 million). To keep matters simple, we will assume that each of the scenarios is equally likely (in other words, that each has a $\frac{1}{3}$ probability of occurring). Let us also assume that there are two equally likely cases for the revenue (probability $\frac{1}{2}$ each): low (\$50 million) and high (\$130 million). To focus on the question of how uncertainty and option values modify the usual NPV analysis and to keep the example simple, we will also assume that the time frame is short enough that the usual discounting to reflect the time value of money can be ignored.

Should you make the \$15 million investment in R&D? First, let us analyze the problem by using a simple NPV approach. The expected value (i.e., the probability-weighted average) of the cost of the production facility is $(\frac{1}{3} \times \$40 \text{ million}) + (\frac{1}{3} \times \$80 \text{ million}) + (\frac{1}{3} \times \$120 \text{ million}) = \$80 \text{ million}$. Likewise, the expected value of the revenue is $(\frac{1}{2} \times \$50 \text{ million}) + (\frac{1}{2} \times \$130 \text{ million}) = \$90 \text{ million}$. Therefore, the expected value of the operating profit is \$10 million, which does not justify the expenditure of \$15 million on R&D. So the conventional thinking would kill the project at the outset.

However, suppose that by doing the R&D, you are able to narrow the uncertainty by finding out which of the three possibilities for the cost of the production facility is closest to reality. After learning about the cost, you would be able to make a decision to go ahead and continue the project or to drop it. Thus the \$15 million you invest in R&D creates an option—a right with no obligation to proceed with the actual production and marketing.

For a moment, we will put aside the market uncertainty and suppose that the revenue will always be \$90 million. If the high-cost (\$120 million) scenario is the one that materializes, you will decide not to proceed with the production, and your operating profit will be zero. In the other two cases, however, you will proceed. The operating profit is \$90 million – \$80 million = \$10 million in the middle-cost case and \$90 million – \$40 million = \$50 million in the low-cost case. The probability-weighted average of your operating profit across all three possible outcomes is $(\frac{1}{3} \times 0) + (\frac{1}{3} \times \$10 \text{ million}) + (\frac{1}{3} \times \$50 \text{ million}) = \$20 \text{ million}$. That exceeds your research and development cost of \$15 million, and, therefore, the investment in R&D would be justified.

The logic shows that an action to *create* an option should be valued more highly than a naïve NPV approach would suggest. The gap between the naïve calculation and the correct one arises because the option itself is valuable. You can exercise it selectively when doing so is to your advantage, and you can let it lapse when exercising it would be unprofitable. The amount that an option should be valued over and above the \$10 million expected profit (calculated on the assumption of immediate go-ahead) depends on the sizes and the probabilities of the losses that you are able to avoid.

Now let us reintroduce the notion of uncertainty with regard to the expected revenue. Suppose that you have found out that the middle-cost scenario (\$80 million) is the reality. If you need to make a go-or-no-go decision about production at this point, you will choose to proceed because the expected revenue of $(\frac{1}{2} \times \$130 \text{ million}) + (\frac{1}{2} \times \$50 \text{ million}) = \$90 \text{ million}$ exceeds the production cost of \$80 million, resulting in an operating profit of \$10 million. But suppose you can postpone the production decision until you have found out the true market potential. By waiting, you can choose to go ahead only if the revenue is high, and you can avoid the loss-making case where the revenue turns out to be low. If revenue is high (which occurs with probability $\frac{1}{2}$), you will earn an operating profit of \$130 million – \$80 million = \$50 million, and if revenue is low (also probability $\frac{1}{2}$), you will earn zero, for an average or expected value of \$25 million, which is more than the \$10 million you would get if you went ahead at once.

Here the opportunity to proceed with production is like a call option. Making a go-or-no-go decision amounts to exercising that option. If you can identify some eventualities that would cause you to rethink a go-ahead decision (such as a drop in market demand for your product), then the ability to wait and avoid those eventualities is valuable: The option has a time value or a holding premium. The fact that the option is “in the money” (going ahead would yield a positive NPV) does not necessarily mean that you should exercise the option (in this case, proceeding with production). Instead, you should wait until the option is deeper in the

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money – that is, until the net present value of going ahead is large enough to offset the loss of the value of the option.

In this example, we have intentionally left out any explicit cost of waiting. But you can easily include potential waiting costs in the calculation. Suppose that while you wait to gauge the market potential, a rival will grab \$20 million worth of your anticipated revenues. The revenues under your most favorable scenario will be only \$110 million and under the unfavorable one only \$30 million. Now, if you wait, you can expect an outcome of \$110 million – \$80 million = \$30 million with probability $\frac{1}{2}$ and an outcome of zero with probability $\frac{1}{2}$, for an expected value of \$15 million. That is still better than the \$10 million you get if you go ahead at once.

There’s an important lesson here: Just as an action that creates an option needs to be valued more than the NPV analysis would indicate,

an action that *exercises* or *uses up* an option should be valued *less* than a simple NPV approach would suggest. The reason is that the option itself is valuable. You can exercise an option selectively when the action is to your advantage, or you can let it lapse when such a course would be unprofitable. Again, the extra value gain depends on the sizes and the probabilities of the losses you are able to avoid.

It is even possible to put the revenue uncertainty and the cost uncertainty together. Thus if the R&D investment reveals that costs will be at the high end, you should again wait for the resolution of the revenue uncertainty before you proceed, earning $\frac{1}{2} \times (\$130 \text{ million} - \$120 \text{ million}) = \$5 \text{ million}$. If the costs fall in the middle, it is best to wait, as we saw above; the expected operating profit will be \$25 million. If the cost is at the low end (\$40 million), however, the operating profit is positive at both revenue levels. In that case, it is best to proceed with production at once because the expected profit is $(\frac{1}{2} \times \$130 \text{ million}) + (\frac{1}{2} \times \$50 \text{ million}) - \$40 \text{ million} = \50 million . The proper calculation for NPV that results from the \$15 million R&D investment is $(\frac{1}{3} \times \$5 \text{ million}) + (\frac{1}{3} \times \$25 \text{ million}) + (\frac{1}{3} \times \$50 \text{ million}) = \$26.7 \text{ million}$, which is even bigger than the \$20 million we calculated when we left out the revenue uncertainty. We are now valuing the production options correctly, whereas earlier we as-

sumed, in effect, that those options would be exercised immediately; in the high-cost and middle-cost scenarios, exercising the options wouldn't have been optimal.

All of the numbers in this pharmaceutical example were chosen to facilitate simple calculations. But the basic ideas represented in the case can be applied in a variety of real-life situations. As long as there are contingencies under which the company would not wish to proceed to production, the R&D that conveys information about which contingency will materialize creates an option. And insofar as there is a positive probability that production would be unprofitable, building the plant (rather than waiting) exercises an option.

The option theory of investing also has clear implications for companies attempting to raise capital. If financial market participants understand the nature of the options correctly, they will place greater value on the investments that *create* options, and they will be more hesitant to finance those that *exercise* options. Therefore, as the pharmaceutical company proceeds from exploratory R&D (which creates options) to production and marketing (which exercises them), it will find the hurdle rate rising and sources of eager venture capital drying up. It is interesting to note that this is exactly what has been going on recently in the biotechnology industry as it has progressed from searching for several new products to trying to exploit the few it has found.⁵ The increased difficulty of finding venture capital for biotechnology can be explained in other ways—disappointments over earlier biotechnology products, problems securing and enforcing patents, the risk of a health care cost crunch, to name a few. But we believe that, to a large extent, the market is making an astute differentiation between the creation of options and the exercising of options.

As companies in a broad range of industries are learning, opportunities to apply option theory to investments are numerous. Below are a few examples to illustrate the kinds of insight that the options theory of investment can provide.

Investments in Oil Reserves. Nowhere is the idea of investments as options better illustrated than in the context of decisions to acquire and exploit deposits of natural resources. A company that buys deposits is buying an asset that it can develop immediately or later, depending on market conditions. The asset, then, is an option—an opportunity to choose the future development timetable of the deposit. A company can speed up production when

the price is high, and it can slow it down or suspend it altogether when the price is low. Ignoring the option and valuing the entire reserve at today's price (or at future prices following a preset rate of output) can lead to a significant underestimation of the value of the asset.

The U.S. government regularly auctions off leases for offshore tracts of land, and oil companies perform valuations as part of their bidding process. The sums involved are huge—an individual oil company can easily bid hundreds of millions of dollars. It should not be surprising, then, that unless a company understands how to value an undeveloped oil reserve as an option, it may overpay, or it may lose some very valuable tracts to rival bidders.⁶

Consider what would happen if an oil company manager tried to value an undeveloped oil reserve using the standard NPV approach. Depending on the current price of oil, the expected rate of change of the price, and the cost of developing the reserve, he might construct a scenario for the timing of development and hence the timing (and size) of the future cash flows from production. He would then value the reserve by discounting these numbers and adding them together. Because oil price uncertainty is not completely diversifiable, the greater the perceived volatility of oil prices, the higher the discount rate that he would use; the higher the discount rate, the lower the estimated value of the undeveloped reserve.

But that would grossly underestimate the value of the reserve. It completely ignores the flexibility that the company has regarding when to develop the reserve—that is, when to exercise the reserve's option value. And note that, just as options are more valuable when there is more uncertainty about future contingencies, the oil reserve is more valuable when the price of oil is more volatile. The result would be just the opposite of what a standard NPV calculation would tell us: In contrast to the standard calculation, which says that greater uncertainty over oil prices should lead to *less* investment in undeveloped oil reserves, option theory tells us it should lead to *more*.

By treating an undeveloped oil reserve as an option, we can value it correctly, and we can also determine when is the best time to invest in the development of the reserve. Developing the reserve is like exercising a call option, and the exercise price is the cost of development. The greater the

5. See "Panic in the petri dish," *The Economist*, July 23, 1994, pp. 61-2.

6. The application of option theory to offshore petroleum reserves was pioneered by James L. Paddock, Daniel R. Siegel, and James L. Smith, "Option Valuation of Claims on Real Assets: The Case of Offshore Petroleum Leases," *Quarterly Journal of Economics* 103, August 1988, pp. 479-508.

uncertainty over oil prices, the longer an oil company should hold undeveloped reserves and keep alive its option to develop them.

Scale Versus Flexibility in Utility Planning. The option view of investment can also help companies value flexibility in their capacity expansion plans. Should a company commit itself to a large amount of production capacity, or should it retain flexibility by investing slowly and keeping its options for growth open? Although many businesses confront the problem, it is particularly important for electric utilities, whose expansion plans must balance the advantages of building large-scale plants with the advantages of investing slowly and maintaining flexibility.

Economies of scale can be an important source of cost savings for companies. By building one large plant instead of two or three smaller ones, companies might be able to reduce their average unit cost while increasing profitability. Perhaps companies should respond to growth opportunities by bunching their investments—that is, investing in new capacity only infrequently but adding large and efficient plants each time. But what should managers do when demand growth is uncertain, as it often is? If the company makes an irreversible investment in a large addition to capacity and then demand grows slowly or even shrinks, it will find itself burdened with capital it doesn't need. When the growth of demand is uncertain, there is a trade-off between scale economies and the flexibility that is gained by investing more frequently in small additions to capacity as they are needed.

Electric utilities typically find that it is much cheaper per unit of capacity to build large coal-fired power plants than it is to add capacity in small amounts. But at the same time, utilities face considerable uncertainty about how fast demand will grow and what the fuel to generate the electricity will cost. Adding capacity in small amounts gives the utility flexibility, but it is also more costly. As a result, knowing how to value the flexibility becomes very important. The options approach is well suited to the purpose.

For example, suppose a utility is choosing between a large coal-fired plant that will provide enough capacity for demand growth over the next 10 to 15 years or adding small oil-fired generators, each of which will provide for about a year's worth of demand growth as needed. The utility faces uncertainty over demand growth and over the relative prices of coal and oil in the future. Even if a straightforward NPV calculation favors the large coal-fired plant, that does not mean that it is the more economical alternative. The reason is that if

it were to invest in the coal-fired plant, the utility would commit itself to a large amount of capacity and to a particular fuel. In so doing, it would give up its options to grow more slowly (should demand grow more slowly than expected) or to grow with at least some of the added capacity fueled by oil (should oil prices, at some future date, fall relative to coal prices). By valuing the options using option-pricing techniques, the utility can assess the importance of the flexibility that small oil-fired generators would provide.

Utilities are finding that the value of flexibility can be large and that standard NPV methods that ignore flexibility can be extremely misleading. A number of utilities have begun to use option-pricing techniques for long-term capacity planning. The New England Electric System (NEES), for example, has been especially innovative in applying the approach to investment planning. Among other things, the company has used option-pricing techniques to show that an investment in the repowering of a hydroelectric plant should be delayed, even though the conventional NPV calculation for the project is positive. It has also used the approach to value contract provisions for the purchase of electric capacity and to determine when to retire a generating unit.⁷

Price Volatility in Commodities. Commodity prices are notorious for their volatility. Copper prices, for example, have been known to double or drop by half in the space of several months. Why are copper prices so volatile, and how should producers decide whether to open new mines and refineries or to close old ones in response to price changes? The options approach to investment helps provide answers to such questions.

Investment and disinvestment in the copper industry involve large sunk costs. Building a new copper mine, smelter, or refinery involves a large-scale commitment of financial resources. Given the volatility of copper prices, managers understand that there is value to waiting for more information before committing resources, even if the current price of copper is relatively high. As we showed in the earlier pharmaceutical example, a positive NPV is not sufficient to justify investment. The price of copper and, correspondingly, the NPV of a new copper mine must be high enough to cover the opportunity cost of giving up the option to wait. The same is true with disinvestment. Once a mine, smelter, or refinery is closed, it cannot be reopened easily.

7. For a more detailed discussion of utility industry applications and NEES's experience in this area, see Thomas Kaslow and Robert S. Pindyck, "Valuing Flexibility in Utility Planning," *The Electricity Journal* 7, March 1994, pp. 60-5.

As a result, managers will keep these facilities open even if they are losing money at current prices. They recognize that by closing a facility, they incur an opportunity cost of giving up the option to wait for higher future prices. Thus many copper mines built during the 1970s, when copper prices were high, were kept open during the mid-1980s, when copper prices fell to their lowest levels in real terms since the Great Depression.


Given the large sunk costs involved in building or closing copper-producing facilities and given the volatility of copper prices, it is essential to account for option value when making investment decisions. In reality, copper prices must rise far above the point of positive NPV to justify building new facilities and fall far below average variable cost to justify closing down existing facilities. Outside observers might see that approach as a form of myopia. We believe, however, that it reflects a rational response to option value.

Understanding option value and its implications for irreversible investment in the copper industry can also help us understand why copper prices are so volatile in the first place. Corporate inertia in building and closing down facilities feeds back into prices. Suppose that the demand for copper rises in response to higher-than-average GNP growth, causing the price of copper to rise. Knowing that the price might fall later, producers typically wait rather than respond immediately with new additions to capacity. Since greater supply is not readily forthcoming, the pressure of demand translates into rapid increases in price. Similarly, during downturns in demand, as mines remain open to preserve their options, the price collapses. Recent history has illustrated this phenomenon: The reluctance of producers to close mines during the mid-1980s, when demand was weak, allowed the price to fall even more than it would have otherwise. Thus the reaction of producers to price volatility in turn

sustains the magnitude of price volatility, and any underlying fluctuations of demands or costs will appear in an exaggerated way as price fluctuations.

The economic environment in which most companies must now operate is far more volatile and unpredictable than it was 20 years ago—in part because of growing globalization of markets coupled with increases in exchange-rate fluctuations, in part because of more rapid technology-induced changes in the marketplace. Whatever its cause, however, uncertainty requires that managers become much more sophisticated in the ways they assess and account for risk. It's important for managers to get a better understanding of the options that their companies have or that they are able to create. Ultimately, options create flexibility, and, in an uncertain world, the ability to value and use flexibility is critical.

Decisions that enhance a company's flexibility by creating and preserving options (decisions, for example, about R&D and test marketing) have value that transcends a naïve calculation of NPV. More readily than conventional calculations suggest, managers should make decisions that increase flexibility. Choices that reduce flexibility by exercising options and committing resources to irreversible uses (construction of specific plants and equipment, advertising of particular products) will be valued less than their conventional NPV. Such choices should be made more hesitantly—and subjected to stiffer hurdle rates than the cost of capital—or delayed until circumstances are exceptionally favorable.

The bottom line for managers is that learning how to apply the net present value rule is not sufficient. To make intelligent investment choices, managers need to consider the value of keeping their options open. In this case, we don't think there is any option. 

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