THE NEW OPTION VIEW OF INVESTMENT

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Abstract: This paper provides a simple introduction to the new option view of investment. We explain the shortcomings of the orthodox theory, and then outline the basic ideas behind the option framework. Several industry examples are briefly discussed.

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Companies undertake capital investments in order to create, exploit, and in some cases foreclose future profit opportunities. Investments in R&D, for example, can lead to patents and new technologies that create new profit opportunities. The commercialization of patents and technologies, through construction of new plants and expeditures on marketing, exploits profit opportunites. And shutting down a plant or scrapping equipment can foreclose opportunities.

An opportunity is an *option* — the right but not the obligation to take some action in the future. Hence capital investments are essentially about options. Some investments (e.g., in R&D) create options, while others (building a plant) exercise options. Work that we and others have done over the past several years has explored this basic insight, and found that it substantially changes the theory and practice of capital investment decisions. Unlike the orthodox theory, the roles of irreversibility, uncertainty, and investment timing become crucially important.

This article introduces the new view of investment. Our goal is to explain the shortcomings of the orthodox theory, and then briefly outline a better framework for thinking about a firm's capital investment decisions. (We provide a detailed treatment of this framework in our recent book, *Investment Under Uncertainty*, Princeton University Press, 1994.)

To understand the shortcomings of the orthodox theory, let's begin with the basic question that it — and any new theory of investment — must address. *How should a firm, facing uncertainty over future market conditions, decide whether to invest in a new factory?*

Most business school students are taught a simple rule to apply to problems of this sort. First, calculate the present value of the expected stream of profits that this factory will generate. Second, calculate the present value of the stream of expenditures required to build the factory. Finally, determine whether the difference between the two — the *net present value* (NPV) of the investment — is greater than zero. If it is, go ahead and invest.

Of course there are issues that arise in calculating this net present value. Just how should the expected stream of profits from a new factory be estimated? How should inflation and taxes be treated? And perhaps most important, what discount rate (or rates) should be used in calculating the present values? Resolving issues like these are important topics in courses in corporate finance, and especially in capital budgeting. But the basic principle is fairly simple — calculate the NPV of an investment project and see whether it is positive.

Unfortunately, this basic principle is often wrong. Although it is relatively simple and easy to apply, the Net Present Value Rule is based on some implicit assumptions that are often overlooked. Most important, it assumes that either the investment is reversible, i.e., it can somehow be undone and the expenditures recovered should market conditions turn out to be worse than anticipated, or, if the investment is irreversible, it is a now or never proposition, i.e., if the firm does not undertake the investment now, it will not be able to do so in the future.

While some investments meet these conditions, most do not. Irreversibility and the possibility of delay are very important characteristics of most investments in reality. As a growing body of new research has shown, the ability to delay an irreversible investment expenditure can profoundly affect the decision to invest, and also undermines the simple net present value rule. It means that we need a different framework for analyzing investment decisions.

The new research on investment stresses the fact that a firm has *opportunities* to invest, and must decide how to best exploit those opportunities. This research exploits an important analogy with *financial options.* A firm with an opportunity to invest is holding something much akin to a financial call option — the firm has the right but not the obligation to buy an asset at some future time of its choosing. When a firm makes an irreversible investment expenditure, in effect it "exercises" this call option. Hence the problem of how to best exploit an investment opportunity boils down to how to optimally exercise a call option. (Indeed, we like to refer to investment opportunities as "real options.") As it turns out, the valuation and optimal exercising of financial options has been studied intensively over the past two decades.[1] Therefore, when analyzing investment opportunities we can bring to bear a large body of knowledge about financial options.

[1]For an overview of financial options and their valuation, see John C. Cox and Mark Rubinstein, *Options Markets*, Englewood Cliffs, NJ: Prentice-Hall, 1985; John Hull, *Options, Futures, and Other Derivative Securities*, Prentice-Hall, 1989; or Hans R. Stoll and Robert E. Whalley, *Futures and Options: Theory and Applications*, Southwestern Publishing Co., 1993.

We will see that the new view of investment provides a number of valuable insights. But why does it imply any shortcoming in the NPV rule? The reason is that when a firm exercises its option by making an irreversible investment, it effectively "kills" the option. In other words, the firm gives up the possibility of waiting for new information to arrive that might affect the desirability or timing of the investment; it cannot disinvest should market conditions change adversely. This lost option value is an opportunity cost that must be included as part of the cost of the investment. As a result, the simple NPV rule must be modified: The present value of the expected stream of profits 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 this opportunity cost of investing can be large, and investment rules that ignore it can be grossly in error.[3] Also, this opportunity cost is highly sensitive to uncertainty over the future value of the project, so that changing economic conditions that affect the perceived riskiness of future cash flows can have a large impact on investment spending — much larger than, say, a change in interest rates. Thus, compared to the traditional view, the new view of investment puts greater emphasis on the role of risk, and less emphasis on interest rates and other financial variables.

Another problem with the simple NPV rule is that it ignores the value of *creating* options. Sometimes an investment appears uneconomical when viewed in isolation, but it creates options that enable the firm to undertake other investments in the future should market conditions turn out to be favorable. Those options must be valued in order to properly evaluate the investment. Investments in research and development are an example of this; by not accounting properly for the options that such investments potentially yield, a simple

[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 say that the rule "invest if NPV is positive" holds once this correction has been made. But to do so is to accept our criticism. To highlight the importance of option values, we prefer to keep them separate from the conventional NPV. But if others prefer to continue to use "positive NPV" terminology, that is fine so long as they are careful to include all relevant option values in their definition of NPV. We will illustrate this in the numerical example developed below.

[3]We review many of these studies in our book, *Investment Under Uncertainty*, and in two review articles: Avinash Dixit, 1992, "Investment and Hysteresis," *Journal of Economic Perspectives* **6**, 107-132; and Robert S. Pindyck, 1991, "Irreversibility, Uncertainty, and Investment," *Journal of Economic Literature* **29**, 1110-1152.

NPV analysis can lead the firm to invest too little.

We will see that option value has important implications for the way firms should 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. On the other hand, there can also be situations in which uncertainty over future market conditions should lead a firm to *speed up* certain investments. This is the case when the investments create additional options (such as patents or mineral reserves) that give the firm the ability (but not the obligation) to do additional investing in the future, or when the investments yield information and thereby reduce uncertainty. And we will see that option value also has implications for designing and assessing various government economic policies — for example, antitrust policy, and policies such as interest rate reductions or tax incentives designed to stimulate investment.

NPV in Theory and in Practice.

There is evidence that many managers already understand that something is wrong with the simple Net Present Value Rule as it is taught in business schools — that there is a value to waiting for more information, and that this value is missing from the standard calculation. Managers often seem to require an NPV that is much more than just positive. Equivalently, they often require that the NPV be positive even when it is calculated using a discount rate that is much larger than the firm's cost of capital — even though finance textbooks would tell them that the firm's cost of capital is, at least to a first approximation, the "correct" discount rate. Some people have argued that this reluctance to go ahead with risky capital investments — to require rates of return that are very large according to textbook theory — is evidence of "myopia" on the part of American managers. But as we will see, it may instead just reflect an understanding that the firm's options are valuable, and that it is often desirable to keep those options open.

Let's begin by examining the NPV rule and its application in a bit more detail. There are two basic issues in the use of NPV. The first is how to determine the expected stream of profits that the proposed project will generate, along with the expected stream of costs required to construct the project. Textbook theory doesn't have a lot to say about this. In practice, managers often seek a "consensus" projection for these streams, or use an average of "high," "medium," and "low" estimates. But for our purposes, it is important to be aware of the fact that however these expected streams of profits and costs are determined, there is an implicit assumption here that is often ignored. The assumption is that construction of the project will begin at a fixed point in time (usually the present). In effect, the NPV rule assumes a fixed scenario in which a project is started and completed, and then generates a profit flow over some expected lifetime. There are no *contingencies* in the NPV rule. Most important, there is no contingency for delaying the project and then abandoning it if market conditions turn sour. In effect, the NPV rule compares investing today with never investing. The correct comparison involves many more possibilities: investing today, or waiting and perhaps investing next year, or waiting longer and perhaps investing in two years, etc.

The second important issue in the use of NPV is the choice of discount rate for the calculation of present values. A low discount rate will give more weight to cash flows that a project is expected to earn in the distant future. On the other hand, a high discount rate will give distant cash flows much less weight, and hence make the firm more "myopic" in its evaluation of potential investment projects.

This choice of discount rate receives considerable attention in introductory courses in corporate finance. In those courses, most business school students are taught that the correct discount rate is simply the opportunity cost of capital for the particular project — i.e., the expected rate of return that could be earned from an investment of "similar risk." In principle, this opportunity cost would reflect the nondiversifiable (or "systematic") risk associated with the particular project (and which might differ from the risk characteristics of the firm's other individual projects, or from the firm's "average" investment activity). In practice, however, this project-specific opportunity cost may be hard to measure, so students learn that a reasonable proxy is the firm's *weighted average cost of capital* (WACC). The WACC will provide a good approximation so long as the firm's projects do not differ very much from each other in terms of their nondiversifiable risk, or if the project in question is fairly "typical" for the firm. (For a more comprehensive discussion of the standard techniques of capital budgeting, see a corporate finance textbook; a good choice is Richard A. Brealey and Stewart C. Myers, *Principles of Corporate Finance*, Fourth Edition, New York: McGraw-Hill, 1992.)

Most students, then, 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, then using the firm's weighted average cost of capital (perhaps adjusted up or down to reflect the risk characteristics of the particular project), calculate the NPV for the project, and finally, invest if that NPV is positive. Reality, however, is somewhat different. As we said earlier, firms tend to invest only in projects that are expected to yield a return well in excess of their cost of capital.

This hesitancy of managers to apply NPV "correctly" has been borne out by anecdotal evidence and by formal studies. Observers of business practice find that firms use "hurdle rates" that are often three or four times their weighted average cost of capital. For example, in one study Lawrence Summers found hurdle rates ranging from 8 to 30 percent, with a median of 15 and a mean of 17 percent. The cost of riskless capital was much lower; allowing for the deductibility of interest expenses, the nominal interest rate was 4 percent, and the real rate was close to zero. The hurdle rate appropriate for investment with nondiversifiable risk will exceed the riskless rate, but not by nearly enough to justify the large discrepancies observed. More recently, James Poterba and Summers confirmed this finding in a survey of CEOs that showed that hurdle rates were regularly and consciously set well above the cost of capital. Dertouzas et al made a similar observation, which they took to be evidence of myopia on the part of U.S. managers, as did Hayes and Garvin.[4]

Confirmatory evidence comes from firms' *dis*investment decisions. In many industries, firms stay in business for lengthy periods of time while absorbing large operating losses,

[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 Dertouzas, Richard K. Lester, and Robert M. Solow, *Made in America*, Harper Paperback, N. Y., 1990, p. 61; and R. H. Hayes and D. A. Garvin, "Managing as if Tomorrow Mattered," *Harvard Business Review*, May–June, 1982, pp. 71–79.

even though an NPV analysis would indicate that it is preferable to close down a factory and/or go out of business. At the industry level, we observe that price can fall far below average variable cost without inducing significant disinvestment or exit from the industry. Many U.S. farmers in the mid-1980s were in this situation, as were producers of copper, aluminum, and other metals during this period. Once again, this kind of behavior can be easily explained once irreversibility and option value are accounted for. Closing a plant or going out of business would mean an irreversible loss of much tangible and intangible capital — the specialized skills that the workers have developed on the job would disappear as they disperse to different industries and localities, brand name recognition would fade, and so on. If the conditions were to become favorable again in the near future and operation could be resumed profitably, this capital would have to be reassembled at substantial cost. Continuing operation preserves this capital intact and therefore keeps alive the option to resume profitable production later. This option is valuable, and therefore firms may quite rationally retain it, even at the cost of suffering some operating loss in the meantime.

Another example that combines upside and downside aspects is the very slow response of U.S. imports to changes in the exchange rate. From 1980 to the end of 1984, the real value of the U.S. dollar increased by about 50 percent. The competitive advantage of foreign firms in the U.S. market rose dramatically. But import volume began its persistent rise only at the start of 1983: a lag far longer than the year or 18 months previously believed to be typical. In the first quarter of 1985 the dollar started to fall, and by the end of 1987 was almost back to its 1978 level. But import volume did not decrease for another two years; if anything it rose a little. Once established in the U.S. market, foreign firms were very slow to scale down or shut down their export operations when the exchange rate moved unfavorably. While this behavior might seem inconsistent with traditional investment theory, it is easily understood as an implication of irreversibility and option value: the firms were willing to suffer a temporary loss to retain a foothold in the U.S. market, thereby keeping alive their option to operate profitably in the future should the dollar rise again.

We have dwelt on the apparent shortsightedness of managers making investment decisions, and offered an explanation based on the value of the option to wait and invest later.

But there are some apparent departures from the NPV rule in the opposite direction – entrepreneurs sometimes seem to invest in excessively risky projects, which would be difficult to justify by a conventional NPV calculation using the appropriately risk-adjusted cost of capital. Such projects are generally ventures involving R&D or some exploratory investment. Once again we suggest a possible explanation grounded in the idea of options. What such investments do is to reveal some information, for example about the technological possibilities, production costs, or the market potential. Armed with the information, the entrepreneur can then decide whether to proceed with the larger project of production. In other words, the exploratory investment creates a valuable option, that of whether to undertake further investment. Once the value of this option is included in the returns from the initial investment, it may be justified, even though a conventional NPV rule would not justify it.

Irreversibility, Uncertainty, and the Option to Invest.

Before proceeding, it is important to clarify the notions of irreversibility, the ability to delay an investment, and the option to invest. Most important, what makes an investment expenditure irreversible? And how do firms obtain their options to invest?

Investment expenditures are irreversible — i.e., are *sunk costs* — when they are firm- or industry-specific. For example, most investments in marketing and advertising are firm specific, and cannot be recovered. Hence they are clearly sunk costs. A steel plant, on the other hand, is industry specific — it can only be used to produce steel. One might think that because in principle the plant could be sold to another steel company, the investment expenditure is recoverable and is not a sunk cost. But this is incorrect. If the industry is reasonably competitive, the value of the plant will be about the same for all firms in the industry, so there would be little to gain from selling it. For example, if the price of steel falls so that a plant turns out, *ex post*, to have been a "bad" investment for the firm that built it, it will also be viewed as a bad investment by other steel companies, and the ability to sell the plant will not be worth much. As a result, an investment in a steel plant (or any other industry-specific capital) should be viewed as largely a sunk cost, i.e., irreversible.

Even investments that are not firm- or industry-specific are often partly irreversible because buyers in markets for used machines, unable to evaluate the quality of an item, will offer a price that corresponds to the average quality in the market. Sellers, who know the quality of the item they are selling, will be reluctant to sell an above-average item. This will lower the average quality in the market, and therefore the market price. Thus office equipment, cars, trucks, and computers, which are not industry specific and can be sold to companies in other industries, will have a resale value that is well below their purchase cost, even if they are almost new.

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

What about the ability to delay an irreversible investment? Of course, firms do not always have the opportunity to delay their investments. For example, there can be occasions in which strategic considerations make it imperative for a firm to invest quickly and thereby preempt investment by existing or potential competitors. But in most cases, delay is at least feasible. There may be a cost to delay — the risk of entry by other firms, or simply foregone cash flows — but this cost must be weighed against the benefits of waiting for new information. Those benefits are often large.

We have stressed that an irreversible investment opportunity is like a financial call option. A call option gives the holder the right, for some specified amount of time, to pay an exercise price and in return receive an asset (e.g., 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. A firm with an investment opportunity likewise has the option to spend money (the "exercise price") now or in the future, in return for an asset (e.g., a project) of some value. Again, the asset can be sold to another firm, but the investment is irreversible. As with the financial call option, this option to invest is valuable in part because the future value of the asset obtained by investing is uncertain. If the asset rises in value, the net payoff from investing rises. If it falls in value, the firm need not invest, and will only lose what it spent to obtain the investment opportunity. So long as there are *some* future contingencies in which the firm would prefer not to have invested (i.e., there is some probability of loss), the opportunity to delay the decision — and keep the option alive — has value. The problem, then, is when to exercise the option. That is the essence of the optimal investment decision.

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

Likewise with a capital investment opportunity. The greater the uncertainty over the potential profitability of the investment, the the greater the value of the opportunity, and the greater the incentive to wait and keep the opportunity "alive," rather than exercise it by investing now. Of course uncertainty also plays a role in the conventional NPV rule — nondiversifiable uncertainty enters the risk premium that is added 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 to a substantial delay for some investments (those that involve the exercising of options, such as the construction of a factory), and a substantial acceleration for others (those that generate options or reveal information, such as R&D programs). Shortly we will use a simple numerical example to help make this point clear.

Before proceeding, it is worth considering how firms obtain their investment opportunities, i.e., their options to invest, in the first place. Sometimes investment opportunities result from patents, or ownership of land or natural resources. In this case, the investment opportunity is probably the result of an *earlier* investment, e.g., in research and development (leading to a patent), or in the purchasing of land or mineral rights. More generally, investment opportunities arise from a firm's managerial resources, technological knowledge, reputation, market position, and possible scale, all of which may have been built up over time, and which enable the firm to productively undertake investments that individuals or other firms cannot undertake.

Most important, these options to invest are valuable. Indeed, for most firms, a substantial part of their market value is attributable to their options to invest and grow in the future, as opposed to the capital they already have in place. (This is particularly true for companies in industries that are very volatile and unpredictable, such as electronics, telecommunications, and biotechnology.) Most of the economic and financial theory of investment has focused on how firms should (and do) exercise their options to invest. To better understand investment behavior it may be just as important to understand how firms obtain their investment opportunities in the first place.

The Value of Information and Options – An Example.

We can illustrate the implications of this new theory, and the problems with the traditional NPV rule, by working through a very simple numerical example of a capital investment decision.

Imagine that you are the CFO of a pharmaceutical company, considering the development and production of a new drug. Both the costs and the revenues from the venture are highly uncertain. The cost will depend on the purity of the output of the chemical process, the efficacy of the compound, etc. The revenue will depend on the principal market for the compound and any secondary uses that might be discovered, the development of similar compounds by your rivals, etc.

Suppose that you must decide whether to invest an initial \$15 million in R&D. Afterwards, 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 these scenarios is equally likely (i.e., each scenario has a probability $\frac{1}{3}$ of occuring). We will also assume that there are two equally likely (probability $\frac{1}{2}$ each) cases for the revenue, 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 arithmetic simple, we will assume that the time frame is short enough that the usual discounting to account for the time value of money can be ignored.

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

However, suppose that by doing the R&D, you can find out which of the three possibilities for the cost of the production facility is the reality. After learning about this cost, you can make a decision to go ahead and continue the project or not. Thus the initial $15 million investment in R&D is *creating an option* — it creates a right, but not an obligation, to proceed with the actual production and marketing.

For a moment, leave out the market uncertainty, and suppose that the revenue will always be $90 million. If the high-cost ($120 million) scenario materializes, you will decide not to proceed with the production, and your operating profit will be zero. In the other two cases you will proceed. The operating profit is $90 - 80 = 10$ million dollars in the middle-cost case, and $90 - 40 = 50$ million dollars in the low-cost case. The probability weighted average of your operating profit across all three possible outcomes is

$$\tfrac{1}{3} \times 0 + \tfrac{1}{3} \times 10 + \tfrac{1}{3} \times 50 = 20\,.$$

This exceeds your R&D cost of $15 million. Thus the investment in R&D *is* justified.

This shows that an action that *creates* an option should be valued *more* highly than a naive NPV approach would suggest. The gap arises because the option itself is valuable. It gives you the ability to exercise it selectively when that is to your advantage, and to let it lapse when exercise would have been unprofitable. This extra value therefore depends on the sizes and the probabilities of the losses you can thus avoid.

Now let us reintroduce the uncertainty concerning the revenue. Suppose you have found out that the middle scenario for the cost ($80 million) is the reality. If you must make a go-or-no-go decision about production at this point, you will choose to proceed, because the expected revenue,

$$\tfrac{1}{2} \times 130 + \tfrac{1}{2} \times 50 = 90$$

exceeds the production cost, 80, leaving an operating profit of $10 million. But suppose you can postpone the production decision until you have found out the true market potential. Then, by waiting, you will be able to pick the profitable outcome, namely the case where the revenue is high, and avoid the loss-making case where the revenue turns out to be low. This will get you an operating profit of $130 - 80 = 50$ with probability $\frac{1}{2}$ (and zero in the other case), for an average or expected value of $25 million, much bigger 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 at once amounts to exercising that option. If there are some future eventualities in which you would regret having proceeded (such as a drop in market demand for the product), then the ability to wait and avoid those eventualities is valuable — the option has a time value or a holding premium. You should not exercise the option (proceed with production) just because it is "in the money" (i.e., just because going ahead would yield a positive NPV). Instead, you should wait until the option is sufficiently deep in the money — in other words, until the NPV of going ahead is large enough to offset the loss of the value of the option.

This example has loaded the dice in favor of waiting, because it has left out any explicit cost of waiting. But we can accommodate some such cost quite easily. Suppose that while you wait to gauge the market potential, a rival will steal as much as $20 million worth of it. Thus you will get only $110 million in the favorable scenario, and only $30 million in the unfavorable one. Now waiting gets you $110 - 80 = 30$ with probability $\frac{1}{2}$ and zero with probability $\frac{1}{2}$, for an expected value of $15 million, which is still better than the $10 million you get if you go ahead at once.

To sum up, an action that exercises or *uses up* an option should be valued *less* highly than a naive NPV approach would suggest. The gap arises because the option itself is valuable. It gives you the ability to exercise it selectively when that is to your advantage, and to let it lapse when exercise would have been unprofitable. This extra value again depends on the sizes and the probabilities of the losses you can thus avoid.

We can even put the two types of uncertainty together. Thus, if the R&D reveals the cost to be at the high end, we should again wait for the resolution of the revenue uncertainty before we proceed, earning

$$\tfrac{1}{2} \times (130 - 120) = 5\,.$$

If the cost is at the middle point, we saw above that it is optimal to wait, and the expected operating profit is \$20 million. If the cost is at the low end, however, the operating profit is positive in both the revenue eventualities. In this case it is best to proceed with production at once, and the expected profit is

$$\tfrac{1}{2} \times 130 + \tfrac{1}{2} \times 50 - 40 = 50\,.$$

Therefore the correctly calculated NPV that results from the initial \$15 million investment in R&D is

$$\tfrac{1}{3} \times 5 + \tfrac{1}{3} \times 20 + \tfrac{1}{3} \times 50 = 25\,,$$

which is even bigger than the \$20 million we calculated when we left out the revenue uncertainty. The point is that now we are valuing the subsequent production options correctly, whereas what we did before amounted to assuming immediate exercise of those options, which was not optimal in the high and middle cost scenarios.

All the numbers in this example — the profit or loss figures, as well as the probabilities — were chosen to facilitate simple numerical calculations. But the general ideas do not depend on the specific numbers. So long as there are some contingencies where the firm would not wish to proceed with the production stage, the R&D that reveals this information creates an option. And so long as there is some probability that production would be unprofitable, building the plant (rather than waiting) exercises an option.

Now consider the question of raising capital for this venture. If financial market participants understand the nature of the options correctly, they will value more highly the investments that *create* options, and be more hesitant to finance those that *exercise* options. Therefore, as your pharmaceutical company proceeds from the stage of exploratory R&D (which creates options) to the stage of production and marketing (which exercises them), you will find your cost of capital rising, and supplies of eager venture capital drying up. Remarkably, this is exactly what has been happening to the biotechnology industry, as it progresses from searching for several new products to trying to exploit the few it has found.[5] There are other explanations for this phenomenon — past disappointments about several products, problems securing and enforcing patents, the risk of a health care cost crunch, etc. — but we believe that the market's correct evaluation of the creation versus the exercising of options is a significant element in the puzzle.

Other Industry Examples.

Applications of this new theory are ubiquitous, as companies in a broad range of industries are learning. Here we discuss a few examples, to illustrate the kinds of insight that the theory 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 underground deposits of natural resources, such as crude petroleum or metal ores. A company that buys such a deposit is buying an asset that it can develop immediately or later, depending on market conditions. Therefore the asset is an option — the opportunity to choose the future policy for development of the deposit, speeding up the rate of production when the price of oil or the metal is high, and slowing down or suspending production when the price is low. The value that the company should place on the deposit should reflect the value of this option. Ignoring it, and valuing the reserve at

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

today's price (or the expected future price, following some assumed stream of output) can lead to a serious underestimate of the value of the asset.

The sums involved are huge. The U.S. government regularly auctions off leases for tracts of land, and oil companies perform valuations of such tracts as part of their bidding process. These bids can involve hundreds of millions of dollars, and errors in valuation can mean substantial overpayments, or alternatively the loss of valuable tracts to rival bidders. Of course, to get the full value of the tract once it has been acquired, the company must make its development and production decisions correctly. In other words, it must determine when to optimally exercise its options. Let us now see in somewhat greater detail how the naive NPV approach can lead to errors, and how the theory developed above helps the firm do these calculations correctly.[6]

Suppose one 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 price, and the cost of developing the reserve, one might construct a scenario for the timing of development and hence the timing (and size) of the future cash flows from production. One would then value the reserve by discounting these numbers and summing. And, since oil price uncertainty is not completely diversifiable, the greater the perceived volatility of oil prices the larger would be the discount rate, and the smaller the estimated value of the undeveloped reserve. But this would grossly *underestimate* the value of the reserve. The reason is that it ignores the flexibility that the owner has over when to actually develop the reserve, i.e., the reserve's option value. And note that because of this option value, the greater the volatility of oil prices the *larger* is the value of the reserve. This result is just the opposite of what a standard NPV calculation would tell us — unlike in the standard calculation, greater uncertainty over oil prices should lead to *more* investment in undeveloped oil reserves.

By treating an undeveloped oil reserve as an option, we can value it correctly, and we can also determine when to optimally invest in the development of the reserve. Developing the

[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*, Aug. 1988, **103**, 479–508.

reserve is like exercising a call option, where the exercise price is the cost of development. The greater the uncertainty over oil prices, the longer an oil company should hold undeveloped reserves, and keep its option to develop the reserves open.

It should be clear, then, why oil companies and other firms in extractive resource industries have developed a keen interest in this new approach to investment. These firms must regularly make decisions regarding large irreversible investments, and they have begun to realize that traditional approaches to these decisions can lead them far astray.

Scale versus flexibility in utility planning.

The option view of investment can also help firms value *flexibility* in their capacity expansion plans. Should a firm commit itself to a large amount of production capacity, or retain flexibility by investing slowly and keepings its options to grow open? While this problem confronts many firms, it has been 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.

As we all know, economies of scale can be an important source of cost savings. By building a large plant instead of two or three smaller ones, a firm might be able to reduce its average cost and increase its profitability. This suggests that firms should respond to growth in demand by bunching their investments, i.e., investing in new capacity only infrequently, but adding large and efficient plants each time. But should firms do when there is uncertainty over demand growth (as there usually is)? If the firm irreversibly invests in a large addition to capacity, and demand grows only slowly or even shrinks, it will find itself holding 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 increments to capacity as they are needed.

This problem is particularly important for the electric utility industry because it is much cheaper per unit of capacity to build a large coal-fired power plant than it is to add capacity in small amounts. But at the same time, utilities face considerable uncertainty over the rate that electricity demand will grow, and over the cost of fuel to generate the electricity.

Adding capacity in small amounts gives the utility flexibility, but is also more costly. Hence it is important to be able to value this flexibility. The options approach is well suited to do this.

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, versus adding small oil-fired generators, each of which will provide for about a year's worth of demand growth, as they are needed. It 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, it need not be the more economical alternative. The reason is that by investing in the coal-fired plant, the utility commits itself to a large amount of capacity and to a particular fuel — it gives 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 fall relative to coal prices in the future). By valuing these options using option-pricing techniques, the utility can value the flexibility afforded by the small oil-fired generators.

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 the use of this new approach to investment planning, and has found that maintaining flexibility can be extremely valuable. Among other things, they have used the approach to show that investing in the repowering of a hydroelectric plant should be delayed, even though it has a conventional NPV that is positive. They have also used the approach to evaluate the timing of early retirement for a generating unit, and to value contract provisions for the purchase of electric capacity. (For a more detailed discussion of utility applications and NEES's experience in this area, see Thomas Kaslow and Robert S. Pindyck, "Valuing Flexibility in Utility Planning," *The Electricity Journal*, March 1994.)

This use options for valuing flexibility and making investment decisions is becoming increasingly relevant for the utility industry as a whole, given the new uncertainties stemming from emerging competition in this industry, along with the uncertainties that have always existed over demand growth and the evolution of fuel prices. Utilities are finding that the value of flexibility is often large, and the use of standard NPV methods that ignore it can be very misleading.

The volatility of prices of natural resources.

The prices of copper and other commodities are notoriously volatile. Copper prices, for example, have occasionally doubled or halved in the space of several months. Why are copper prices so volatile, and how should copper producers decide whether to open new mines and refineries or close old ones in response to price changes? The option view of investment can help us answer these questions.

Investment and disinvestment in the copper industry involves 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 these resources, even if the price of copper is currently relatively high. As was the case earlier with our simple pharmaceutical example, a positive NPV is not sufficient to justify this investment. The price of copper, and correspondingly the NPV of a new copper mine, must be sufficiently high to cover the opportunity cost of giving up the option to wait. Likewise with disinvestment. Once a mine, smelter, or refinery is closed, it cannot easily be reopened. 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 the possibility that prices will rise in the future. That is why many copper mines built during the 1970s when copper prices were high were kept open during the mid-1980s when copper prices had fallen to their lowest levels (in real terms) since the Great Depression.

Given the large sunk costs involved when building or closing copper producing facilities, and given the volatility of copper prices, it is essential to account for option value when making these investment decisions. As we have shown in our book (*Investment Under Uncertainty*), copper prices must rise far above the point of "positive NPV" to justify building new facilities, and far below average variable cost to justify closing down existing facilities. Outside observers might interpret this as some kind of myopia, i.e., a tendency to overdiscount when making these decisions. On the contrary, it reflects a rational response to option value.

Finally, 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. Firms' "inertia" in building and closing down facilities feeds back into prices. Suppose the demand for copper rises in response to higher-than-average GNP growth, so that the price of copper begins to rise. Knowing that the price might later fall, producers wait rather than respond immediately with new additions to capacity, and this allows the price to rise even more than it would otherwise. The same thing happens on the downside. For example, the reluctance of producers to close down 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 large price volatility, and any underlying fluctuations of demands or costs will appear in a magnified way as price fluctuations.

Implications for Government Policy

Our discussion of the new option view of investment has thus far concentrated on individual firms' decisions — expansion or contraction, exploration and R&D, etc. — because this is the primary concern of businesspeople. Economists are more often interested in the implications for the performance of whole industries, and for public policy. But businesspeople should also pay some attention to these matters, because the fortunes of their firms are very much dependent on government policies — not only those that bear directly on their particular industry, but also policies of taxation, interest rates, health care, etc. Therefore it is important to understand the policy implications of this new theory. Here are some of them.

Antitrust policy.

We have already pointed out one industry-wide observation – when firms are reluctant to invest or disinvest when facing fluctuating demand or cost conditions, these fluctuations translate into large price volatility. This story is at its most compelling in the case of primary and extractive industries, where the fluctuations in prices are so obvious and so large. But the same idea applies to all industries that require significant irreversible capital investments, and this includes most manufacturing activities.

The textbook economic theory of industry price fluctuations goes back to Alfred Marshall. It distinguishes two threshold levels of cost – the short-run or variable cost, which includes the cost of materials, labor and other inputs which can be varied relatively readily and reversibly, and the long-run or full cost, which includes the interest and depreciation charges on the irreversible or sunk capital costs. If the market price is high enough to cover the full cost, then new investment in this industry is yielding a return high enough to cover the cost of capital (interest and depreciation). If firms are making their investment decisions according to the conventional NPV criterion, they should be expanding their capacity, and new firms should be entering the industry. This increase in supply will keep the price rise in check. Therefore the price cannot rise persistently higher than the full cost. Similarly, if the market price falls below the level of the variable cost, conventional calculation will justify abandonment of existing capital or exit of some firms. This decrease in supply will check the price fall, so the price cannot fall persistently below the variable cost.

The Marshallian theory thus leads economists to believe that prices should normally be confined to the range between the variable cost and the full cost. If prices are seen persistently outside this range, the theory suggests that the normal competitive mechanisms of entry and exit or expansion and contraction in the industry must somehow be impaired. In particular, a price in excess of the full cost is prima facie evidence that there must be some, perhaps well hidden, entry barriers. An antitrust investigation would seem to be justified. A price persistently below variable cost suggests predatory intent on the part of some firm or firms: they are trying to drive the rivals out of the industry and then enjoy a monopoly. The suspicion is generally strongest if foreign firms are involved. The suspected action is then called "predatory dumping," and countermeasures are often instituted after a quick and loaded administrative process. (For an entertaining account of U.S. antidumping actions, see James Bovard, *The Fair Trade Fraud*, New York: St. Martin's Press, 1991.)

The new options view offers an alternative explanation of the same observations, with very different policy implications. A price persistently in excess of the full cost is not necessarily evidence of entry barriers. Perfectly competitive firms that are free to enter and expand would rationally hesitate before exercising and thereby killing their options to enter or expand. The price would have to rise to a threshold in excess of the full cost, thereby offering a return above normal, before they will invest. Numerical simulations based on typical values of sunk costs and uncertainty show that this departure from the Marshallian standard can be very large. Current returns two or three times above the cost of capital are needed to justify investment, and the price can stay above the full cost (but below this higher threshold) for several years without attracting new entry. (See our book, *Investment Under Uncertainty*, Princeton University Press, 1994, especially chapters 5–7, for examples of such calculations.)

Therefore antitrust authorities should not be too quick to jump to the conclusion of a failure of competition, or assume the existence of entry barriers, based solely on the evidence of a price persistently in excess of cost. They should be required to look for, and produce, more direct evidence of anticompetitive practices before they act against the supposedly offending firms.

Similarly, firms that continue to operate at a loss may be quite rationally preserving their option to stay in the industry in the hope of an upturn. They need have no predatory intent. Once again, more direct evidence of predation should be produced before antitrust action is taken or antidumping duties are levied.

Policies to stimulate investment.

Government policies not only respond to uncertainty in the economy and its observed consequences for prices, investment, etc., but also introduce some irreversibilities and uncertainties of their own. The process of policy-making is long and involved, especially when the choices are important or contentious. And because the process is so costly in its requirements of time, political capital etc., major policy debates are not initiated casually or frequently; a decision once made will stay with us for years or decades, whether for good or for bad. Therefore we should regard a policy decision itself as an irreversible choice made under conditions of uncertainty, and examine what the new options view of investment can tell us about the right way to make such decisions.

Consider policies to encourage investment. This is a frequent concern of governments, and is based on the belief that market forces do not produce sufficient investment — in physical capital, and even more so in human capital — for the nation's long run growth. Policies like investment tax credits and training schemes are constantly floated as ways to improve upon matters.

At first glance, the new view of investment seems to support such claims. If firms facing uncertainty are hesitant to incur the sunk costs, should not the government offer inducements to them?

But this ignores the reality of the uncertainty. If firms are hesitant to sink capital because future demand and technology are uncertain, and waiting enables them to reduce the risk of being stuck with excess capacity or an obsolete plant, the same is no less true of society as a whole. A social planner should also consider waiting. And the general economic proposition about the efficiency of markets continues to apply here. So long as *all* markets — those for goods, services and capital — function perfectly, the outcome is socially optimal, and government intervention cannot improve upon it. Any justification for policy activism must be based on evidence of some *failure* in one or more of these markets.

Failures in the markets for goods generally take the form of monopoly or oligopoly, and we discussed issues of antitrust policy above. The prevalence of uncertainty brings with it the possibility of capital market failure, specifically in the allocation of risks. The efficiency of such markets is a hotly debated issue, but there is no clear evidence that governments can do any better. Perhaps the best case for market failure can be made in the case of human capital; the risks of acquiring specific skills are not easy to diversify, because one cannot sell the equity in one's future labor earnings. Therefore there may be a good case for the government to facilitate or subsidize investments in human capital.

But let us grant, for the sake of argument, that the case for a policy to stimulate investment in plant, equipment etc. has been made, and initiate a discussion of the best way to achieve this effect. We pointed out above that the policy debate is often very prolonged, and its conclusion quite uncertain. This creates its own uncertainty, which adds to the underlying economic uncertainty. Firms faced with this added uncertainty have even more reason to wait before committing their capital. Why invest now when there is a chance that a 10% tax credit will be available for investing next year? Thus the policy *process* can reduce investment temporarily, even though the ultimate aim of the policy being discussed is to increase investment. If there is genuine reason for concern about the low level of investment, then the temporary reduction comes at exactly the wrong time. Governments should pay attention to such harm they may be causing when they initiate the policy process. If they want to stimulate investment, the worst thing they can do may be to spend several months discussing the right way to do so.

Conclusions.

It seems evident to us from casual observation that the economic environment in which most firms must now operate is far more volatile and unpredictable today than was the case twenty years ago. This is partly the result of growing globablization of markets with a concommitant increase in exchange rate volatility, and partly the result of more rapid technology-induced changes in market structure. But whatever the source of this increased volatility and uncertainty, it means that business planners need to become much more sophisticated in the ways they assess and account for risk. An important element of this is getting a better grasp of the options that firms have (or can create). These options create flexibility, and in an uncertain world, it is very important to be able to value that flexibility.

So for those readers who feel that learning the Net Present Value Rule and its application was difficult enough, we come with bad news. Now you must learn these new techniques. You really don't have an option.

BOXED MATERIAL:
Investments in Oil Reserves.

The valuation and exploitation of an offshore oil tract can be viewed as part of a multi-stage investment problem. The first stage involves exploration — seismic and drilling activity to find out how much oil is present and the cost of extracting it. The second stage (which would only occur if the exploration results are favorable) involves development — the installation of the platforms and production wells that are needed to extract the oil. The last stage involves the extraction of the oil over some period of years. Since it is the development stage that involves the largest capital expenditures, it is the stage for which option value is most important. Hence we will focus on the valuation of an undeveloped (but well delineated) reserve, and the decision as to when to develop it. In doing so, we must account for the fact that the option to develop the reserve is not a perpetual one; offshore leases are usually subject to *relinquishment requirements*, which limit the time the company can hold the tract before developing it.

The close connection between the value of an undeveloped reserve and a call option on a stock is illustrated in Table 1.[7] (The table is from Paddock, Siegel, and Smith, op cit.) The underlying asset in the case of a call option is the stock price; for an undeveloped reserve it is the value of a developed reserve (which, as we will see, is in turn a function of the price of oil). The exercise price for the undeveloped reserve is the development cost, and the time to expiration is the relinquishment requirement.

The value and optimal exercise rule for a call option on a stock also depend on the stock's dividend rate; the higher the dividend the greater the opportunity cost (in terms of foregone dividends) of holding the option rather than exercising it. The analogous variable for the developed reserve is the net production revenue less the rate of depletion; one forgoes this by delaying development. One can determine this "dividend rate" by estimating the rate of production from the developed reserve, and the reserve's expected lifetime. Given the

[7]The analogy is with an *American* call option, i.e., an option that can be exercised at any time up to an including the expiration date. A European option can only be exercised on its expiration date.

Table 1 – Comparison of A Call Option to an Undeveloped Oil Reserve

Call Option	Undeveloped Reserve
Stock Price	Value of Developed Reserve
Exercise Price	Cost of Development
Time to Expiration	Relinquishment Requirement
Volatility of Stock Price	Volatility of Value of Developed Reserve
Dividend on Stock	Net Production Revenue from Developed Reserve less Depletion

current price of oil and the variable cost of production, we calculate net production revenue. Subtracting the rate of depletion and dividing by the current value of the reserve gives the effective "dividend rate."

For offshore petroleum reserves in the Gulf Coast of the United States, this "dividend rate" is about 4 percent. Since the value of a developed reserve is proportional to the price of oil, its volatility will equal to volatility of oil prices, which has been estimated to be about 15 percent per year. Using an after-tax real risk-free rate of interest of 2 percent and a relinquishment requirement of 10 years, one can calculate that the "development option" should not be exercised until the value of a developed reserve exceeds the cost of development by at least 25 percent.

BOXED MATERIAL:

Irreversibility and Uncertainty in Everyday Life

All the decisions we analyzed above were weighty ones in business and public policy, involving billions or even trillions of dollars. But all of us constantly face similar decisions in our lives, and from our personal perspective they seem just as important. Therefore we would like to conclude by showing how the ideas we have developed can be fruitfully applied when thinking about many personal choices. You may think this trivializes the theory, but our experience shows that people remember these "close to home" examples particularly vividly, and that helps their thought processes when a similar major business decision comes along.

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 the sector for which one chooses to train, one's own skill in, and enjoyment of, that particular line of work, 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 a surplus of physicists emerge in the 1970s. There are signs that the same may happen to today's medical students in the next two decades.

The options view suggests appropriate caution. First, it suggests proceeding in steps. Rather than committing oneself in the freshman year to a specialized program that leads only to medical school, for example, 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 this information, and gathers more information about the likely career prospects in medicine versus, say, chemical engineering, one can gradually specialize in the appropriate direction. Second, one should take the final and irreversible plunge into a very specialized line only if the rewards are sufficiently high — the rate of return to the investment is sufficiently greater than the cost — to justify killing the option of flexibility.

Marriage is a similar decision — costly to reverse, and with significant uncertainty about future happiness or misery. Therefore one should enter into it with due caution, only when the expected return is sufficiently high. The criterion should be stiffer the higher are costs of separation, as is the case with some religions or cultures. On the other hand, courtship is the equivalent of exploratory or R&D investment in this case. One should be willing to undertake it even if the expected return is not very high, 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 step.