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Innovation Options and Organizational Capabilities

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EXECUTIVE SUMMARY

Organizational capabilities, whether in product development, efficient production, or market access, provide firms with opportunities to achieve and maintain strategic advantages over competitors. Recently, many researchers have argued that certain organizational capabilities add to a firm's value in the form of its yet-to-be realized opportunities for profitable investments. But do such capabilities help all firms and under all conditions? The objective of this paper is to develop a model that helps us better understand the factors that influence the value of future growth opportunities for the firm and the organizational capabilities required to realize those opportunities.

We define an *innovation option* as opportunity for a firm to realize the commercial potential of a new technology by translating it into a novel product or service. During the course of development, information concerning the technical and market feasibility of a project is revealed. The firm can utilize the accumulated information about the potential net benefits of a project before committing partially or completely irreversible resources to commercialize the technology. In its most simple form, innovation projects should be viewed as a sequence of two decisions; a decision to gather information about the project's prospects (experimentation stage) followed by a decision to commercialize the project (implementation stage).

We present a basic two-stage model that illustrates how a firm can maximize the value of its innovation efforts by investing in projects that match its organizational capabilities. First, we identify characteristics that determine the potential option value of an innovation project. We then turn our attention to firm capabilities that permit it to exploit high option value opportunities. We specifically investigate a firm's *learning capability* and *abandonment capability*. We find that an appropriate fit between project and firm characteristics will permit the firm to effectively appropriate the option value associated with its innovation opportunities. We contend that firms that are endowed with projects that tend to have high potential option value can improve their innovation processes by investing in firm capabilities that allow them to exploit their opportunities. On the other hand, firms that are endowed with projects that have low potential option value may be better off shedding potentially expensive, but relatively valueless, capabilities. While learning capabilities and abandonment capabilities represent potentially valuable organizational resources that can be the basis of strategic advantage, this paper offers a framework to better establish their value to the firm.

INTRODUCTION

Organizational capabilities are recognized as important sources of competitive advantage for firms. Proponents of the resource-based view (RBV) perspective (see, for example, Barney 1992; Peteraf 1993) argue that capabilities, whether in product development, efficient production, or market access, provide firms with opportunities to achieve profitable strategic positions in product markets. Over time, firms accumulate idiosyncratic combinations of capabilities that, in turn, provide unique opportunities for profitable business growth or expansion (Baldwin and Clark 1992; Dierickx and Cool 1989; Henderson and Cockburn 1994; McGrath, MacMillan and Venkataraman 1995; Teece, Pisano and Shuen 1992).

The options framework, developed in the financial economics field, has been applied to address this concept of firm capabilities. Myers (1977) proposed that some portion of a firm's value is based on *growth options*, yet-to-be realized opportunities for profitable investments. Analogous to an option on a financial security, a growth option is a discretionary opportunity to invest in productive assets, whether physical or intangible, at some future date. Existing research has focused on capital investment decisions (Dixit and Pindyck 1994; Pindyck 1991) and firm or technology acquisition decisions (Folta and Leiblein 1994; Hurry, Miller and Bowman 1992; Kogut 1991). Given the importance of product development as a source of new business opportunities, the application of the options framework for the management of R&D activities has received surprisingly little attention. While it is understood that decisions concerning R&D that create and preserve options are of value to the firm (Bowman and Hurry 1993; Dixit and Pindyck 1995; Kogut and Kulatilaka 1994) and that uncertainty can actually increase a project's value (Morris, Teisberg and Kolbe 1991), the relationships among project and firm characteristics that determine option value remain unexplored and real options approaches have only had limited acceptance (Hartmann & Hasan, 2006). This paper asks the question: What drives option value for an organization?

An innovation option represents an opportunity for a firm to realize the commercial potential of a new technology by translating it into a novel product or service. During the course of development, information concerning the technical and market feasibility of a project is revealed. The firm has the opportunity to exploit the accumulated information about the potential net benefits of a project before committing partially or completely irreversible resources to commercialize the technology.[1] In its most simple form, an innovation project should be viewed as a sequence of two decisions; a decision to gather information about the project's prospects (experimentation stage) followed by a decision to commercialize the project (implementation stage). With this sequence of events, investment decisions for these innovation options should differ from the standard investment criteria associated with other productive assets (Roberts and Weitzman 1981; Smith and Nau 1995).

The flexibility to delay making investment decisions involving commercialization activities, such as investments in specialized plant and equipment or introductory marketing campaigns, limits the appropriateness of standard investment criteria. For example, a computer software firm might initiate numerous seemingly negative NPV projects to develop new application programs given that it maintains the flexibility to abandon any individual project if

[1] Thus, *exploiting* an innovation option is defined as the realization of additional expected value by developing the project to a later stage. The *commercialization* of an innovation option would involve the actual production of goods or delivery of services.

prospects appear unfavorable after early development steps are conducted. Under these circumstances, the firm will find it worthwhile to finance the first steps to gather preliminary information even on those projects that initially seem least attractive.

We can combine ideas from statistical decision theory with the concept of firm capabilities. While a number of authors have prescribed that R&D projects should be treated as options (e.g., Morris, Teisberg and Kolbe, ibid), the mechanics of how to do so remain unclear because initial project variance is treated as the primary contributor to option value.[2] We examine additional project and firm-level variables to develop an analytic model of how firms can best manage their investments in innovation opportunities.

We present a basic dyadic model that illustrates how a firm can maximize the value of its innovation efforts by investing in projects that match its organizational capabilities. First, we identify characteristics that determine the potential option value of an innovation project. We then consider firm capabilities that permit the firm to exploit high option value opportunities. We specifically investigate a firm's *learning capability* and *abandonment capability*. We find that an appropriate fit between project and firm characteristics will permit the firm to appropriate the option value associated with its innovation opportunities. In conclusion, we contend that firms that are endowed with projects that tend to have high potential option value can improve their innovation processes by investing in firm capabilities that allow them to exploit their opportunities. On the other hand, firms that are endowed with projects that have low potential

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[2] For example, Sykes and Dunham (1995) suggest identifying *critical assumptions* (those factors whose uncertainty can lead to a significant negative project NPV) as a risk management technique. They advocate setting tasks and milestones for uncertain ventures so as to achieve maximum learning (reduction in the range of uncertainty) per dollar. Our model captures this concept of maximum learning per dollar more explicitly, in a way that is consistent with Bayes' rule and with the actual loss function faced by the investor.

option value may be better off shedding potentially expensive, but relatively valueless, capabilities.

THE ONE-SHOT VS. OPTION DECISION FRAME

In our model, we translate qualitative characteristics of the firm and the project into quantitative descriptions of the determinants of project value, from which option value is computed (see figure 1). In determining how option value changes as firm and project characteristics change, we identify simple, testable explanations for differences in firm performance. This modeling approach is flexible since future extensions can quantify the impact on firm option value of any number of different capabilities and characteristics. Since the same units will be used to value projects and value organizational capabilities, our framework provides a set of tools for R&D management decisions.

We consider two possible cases of a firm evaluating its decision concerning an innovation project.

CASE A — First, consider a firm endowed with a project, but with no option to delay decisions about implementation until a later date. The firm can decide to go ahead with the project or to abandon the project at time t_0 only. We call this case the *one-shot decision frame*, and refer to the expected value of the project to the firm here as the *intrinsic value* (V_1). In practice, such a firm would use a rule that depends on *a priori* information; the firm might, for example, approve projects that exceed a pre-set hurdle rate adjusted for risk. If proceeding with the project has positive expected value (EV), then V_1 is the project EV, otherwise the firm would reject the project and $V_1 = 0$.

CASE B — The firm can decide to go ahead with the project or to abandon the project either at time t_0 or later at time t_f, when more information is available. We call this case the *option decision frame*, and refer to the expected value of the project to the firm here as the *potential project value* (V^*_2). The firm is again assumed to act to maximize its EV.[3] We will often refer to the value of the option implicit in *CASE B*. We call this the *potential option value*, $V^*_{(2-1)} = V^*_2 - V_1$.

In practice, we may observe that a firm treats certain investments as one-shot decisions, and others as option-type decisions. What might determine the type of behavior observed? In *CASE A*, the firm's observed behavior could be due to the fact that the project has no potential option value or the fact that the firm is not in a position to realize the potential option value of the project.[4] In *CASE B*, we can infer that there is both an option and the firm is in a position to exploit it.

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[3] The firm is assumed to maximize the following: Max[0, E(Max[0-abandonment costs at t_f , E(project value at t_f)])]. For simplicity, we have no discounting and use EV instead of expected net present value.

[4] The firm would not be able to *exploit* the innovation option because it lacked the capability to reveal information about the project through development efforts. For our basic model, we assume that projects or innovation options are non-transferable. The transferability of a project (project characteristic) and the capability to engage in inter-firm R&D transactions (firm capability) are factors that can be added to future extensions of this model.

Project Factors that Contribute to Option Value

Before we analyze the factors that determine the magnitude of a project's option value, we define the following terms.

x = the ultimate value of the project if it is pursued
μ_0 = E(x) at t_0 = EV of the project if the firm proceeds at t_0
μ_f = E(x) at t_f = EV of the project at t_f.

We assume that at time t_0 , the ultimate value of the project, x, is normally distributed with mean μ_0 and variance U, where U = σ_0^2. At time t_f , x is normally distributed with mean μ_f and variance σ_f^2; this implies some uncertainty may remain at t_f. Finally, at time t_0, μ_f is normally distributed with mean μ_0 and variance σ_{0f}^2 (*pre-posterior variance* of μ_f).

We assume normally distributed variables and a constant rate of information revelation (resolvability, denoted as R) for a project:

$$\sigma_0^2 = \sigma_{0f}^2 + \sigma_f^2$$
$$R = (\sigma_f^{-2} - \sigma_0^{-2}) / (t_f - t_0).$$

In order to simplify exposition, let us now assume that

$$(t_f - t_0) = 1, \text{ so } R = (\sigma_f^{-2} - \sigma_0^{-2}),$$

in other words, R is the percentage of uncertainty that can be resolved prior to the final decision point (t_f). It is useful to include R as the parameter for a temporal rate to leave the model open to future extensions. R can be thought of as the upper bound on the rate of increase in precision (inverse of variance) in the estimate of the project's value (i.e., how fast uncertainty can be resolved). It is a permanent project characteristic that does not change when t_0 and t_f are varied, nor does it vary across firms. If not all of the uncertainty is resolved before the decision, then not all the volatility is actionable (Lewis et al, 2008) and able to be captured as option value.

We define

$z = \mu_0 / \sigma_{0f}$
$V_1 = \text{Max}(\mu_0, 0)$.

The term z is the standardized value of the mean of the distribution; it serves as a useful measure of whether, in practical terms, the decision is more or less of a long-shot. Now, the upper limit on the option value, (*potential option value*) only depends on certain project characteristics and is determined by the equation:

$$V^*_{(2\text{-}1)}\ (\mu_0, U, R) = V_2^* - V_1 = E[\max(x, 0)] - \max[0, E(x)].$$

Where x is normally distributed with mean μ_0 and variance = $U - [U/(1-R)]^{-1}$, and H(z) refers to the standard normal hazard function[5] evaluated at z, we get

$$V^*_{(2\text{-}1)} = \sigma_{0f} \bullet H(z), \qquad (1)$$

This value is increasing in σ_{0f} and decreasing in the absolute value of μ_0, as shown in charts 2 and 3. These relationships restate the conclusions of Raiffa and Schlaifer (1961).

By definition, when $V_{(2\text{-}1)}^* = 0$, it makes no difference whether a firm uses the option decision frame or the one-shot decision frame. However, when $V_{(2\text{-}1)}^* > 0$, viewing the project as a one-shot decision could mean a forfeit in expected value; the potential option value component

[5] The hazard function for a probability distribution evaluated at the point z is the ratio of the probability density at z divided by the cumulative probability at z.

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of the project would go unrecognized. In fact, the higher the potential option value, the greater the opportunity that may be lost.

We find that there are relationships among the different project characteristics as they relate to potential option value. For example, increasing pre-posterior variance increases option value more for projects with mean near 0 than projects with mean far from 0; and similarly, shifting a project's mean value toward 0 increases potential option value more for high variance projects than for low variance projects.

Equation (1) demonstrates that in our model the only three project characteristics are needed to determine potential option value, and therefore the appropriate decision frame. These are *mean* (μ_0, ranging from $-\infty$ to ∞) and resolvable *uncertainty* (σ_{0f}^2), which can be determined from the initial uncertainty ($U = \sigma_0^2$, ranging from 0 to ∞) and the *resolvability* of that uncertainty (R, ranging from 0 to 1). Mean, initial uncertainty, and resolvability are sufficient to determine option value because R and U determine σ_f , while U and σ_f determine σ_{0f}. Specifically, the potential option value component of an innovation project is high when:

- Mean is close enough to 0 that there is a reasonable likelihood that the firm would change its decision on the basis of what it learns during the experimentation stage.

- There is uncertainty to resolve. Prior standard deviation must be large enough that under some circumstances, a firm would want to change its decision after experimentation.

- The uncertainty must be resolvable. Posterior standard deviation must be lower than prior standard deviation, or else the presence of uncertainty merely implies risk that cannot be avoided.[6]

[6] It is possible to have two projects with identical resolvable uncertainty values, σ_{0f}, one of which arises from high values for both σ_0 and σ_f , and the second from low values for both σ_0 and σ_f. Since resolvable uncertainty rather than initial uncertainty determines option value, both projects, all else being equal, have the same option value component. Thus, it is not enough to merely state that projects with high uncertainty should be viewed through the option frame; it is the resolvability of uncertainty, as well as the uncertainty itself that drives potential option value.

Firm Characteristics and Option Exploiting Capabilities

Firms in our basic model have two characteristics: *Abandonment capability* and *learning capability*. Abandonment capability is incorporated into the model simply as the cost the firm pays to abandon the project at t_f.[7] The lower the cost to drop out of projects, the greater the firm's abandonment capability. We denote this capability as A, and define it as the incremental cash flow[8] to the firm when it drops out of a project. A is assumed to be negative, ranging from $-\infty$ to 0.

For learning capability from experimentation, we define L, with values that can range from 0 to 1. A value of 1 corresponds to a perfect firm that resolves all the uncertainty that can be resolved between t_o and t_f. The actual effectiveness of experimentation for a given firm on a given project is simply $(R \bullet L)$, that is, the product of the resolvability of the uncertainty for the project and the firm's learning capability about (resolvable) uncertainty. We shall denote the values that depend on L by using it as a superscript, to distinguish those values from what they would be for the perfect firm (potential values) which are denoted with the superscript "*".

The firm's learning capability is a reflection of its technical expertise as well as its organizational skills at absorbing and applying new information. Making an analogy between

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[7] In a more general model, we could also include the cost of experimentation, which would allow L to be treated directly as a choice variable that could be changed for specific projects (e.g., working staff overtime). For the purpose of discussing permanent capabilities, we assume instead that there is no incremental cost to experimentation, but rather that the effectiveness of that experimentation is a firm characteristic. The abandonment capability parameter is specifically the additional cost incurred by abandoning the project at t_f rather than any sunk costs incurred prior to t_f.

[8] It is conceivable that a project would have a positive salvage value, but it is unlikely this would exceed the investment in the experimental stage which is considered lost if the project is abandoned, and capitalized if the project is pursued. A is the incremental amount written off.

information revelation and sampling,[9] we define the increase in precision (σ^{-2}) between t_0 and t_f for the firm with learning capability, L, as

$$\Delta(\sigma_{0f}^{-2})^L = L \bullet \Delta(\sigma_{0f}^{-2})^*.$$

Since precision is additive, we can paraphrase this as:

$$(\sigma_f^{-2})^L = \sigma_0^{-2} + \Delta(\sigma_{0f}^{-2})^L. \tag{2}$$

Because the pre-posterior variance and the posterior variance must sum to the prior variance, we also have,

$$(\sigma_{0f}^2)^L = \sigma_0^2 - (\sigma_f^2)^L.$$

If we modify our definition of z such that,

$$z\,(L, A) = (\mu_0 - A) / \sigma_{0f}^L,$$

we find that the firm's realized project value is

$$V_2\,(L, A) = \sigma_{0f}^L \bullet H(z\,(L, A)) + V_1 + A. \tag{3}$$

And therefore, the firm's *realized option value*, $V_{(2\text{-}1)}\,(L, A) = E[\max(x, A)] - \max[0,E(x)]$. Under our assumptions, x is normally distributed with mean μ and variance σ^2, where $\sigma^2 = U - [(1\text{-}L)/U + LU/(1\text{-}R)]^{-1}$. Analogous to (1), this is

$$V_{(2\text{-}1)}\,(L, A) = \sigma_{0f}^L \bullet H(z\,(L, A)) + A. \tag{4}$$

[9] In sampling, adding a single sample increases precision by the inverse of the sample standard deviation squared; the latter is analogous to R in our model. The increase in precision per dollar is this value divided by the cost of a sample. A more efficient sampler would simply be one with a lower cost of sampling. This way of quantifying the

Realized project value and option value both depend directly on μ_0 , $\sigma_{0f}{}^{L}$ and A. As a check, when the firm has perfect capabilities, the realized value is the same as the potential value (i.e., $V_{(2\text{-}1)}{}^{*} = V_{(2\text{-}1)}(1, 0)$). The comparative statics of the model (with results similar to those in Keisler, 2004) provide insights about the relationships among project and firm characteristics. First, we observe that $\sigma_{0f} = (RUL)^{0.5}$, and that this is the only impact of R, U and L on realized option value. This implies that a given percentage change in R, U or L would have the same impact on option value, and that the impact on σ_{0f} of an increase in L is larger when R and U are larger.

Where $V_{(2\text{-}1)}(L,A) > 0$, several facts are known about the value of sample information (analogous to option value) in two-act linear loss problem with normal prior distributions (for details, see Raiffa and Schlaifer 1961). The impact on option value of an increase in σ_{0f} starts low and approaches a constant slope as σ_{0f} increases. Also, the impact of a change in σ_{0f} on realized option value is highest when z is nearest 0. The impact on z of a change in A is the same as the impact on z of the same absolute change in μ_0 , while there is an additional one to one increase in realized option value for increases in A.

These observations can be summarized as several theorems, for which proofs are given in the appendix:

T1: A firm's realized option value $V_{(2\text{-}1)}$ is positively related to its abandonment capability (A).

T1a: The magnitude of the relationship in H1 is positively related to project uncertainty (U) when abandonment capability is low, and negatively related when abandonment capability is high.

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real-world characteristics corresponding to R and L allows the use of statistical decision theory to describe them, thus creating a rich framework for theoretical investigation.

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T1b: The magnitude of the relationship in H1 is positively related to project resolvability (R) when abandonment capability is low, and negatively related when abandonment capability is high.

T1c: The magnitude of the relationship in H1 is negatively related to project mean (μ).

T1d: The magnitude of the relationship in H1 is positively related to the firm's learning capability (L).

T2: A firm's realized option value is positively related to its learning capability (L).

T2a: The magnitude of the relationship in H2 is positively related to project uncertainty (U).

T2b: The magnitude of the relationship in H2 is negatively related to project resolvability (R), if uncertainty (U) is varied to maintain a constant potentially resolvable uncertainty, U(1-R) = k.[10]

T2c: The magnitude of the relationship in H2 is negatively related to absolute value of project mean (μ).

T2d: The magnitude of the relationship in H2 is positively related to the firm's abandonment capability (A).

It is important to note that the option pricing approach for financial securities can be considered a special case of our model. The term μ is comparable to the strike price less the current price, however, resolvability (R) is trivial in the case of financial assets. In the case of financial call options, the quantity about which uncertainty is resolved is the price of the underlying asset at a given point in time. Since the market updates such information over time, all parties are equally capable of assessing the market value of a share price at the appropriate date. Even though there will be uncertainty about the future value of the asset, the uncertainty of the asset at the exercise date is completely resolved.

[10] As R increases, UR = R(1-R)/k = (R - R^2)/k, the coefficient on L in determining σ_{0f} , increases more slowly for

Furthermore, the literature on option pricing for financial securities does not generally treat abandonment as a variable quantity as it is in this innovation option model.

The costs of letting a financial call option expire are trivial when compared to abandoning innovation projects, and do not vary significantly among financial market traders.

A simulation of the model provided a means to examine numerical examples with varying firm capabilities and project characteristics. The more interesting results are described below.

Learning capability. As chart 1 and chart 2 show, increasing variance of a project does not necessarily add to its expected value to an option oriented firm. Only increasing the uncertainty that can be resolved by the firm adds value. Firms can maximize expected value by (a) selecting projects to increase the initial uncertainty while holding the final uncertainty relatively constant, and (b) improving their learning capability to decrease the final uncertainty.

The resolvable uncertainty facing the firm is best described by our term σ_{0f}^{L}, and this is what should be increased. Learning capability is particularly interesting from a strategic perspective. It is possible to have two projects with identical *theoretically resolvable uncertainty* (σ_{0f}*) one of which arises from higher values for both σ_0 and σ_f , and the second from lower values for both σ_0 and σ_f. In the first case, the uncertainty is of a more difficult nature; the incremental value of learning capability is seen on chart 2 as the difference between the option value at learning capability L = 1 and L < 1. Since both curves have the same value for L = 1 (when the firm resolves all resolvable uncertainty, regardless of the difficulty of resolution), the fact that the second curve is lower implies that learning capability is more valuable when resolvability is

greater values of R, diminishing to 0 as R approaches 1.

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relatively low. In the extreme, L = 0 implies that the firm has no learning capability, and therefore receives no value added from the option. In fact, a firm with abandonment cost greater than 0 and for which L = 0, would always abandon projects with negative expected value at time t_0 rather than wait to do so at t_f.

Abandonment capability. Abandonment capability improves a firm's ability to realize option value, and it increases it most when (a) the likelihood that the project will be abandoned after the experimentation stage is fairly high, and (b) the project is attractive enough that there is value in going through with experimentation. The value of abandonment capability is seen on chart 3 as the vertical gap between the two curves. In particular, as the cost of abandonment becomes arbitrarily large, no project will be pursued which has negative prior expected value, since none of these projects will be abandoned at t_f. This is the case of the firm that has no abandonment capability and therefore views all project investments as one-shot decisions. As the cost of abandonment goes to 0 (perfect abandonment capability), all projects will be pursued at least until t_f and abandoned then only if the implementation stage expected value (μ_f) is negative. This corresponds to the firm at the other extreme, that views all projects as options.

Interestingly, the value of abandonment capability is asymmetric in terms of project mean value. Projects with a mean value near 0 are fairly likely to be abandoned. Projects with a high mean value are unlikely to be abandoned regardless of abandonment cost, and so abandonment capability is of less value.

It is also clear from our model that abandonment capability is of higher marginal value for projects with high pre-posterior uncertainty. This implies that the marginal value of abandonment capability is greater when firms also have greater learning capability. For this reason, it is conceptually convenient to combine both capabilities as the *option exploiting capability* of the firm. Figure 2 illustrates the complementary nature of abandonment and learning capabilities.

MATCHING PROJECT CHARACTERISTICS AND FIRM CAPABILITIES

The organizational capability to take advantage of the flexibility afforded by certain investment opportunities is without doubt of value (Kogut and Kulatilaka 1994; Teece, Pisano and Shuen 1992). It is clear from our model, however, that the value of a firm's *option exploiting capability* will depend on the availability of innovation projects with suitable option value. Firms operating in a technical and market environment with numerous innovation opportunities with high option value components can more easily recoup investments in abandonment capability and learning capability than firms facing lower option value projects. Figure 3 illustrates that the option decision frame is most appropriate for high option value projects owned by firms with high option exploiting capability (quadrant 2). The one-shot decision frame is appropriate in the three remaining quadrants.

It is critical to note that the need to match capabilities and opportunities is based on an assumption that projects cannot be traded in efficient markets for innovation options. A relevant market could exist if there are other firms whose abandonment capabilities, learning capabilities, or even commercialization capabilities are superior to the original owner of the project. The use of such markets would, of course, depend on the transaction costs involved with transferring innovation related knowledge through contractual arrangements. Our model could be extended to allow for such markets by incorporating the expected price received for transferring the innovation option into our abandonment capability variable (A).

Firms in quadrants 1 and 4 have a mismatch between their capabilities and their opportunities. In quadrant 1, the firm's option exploiting capabilities are under-utilized. Such firms could seek higher option value projects or reduce their investments in option exploiting capabilities and move into quadrant 3. In quadrant 4, the option value of innovation projects goes unrecognized. These firms would miss opportunities for profitable investments and might benefit from investing in their option exploiting capabilities. Firms in quadrant 4 may also have an opportunity to sell their high option value projects to other organizations with the appropriate capabilities to recognize the value of such opportunities. Thus, firms can employ both types of levers—internal capability management and project selection—to achieve an efficient resource balance that does not lead to resources wasted on projects where they are not needed, but also does not lead to losses on projects that another firm may have avoided.

Our analysis also demonstrates that the drivers of option value (e.g., mean, uncertainty, resolvability) and the drivers of option exploiting capability (e.g., abandonment capability, learning capability) should also match each other. If a firm faces large and difficult to resolve uncertainty, then its investment in option exploiting capability should be concentrated in learning capability. If it faces projects with mean generally near 0, its investment in option exploiting capability should be concentrated in abandonment capability. Because of the complementarity between abandonment capability and learning capability, firms should tend toward high levels or low levels of both capabilities.

Our simple model offers insights about the complex inter-relationships that affect how successful a firm might be in extracting option value from its innovation opportunities. The primary implication of this modeling exercise is that a research manager's approach to evaluating projects should depend on both the character of the opportunity and the character of the firm in question. Particularly in high option value environments, firms that can effectively manage market exploration, technical innovation, and other organizational learning activities have a decided advantage in the race to accumulate resources and skills for competitive advantage (Baldwin and Clark 1992; Dierickx and Cool 1989). Therefore, it is important for firms to know what type of option environment they operate in, and what capabilities they need to bring to exploit their particular circumstances.

An Example

The emergence of new biotechnology firms (NBF's) in the pharmaceutical industry provides a useful context to examine the implications of our analysis. Pharmaceutical industry participants are endowed with numerous high option value innovation opportunities associated with recent advances in biotechnology research. Firms can avoid significant costs associated with new drug introductions by abandoning projects if early stage research and preliminary clinical trials reveal unprofitable prospects.

It is evident that the value of biopharmaceutical R&D opportunities have an extremely high option value component.[11] These projects have a relatively low expected mean and high uncertainty that is in large measure resolved during preliminary research procedures. Do the numerous new biotechnology firms (NBFs) that have recently entered the industry have an advantage over incumbent pharmaceutical firms in this high option value environment?[12]

Firm Option Exploiting Capabilities. Small entrant biotechnology firms, most started through the entrepreneurial efforts of academic researchers, have the technical strength to efficiently conduct the experimentation stage of innovation (i.e., high *learning capability*). NBFs also exhibit high *abandonment capability*. Since researchers at these entrepreneurial firms typically have several projects "on the back burner," research attention can be quickly shifted to the most promising projects as information is gained about each project. The research function at biotechnology firms thus resembles a constantly shifting network of projects; a project that appears promising would attract researchers while a failing project would quickly lose support from internal scientists. Furthermore, an NBF's need to attract external sources of capital on an almost continual basis[13] improves their abandonment capability; many biopharmaceutical projects are abandoned when the NBF involved fails to convince its venture capital backers or

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[11] Depending on the project, outcomes might be better modeled not with a normally distributed value, but rather as a project that can take either a high or low value. The uncertainty in this case would be expressed as the probability of receiving the high value. Whatever the firm's initial estimate of the probability that it will receive the high value, this estimate would typically move closer to either 0 or 1 at time t_f. The fundamental arguments about firm capabilities and project characteristics would remain unchanged from our conclusions using the normal distribution.

[12] New biotechnology firms are very active in biopharmaceutical development. In 1991, the Pharmaceutical Manufacturers' Association reported that new biotechnology firms conducted early stage development work for approximately two-thirds of the 132 biopharmaceutical projects under development for the U.S. drug market.

[13] For example, Sahlman (1990) notes that venture capitalists, an important source of funds for NBFs, commonly stage their investments. He observes that "By staging capital the venture capitalists preserve the right to abandon a

public equity market participants of the logic of additional investments in a project with disappointing preliminary results.

Large established pharmaceutical firms, with their strengths in traditional chemical-based disciplines, may be at a disadvantage in the new biology-based biopharmaceutical field (Pisano 1990); this can be interpreted as a lower *learning capability* relative to NBFs. The large size of the R&D function at most pharmaceutical firms requires a formal resource allocation system that may hinder their *abandonment capabilities*.[14] In some corporate cultures, a failed experiment is viewed as a failure of the experimenter; in such environments, abandonment will in practice be more difficult and costly. Ironically, large internal sources of capital to fund research may serve to limit a pharmaceutical firm's *abandonment capability*; unlike NBFs that are at the mercy of the external financial markets, a large firm's internal resource allocation procedure may not respond as quickly to information revealed during the experimentation stage of development.

The high option exploiting capabilities of NBFs may help explain their intensive activity in high option value biopharmaceutical projects. We hypothesize that the efficient production and marketing capabilities of established pharmaceutical firms are more appropriate for implementation (drug commercialization) activities. Thus, incumbent pharmaceutical firms might be better suited to buying the rights to drugs in latter stages of development from NBFs

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project whose prospects look dim. The right to abandon is essential because an entrepreneur will almost never stop investing in a failing project as long as others are providing capital" (Sahlman 1990, pp. 506-507).

[14] In fact, finance executives at Merck & Co., an established pharmaceutical firm, recognize the inadequacies of their traditional net present value analysis and have adopted option analysis for research projects (Nichols 1994). It is unclear, however, how easily Merck will be able to build their option exploiting capabilities; abandonment capability may be very difficult to develop in a large organization that spends over $2 billion in R&D and capital expenditures per year. It is interesting to note that Merck and other pharmaceutical companies continue to enter into numerous interorganizational arrangements with NBFs to gain access to early-stage research projects.

(when the option value component of the project diminishes), rather than developing early stage projects internally.

CONCLUSION

The model presented in this paper identifies the specific characteristics that determine the option value in an investment opportunity. These firm capabilities and project characteristics, for which our model identifies fit and value, have precise definitions that can be quantified borrowing established techniques from decision analysis. While an uncertain outcome is a necessary condition for the creation of option value, our model demonstrates the importance of the *resolvability* of that uncertainty. To capture the inherent option value of a given innovation project, however, a firm must be able to reveal information about its prospects through development efforts and have the flexibility to act in a meaningful way information acquired. Learning capability and abandonment capability represent valuable organizational resources that can be the basis of strategic advantage.

The framework proposed here is a starting point for addressing innovation-related capabilities, and it could be extended to address a number of more detailed questions: how long and how intensely should firms pursue the experimental stage before committing to implementation?; under what conditions would firms specialize in either experimentation or implementation activities?; how should a firm manage interrelated projects within a portfolio?; how much should firms invest in option exploiting capabilities?

The globalization of markets and the quickening pace of technological advance have increased the volatility of many industries. In this environment, a firm’s ability to manage the uncertainties involved in innovation and new product development may determine, in large part, its success. Understanding the role firm capabilities have in realizing the potential option value locked-up in innovation opportunities will aid firms in making long-term investments in such critical organizational resources.

APPENDIX

This appendix provides the analytical support for the hypotheses in the main text. We will use the following notation to simplify the equations in this section:

$\sigma = (RLU)^{1/2}$
$\mu = \mu_0 - A$
$z = \mu/\sigma$

To remove ambiguity from the partial derivatives in this section, we also use the notation

$V(\bullet) = V_{(2\text{-}1)}(R,L,U,A, \mu, \mu_0, \sigma)$,

to define V as a function of the parameters (•) that are allowed to vary, with all other parameters held fixed. Finally, f(z) denotes the standard unit normal probability density function evaluated at z (i.e., $f(z) = \exp(z^2/2)/(2\pi)^{1/2}$) and G(z) denotes the standard unit normal right tail cumulative density function evaluated at z.

Preliminary Facts

Recalling that option value is equal to max(0, G(z) + f(z)-z(G(z)), we note that for A = 0,

$V = \sigma\int_z^{\infty} xf(x)dx = \sigma (f(z) - zG(z))$ (see, Raiffa and Schlaifer 1961).

For $A \neq 0$, z is changed, and the payoff is shifted so that,

$V = \max(0,\sigma(f(z) - zG(z)) + A)$.

We also note for later use that

$d\sigma/dR = R/2\sigma$,
$d\sigma/dU = U/2\sigma$,
$d\sigma/dL = L/2\sigma$,
$dz/d\sigma = 1/(\mu)$,
$dz/d\mu = 1/\sigma$, and
$df/dz = -zf(z)$.

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It is important to note that the following analyses assume V > 0 so that the option frame is appropriate.

Theorems and Proofs

T1: $dV(A, \mu, z)/dA > 0$

proof:

$dV(A, \mu, z)/dA = \partial V(A, \mu, z)/\partial A + \partial V(\mu, z)/\partial \mu \, \partial \mu/\partial A,$
$\partial V(A, \mu, z)/\partial A = 1,$
$\partial \mu/\partial A = -1,$
$\partial V(\mu, z)/\partial \mu = \sigma\, df(z)/d\mu - \sigma dz/d\mu\, (G(z)) + \sigma z dG(z)/d\mu$
$= df(z)/dz - dG(z)/dz + z\, dG(z)/dz.$

Because $dG(z)/dz = -f(z)$, this reduces to

$df(z)/dz + f(z) - z\, f(z) = -f(z),$

the whole derivative becomes $1 + f(z)$, which is greater than 0.

Note, for $\mu_0 > A$, the G term must be replaced by F, the left tail cumulative probability, but the first derivative of option value with respect to A is still positive.

T1a: $\partial^2 V(A,U)/\partial A \partial U > 0$ when $A < \mu_0$, and $\partial^2 V(A,U)/\partial A\, \partial U < 0$ when $\mu_0 < A$.

proof:

$\partial V(A,U)/\partial A = G(z)$, i.e. the probability that the project will be abandoned.
$\partial^2 V(A,U)/\partial A\, \partial U = \partial/\partial U\, (\partial V(A,U)/\partial A)$
$= \partial G(z)/\partial U$
$= (U/2\sigma)\, \partial G(z)/\partial \sigma$
$= (U/2\sigma)\, (-f(z))\, \partial z/\partial \sigma$
$= (U/2\sigma)\, (-f(z))(-(\mu_0 - A))/\sigma^2.$

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Noting that $f(z) > 0$, $U > 0$ and $\sigma > 0$, we can see that the derivative is positive only when $(\mu_0 - A) > 0$. Of course, if the one shot frame is appropriate, then $\partial V(A,U)/\partial A = 0$.

T1b: $\partial^2 V(A, R)/\partial A\, \partial R > 0$

proof:

Same as T1a only replace U with R.

T1c: $\partial^2 V(A, \mu_0) \,/\, \partial A \partial \mu_0 < 0$

proof:

$\partial^2 V(A, \mu_0) \,/\, \partial A \partial \mu_0 = \partial/\partial \mu_0 \left(\partial V(A, \mu_0) \,/\, \partial A\right)$

We know that

$\partial V(A, \mu_0) \,/\, \partial A = G(z)$

because the marginal value from an incremental increase in A is

simply the probability that the project will be abandoned. Knowing also that an increase in μ_0 makes abandonment less likely, we get

$\partial/\partial \mu_0 \,(G(z)) = \partial G(z)/\partial z \;\partial z/\partial \mu_0 = -f(z)/\sigma < 0.$

T1d: $\partial^2 V\,(L,A,\sigma,\mu)/\partial A \partial L > 0$ when $A < \mu_0$

proof:

Same as T1a only replace R with L.

T2: $dV(L,\sigma)\,/dL > 0$

proof:

$dV(L,\sigma)/dL = \partial V(L,\sigma)/\partial L + \partial V(L,\sigma)/\partial\sigma\ \partial\sigma/\partial L$

and that $\partial V(L,\sigma)/\partial L = 0$ (when σ is held constant), $\partial V(L,\sigma)/\partial\sigma > 0$, and $\partial\sigma/\partial L = RU > 0$.

T2a: $\partial^2 V(L,U,\sigma) /\partial L\, \partial U > 0$

proof:

$\partial^2 V(L,U,\sigma) /\partial L\, \partial U = \partial/\partial U\ \partial V(L,U,\sigma) /\partial L$
$= \partial/\partial U\ \ \partial V(L,U,\sigma)/\partial\sigma\ \partial\sigma/\partial L,$
$= \partial/\partial U\ \ (\partial V(L,U,\sigma)/\partial\sigma\ )\ \partial\sigma/\partial L +\ \ \partial/\partial U\ (\partial\sigma/\partial L)\ \partial V(L,U,\sigma)/\partial\sigma$
$= 0 + \partial/\partial\sigma\ \{[(f(z) - zG(z)) + z^2\ f(z)]\ L/2\sigma\}\ \partial\sigma/\partial U$
$\partial\sigma/\partial U =\ \ U/2\sigma > 0$, and
$\partial/\partial\sigma\ (\partial V(U,L,\sigma) /\partial L) > 0$.

Intuitively, increasing σ scales up the effect of L on σ, as well as decreasing the absolute value of z, which makes the option frame decision more likely to differ from the one-shot frame decision.

T2b: $\partial^2 V(R,U,L,\ \sigma)/\partial L\partial R < 0$ when U(1-R) is held fixed

proof:

$\partial^2 V(R,U,L,\ \sigma)\ /\ \partial L\ \partial R = \partial/\partial\sigma\ [\partial V(R,U,L,\ \sigma)\ /\partial L]\ \partial\sigma/\partial R$

If we add the constraint U(1-R) = k, i.e., that total resolvable uncertainty is held constant, we find that

$\partial\sigma/\partial R = -\ L^{1/2}\, k\,/(1-R^2)\ \ < 0$, and noting that

$\partial/\partial\sigma\ [\partial V(R,U,L,\ \sigma)\ /\partial L] > 0$ (shown in T2a),

the product of the two partial derivatives is less than 0.

T2c: $\partial^2 V(L, \sigma, \mu)/\partial L\partial\mu < 0$

proof:

$\partial^2 V(L, \sigma, \mu) / \partial L\partial\mu = \partial/\partial\mu\ (\partial V(L, \sigma, \mu)/\partial\sigma\ \partial\sigma/\partial L)$.

We know that

$\partial/\partial\mu\ (\partial V(L, \sigma, \mu)/\partial\sigma) < 0$

(because a greater value of μ implies a lower probability of exercising the option to abandon and smaller loss avoided by exercising the option), and that

$\partial\sigma(L)/\partial L > 0$,

so their product is also less than 0.

T2d: $\partial^2 V(L,A, \sigma, \mu) /\partial L\ \partial A > 0$ when $A < \mu_0$

proof:

$\partial^2 V(L,A, \sigma, \mu)/\partial L\ \partial A = \partial^2 V(L,A, \sigma, \mu)/\partial A\partial L$

then the proof is the same as H1a only we replace R with L.

Observations

When V = 0 (even the experimentation stage is not worth pursuing), the marginal value of

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changes in parameters are zero until the changes are large enough to change the decision maker from the one-shot frame to the option frame, at which point the results hold. Again when V = 0, it is interesting to consider the dual question of how much of a change in project characteristic or firm capability does it take to shift the decision maker to the option frame. For example, the abandonment capability a firm must have in order to pursue the option frame is decreasing in the amount of uncertainty and decreasing in the project mean, while the uncertainty required to shift the decision maker to the option frame is decreasing in A. We also observe that $\partial^2 V(L)/\partial L^2$ may go from positive to negative, depending on UR, in other words, the value of learning capability saturates at some point.

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Figure 1: Option Frame Decision Model

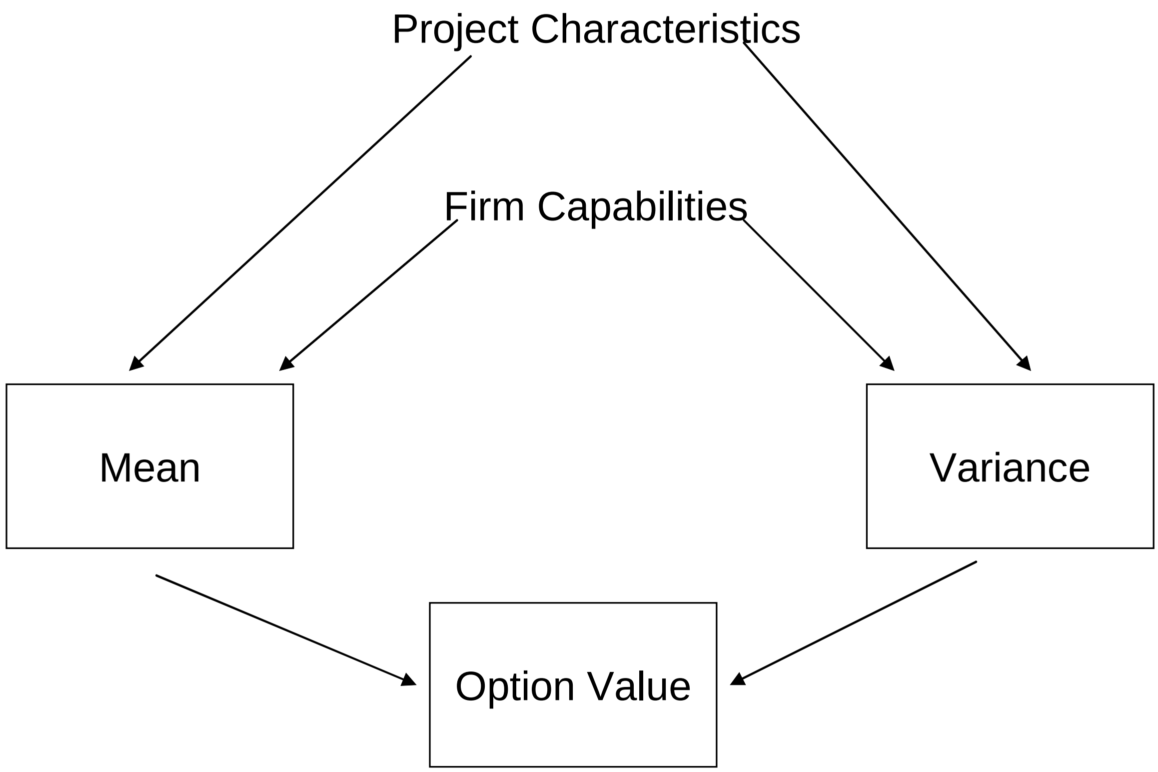

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Figure 2: Option Exploiting Capability

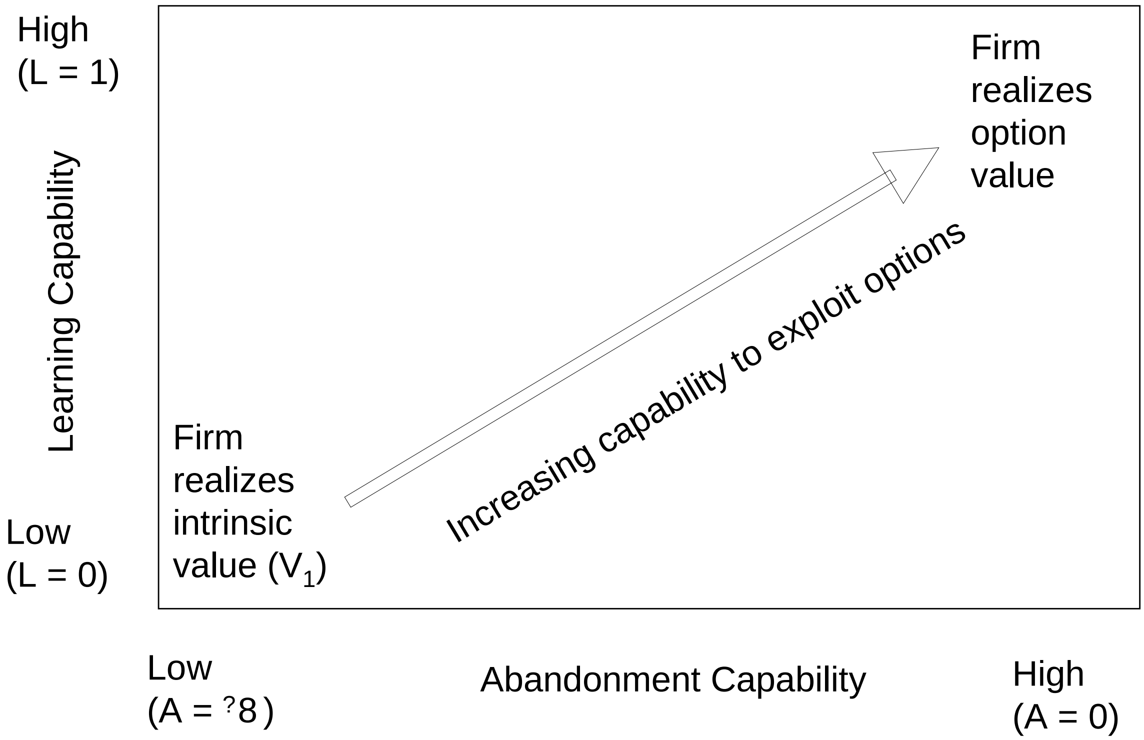


Figure 3: One-Shot versus Option Decision Frames

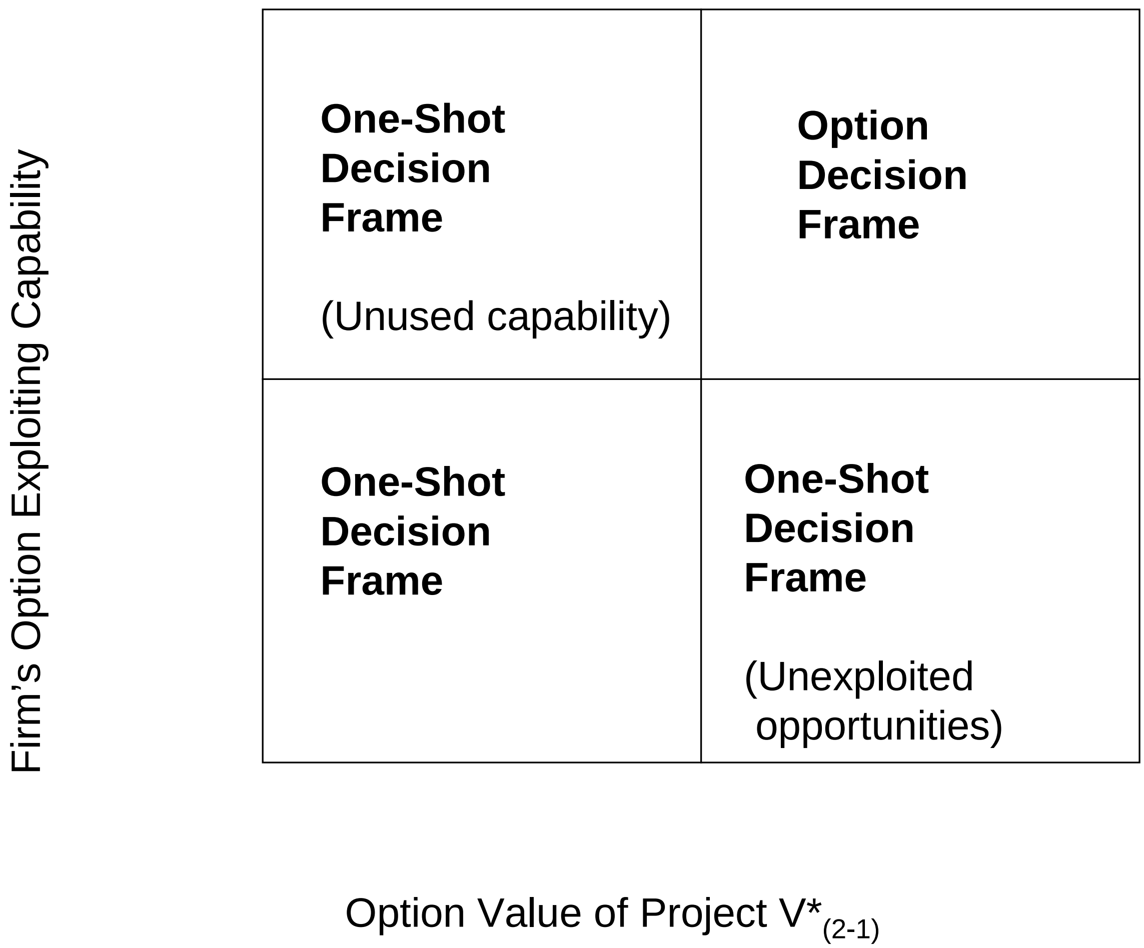
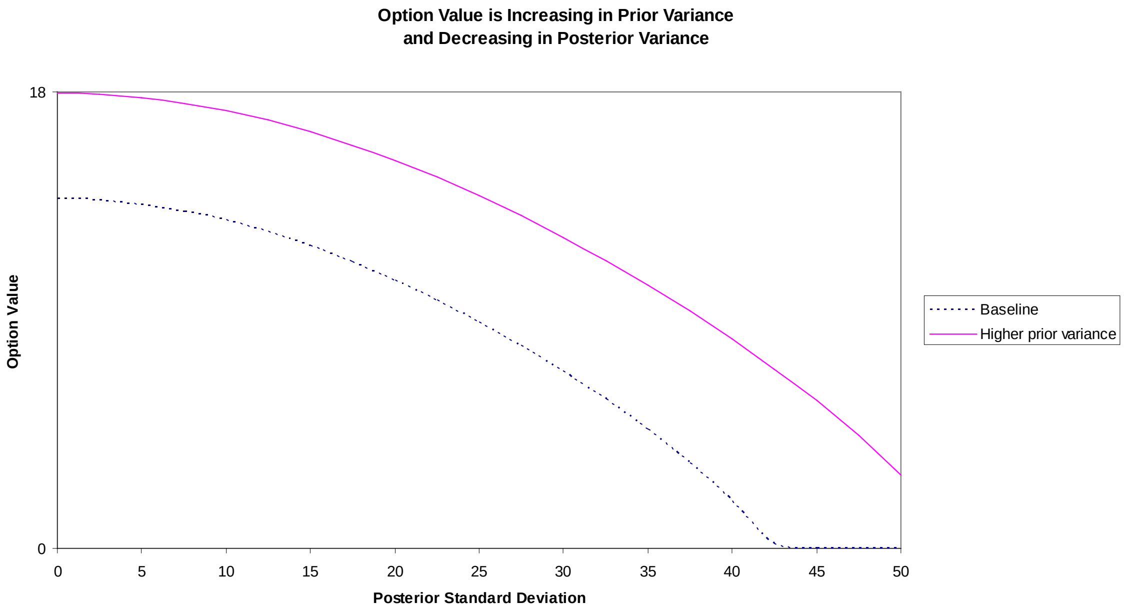


Chart 1:



Option Value is Increasing in Prior Variance
and Decreasing in Posterior Variance
18
0
Option Value
0
5
10
15
20
25
30
35
40
45
50
Posterior Standard Deviation
Baseline
Higher prior variance

Chart 2:

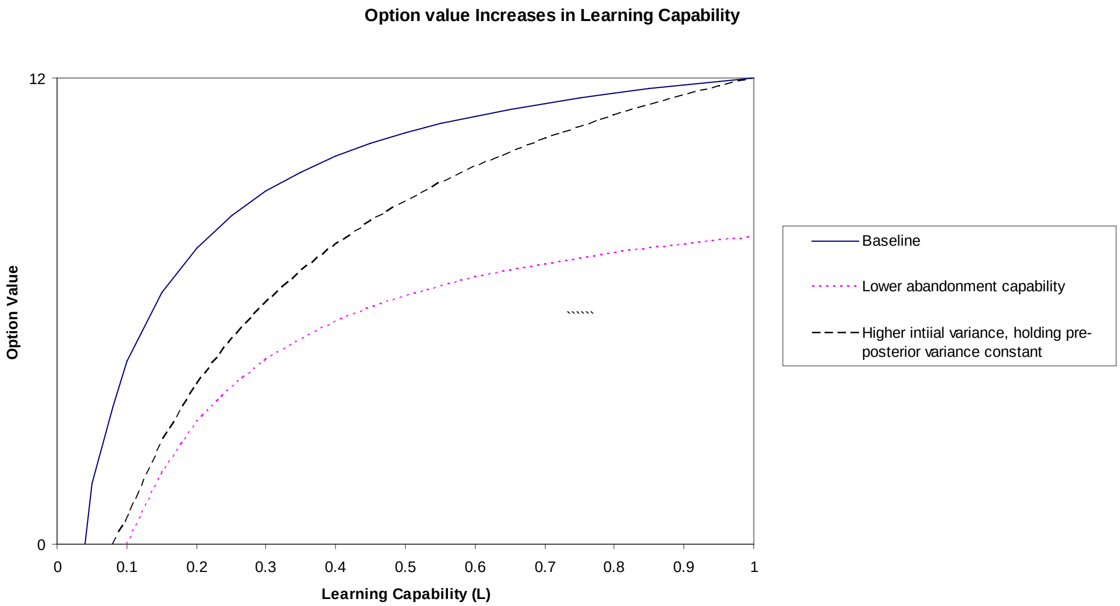


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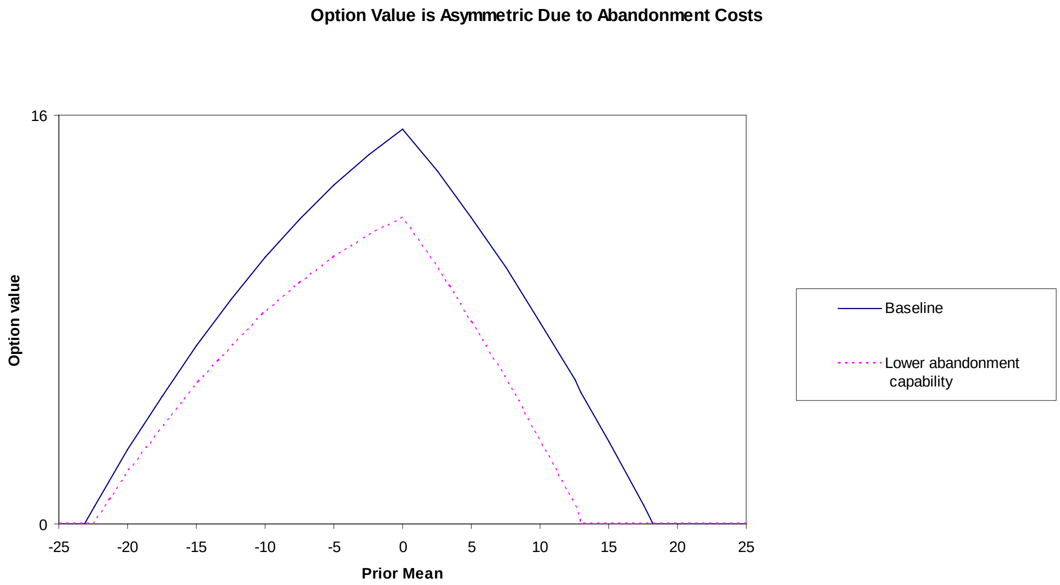
Chart 3:


Option Value is Asymmetric Due to Abandonment Costs
16
0
Option value
-25
-20
-15
-10
-5
0
5
10
15
20
25
Prior Mean
Baseline
Lower abandonment capability