CIRANO
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and Analysis on Organizations

VALUE CREATION, RISK MANAGEMENT AND REAL OPTIONS

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The Burgundy Reports

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1. Introduction

The real options approach considers strategic management and decision-making as a process aimed at actively reducing exposition to downside risk and promoting exposition to upside opportunities. It stands at the hinge between pure finance and other areas of decision making under risk such as project evaluation, market entry and exit, organizational restructuring and re-engineering, technology adoption, climate change and biodiversity decisions, etc.

The approach underlines a frame of mind and uses methodologies that appeal to a wide array of managers, thus providing a common language. Real options have applications in many areas that are central to modern corporations: market coverage and development, finance, human resources management, technology management, R&D and knowledge management, etc.

"...the efficiency of financial systems rests primarily on proper risk assessment and management in project evaluation. "

Thinking in terms of real options represents a major development in strategic but remains relatively unknown in spite of its adoption by firms such as Airbus, GE, Hewlett Packard, Intel, Toshiba and others. Nonetheless, as shown in the academic literature and as argued in some of the quotes below, the contribution of higher level managers to the value of a firm lies in the creation and the exercise of real options. Indeed the value of strategic management itself can be assessed that way.

At a more macroeconomic level, the efficiency of financial systems rests primarily on proper risk assessment and management in project evaluation. The real options approach is the crucial analytical tool to fulfill such a need and act as a link between the financial and the real sectors.

Some quotes from the business press:

"The oil, energy and pharmaceutical industries have long used the real options framework to assign value to non-financial assets like R&D projects and oil leases. 'Real options prices the value of an opportunity,' says Brice Hill, controller in the server division of Intel Corp. in Hillsboro, Ore. And companies can use a real options valuation to determine how much they are willing to spend to create an option on a particular opportunity. 'It used to be that any level of investment was appropriate to create a strategic option,' says Hill. 'But now if an option has a specific value -- say, $50 million -- then a company might be willing to spend up to $50 million to create that option.' " (Business Finance, March 2002)

"The oil, energy and pharmaceutical industries have long used the real options framework to assign value to nonfinancial assets like R&D projects and oil leases."

"Real-options analysis rewards flexibility and that's what makes it better than today's standard decision-making tool, 'net present value.' NPV calculates the value of a project by predicting its payouts, adjusting them for risk, and subtracting the investment outlay. But by boiling down all the possibilities for the future into a single scenario, NPV doesn't account for the ability of executives to react to new circumstances, for instance, spend a little up front, see how things develop, then either cancel or go full speed ahead.**" (Business Week, June 7, 1999)

"The real option approach emphasizes that many investments create important, follow-on opportunities that a company may or may not subsequently exploit. Consequently, the real option approach highlights value that is contingent on earlier investments. For instance, while a given R&D investment may have a very low or even negative net present value, it may also provide platforms for future, favorable investments. Real options bear some other similarities to financial options. For example, the value of both types of options increases with uncertainty. Further, by providing managers discretion - rights but not obligations - financial and real options can help companies limit their downside risk while also gaining access to upside opportunities in the future. However, unlike financial options, real options come into existence by the opportunities created by the company's strategic investments. Because their underlying assets do not trade in liquid markets, real options also present unique valuation challenges." (Financial Times, May 5, 2000)

"Real options valuation grounds strategic thinking and decision-making in concrete financial analysis. 'When companies make strategic investments, they tend to do so with a thumbs up or thumbs down from the CEO and no financial analysis to the decision,' says John McCormack, senior vice president and head of the energy practice at Stern Stewart & Co., a management consultancy in New York City. 'But when you have strategic investments that require choices in the future,' real options can guide those decisions. The model also enables an organization to recalculate the value of a project or investment as it progresses and to understand what must happen before the project or investment can move successfully into the next stage of development. (Business Finance, March 2002)

"Exploit hidden assets and you will succeed. Neglect them and you will wind up with a collection of old nags. What kind of hidden assets do I mean? For example, the unexploited opportunities to add a new product line, expand overseas or engage in e-commerce are hidden assets that do not appear on a company's financial statements and have not yet contributed to its profits. When you buy a company, you often get these features for free. I call them 'real options,' an analogy to the

financial options traded in Chicago. There's a big difference, though. Financial options remain valuable when held by passive investors. But owning a business is not a passive exercise. The owner has a real job to do, providing governance, managing capital and helping a business achieve its potential." (Forbes magazine, May 29, 2000)

"Real options analysis is based on the observation, first made more than 20 years ago, that a company evaluating an existing asset or potential investment is in much the same position as the holder of a financial option, such as those written on stocks or commodity prices. The holder of a financial put option on, say, the price of oil can exercise that option if the price rises above a pre-agreed level, but doesn't have to if the price falls. Similarly, the owner of a marginally profitable oil field has the right to exploit it if the price of oil rises, but is not obliged to do so if it doesn't. That observation leads to the assumption that the future value of such an investment can be best valued in a similar way to financial options, rather than by simply discounting the cash flows expected from it in future. In particular, option valuation takes into account the risks and rewards of future uncertainty, or volatility, which traditional discounted cash flow (DCF) models do not." (CFO Europe, July 1999)

"To evaluate potential projects, they almost invariably have to resort to a theory of corporate finance called the 'Capital Asset Pricing Model' (CAPM). Yet real-life managers tend not to like this model, for the simple reason that it ignores the value of real-life managers. So they might welcome some recent academic work. In the ivory tower, they are talking about ditching the CAPM for a rival, called "real options theory", that places managers at its very core. More fundamentally, the flaw in the CAPM is that it implicitly assumes that when firms buy new assets, they hold these passively for the life of the project. But they do not. Instead, they employ managers precisely in order to react to events as they unfold. Obviously, this managerial flexibility must be worth something. Options on "real" assets (and indeed poker bets) behave rather like options on financial assets (puts and calls on shares or currencies, say). The similarities are such that they can, at least in theory, be valued according to the same methodology. There is a snag, of course: sheer complexity. Pricing financial options is daunting, but valuing real options is harder still. Their term, unlike that of financial options, is usually open-ended or undefinable. The volatility of the underlying asset can be difficult to measure or guess, especially since it is not always clear what it is - if, for example, it is yet to be invented. How can one define the appropriate benchmark asset-class in the case of a new drug for a rare disease? And there may be additional variables to consider, such as the strategic benefit of pre-empting a rival."

"...option valuation takes into account the risks and rewards of future uncertainty, or volatility... "

"Pricing financial options is daunting, but valuing real options is harder still."

(The Economist, August 12, 1999)

As is clear from these quotes, the real options methodology is emerging as a potentially powerful tool for the executive. However, this potential will only be realized by decision-makers who combine the "real option state of mind" with both a good grasp of technical skills and a good information system. The implementation of a real options approach could be very valuable but at the same time is a challenging task. However it is very much in the spirit of real options to finish with a sobering quote from before the Enron debacle:

"Enron President and Chief Operating Officer Jeffrey K. Skilling (credited) realoptions thinking with helping Enron transform itself from a U.S. natural-gas pipeline company into a global wheeler-dealer that trades commodities including gas, electricity, water, and, most recently, telecom bandwidth." (Business Week, June 7, 1999)

Real options does not pretend to be and will not become a substitute for proven business values and virtues. A better appreciation and exploitation of risks and opportunities will neither completely shield a firm from the dangers inherent to business nor fully protect it from the temptations of fraudulent behavior. The paper is organized as follows. Section 2 explores the links between real options and finance. Section 3 considers real options as a tool for project evaluation. Section 4 suggests ways to implement real options in strategic planning exercises. Section 5 surveys the technical tools available in real options analysis. Section 6 presents some detailed real option examples. Section 7 briefly discusses the impact of real options on project risk management and Section 8 concludes.

2.   The Link between Real Options and Finance

As a direct outgrowth of finance, the real options approach uses techniques and methodologies which prevail in that field. However, finance is mostly preoccupied with evaluating and pricing financial instruments, put and call options among them. As the real options approach percolates into various areas of management and decision making, there is a shift of emphasis from pure evaluation to decision analysis and optimization.

The origin of the real options approach can be traced back to the remark by Steward Myers of MIT that holding a real investment project like the construction of a plant (or the adoption of a new technology, a restructuring plan, the exploration of a new market or product, the development of an R&D program) was formally similar to holding a financial call option. A real investment project involves the option, but not the obligation, to spend resources at some future time in order to obtain an asset (an operating plant) whose value is

"Real options does not pretend to be and will not become a substitute for proven business values and virtues."

"A real investment project involves the option, but not the obligation, to spend resources at some future time in order to obtain an asset (an operating plant) whose value is normally stochastic."

normally stochastic. The randomness of a financial option arises from the fact that the underlying asset is usually a stock, so that, at the time the option is acquired, it is not clear whether the known exercise price will be lower or higher than the still unknown stock price in the future; thus the option may never be exercised. Similarly, if the price of the projected plant's output does not evolve favorably, or if further future research reveals that operating costs would be high, then it may not be worthwhile completing, that is engage in the n-th stage, or exercising the plant construction option.

Factors affecting the value of financial and real options	
Call Option on Stock	**Real Option on Project**
Current value of stock	(Gross) PV of expected cash flow
Exercise price	Investment cost
Time to expiration	Time until opportunity disappears
Stock value uncertainty	Project value uncertainty
Risk free interest rate	Risk free interest rate or risk adjusted rate

The distinction between option evaluation and decision making is only a matter of emphasis. In fact evaluation requires solving the decision problem raised by the option: should it be exercised and when? But the distinction is important: it underlines that good decision making creates value. As we argue below, the objective of applying the real options approach to decision making in organizations is to create value by capturing the full value of the firm's potential. This approach brings the strong discipline of finance into other areas of corporate planning activities, of public policies, and of individual endeavors.

"...the objective of applying the real options approach to decision making in organizations is to create value by capturing the full value of the firm's potential."

Another difference between financial options and real options arises from the nature of the uncertainty affecting the underlying asset. In the world of financial options, uncertainty is all about future stock prices. Uncertainty is then a source of value because of the limited downside and unlimited upside fluctuations of the pay-off, fluctuations that are linked to the exogenous (outside the control of the managers) variability or volatility of the price of the underlying financial assets.

In the world of real options, uncertainty has value because of the ability of executives to manage the uncertainty of projects. In a world without uncertainty, managers would not be needed. Executives add value to the firm because they actively manage change as uncertainty unfolds over time. In a sense, the real options approach attempts to quantify that value, that is, the value of active management of uncertainty by managers.

"In the world of real options, uncertainty has value because of the ability of executives to manage the uncertainty of projects."

This crucial difference in the nature of uncertainty has its counterpart in the nature of the information that needs to be used for option evaluation and management. For financial options, most of the time long and frequent data series are available about stock prices. For a real option such as the construction of a production plant, the uncertainty arises from future prices or production costs. While product prices may have some similarity with stock prices, they are not usually recorded with the same accuracy, nor are they driven by the same factors. When it comes to costs evaluation, both the form and the nature of the data available are fundamentally different.

"...beyond techniques, the real options approach is mostly a way of thinking and adjusting one's behavior accordingly."

There are also differences in the institutional environment characterizing the option evaluation and decision making problem. An important one is that financial markets are often rich and dense enough that appropriate portfolios of existing traded assets can duplicate the risks associated with the asset underlying a particular option. It is under such circumstances that the celebrated Black-Scholes-Merton approach is applicable. In the case of many real options, this so-called 'spanning' assumption cannot be invoked because markets are thin and opaque so that other techniques, such as stochastic dynamic programming, must be used instead of the contingent claims approach prevalent in financial applications.

Although widely used in finance, techniques such as stochastic dynamic optimization are by far not specific to that field. Being used by managers and engineers as well, they often constitute a common tool and language by which real options techniques and methodologies are spreading more easily from finance into other areas.

"The real options approach is best seen as an improvement to conventional discounted net present value determination; it does not invalidate the procedure but amends the way it is applied."

Certainly, the technical dimension of option evaluation is important and is part of the conceptual breakthrough that was recognized by the 1997 Nobel prize in economic sciences awarded to Robert C. Merton and Myron S. Scholes "for a new method to determine the value of derivatives." But beyond techniques, the real options approach is mostly a way of thinking and adjusting one's behavior accordingly. It rests on the explicit

- ✍ recognition that uncertainty creates opportunities and value;
- ✍ recognition that such value requires adequate decisions in order to materialize;
- ✍ identification of the sources of uncertainty and collection of information;
- ✍ identification of the decisions (options) that promote exposition to favorable outcomes;
- ✍ identification of the decisions that reduce exposure to downside risk;
- ✍ design of optimal decision *rules*.

3. Project evaluation and Real Options

Project evaluation is the most obvious application of the real options approach, although by no mean the only one or the major one. Before the real options approach, the standard evaluation procedure was discounted net present value (NPV). The real options approach is best seen as an improvement to conventional discounted net present value determination; it does not invalidate the procedure but amends the way it is applied. In fact it rationalizes what many evaluators are already doing on intuitive grounds:

- ✍ attach importance to the timing of decisions;
- ✍ identify and evaluate downside risks and upside opportunities associated with the project;
- ✍ identify, evaluate, and optimize future decisions that may affect exposition to downside or upside fluctuations;
- ✍ to sum up: optimally manage the creation and use of flexibility as a device to exploit uncertainty.

Once these dimensions of the project are introduced, projects become proactive instruments that modify the way uncertainty affects results in the decision maker's favor. Proper evaluation of costs and benefits always was crucial in conventional net present value evaluation. In a real options approach, costs and benefit evaluation becomes more difficult. Options created by the project now enter as benefits; options used up or exercised by the project enter as costs. In both cases these options must be valued and in most cases such evaluation involves finding the optimal way to decide whether and when an option must be created, held, or used up.


Real Options and Active Management

Knowledge of real options empowers managers with the tools to calculate more accurate and appropriate net present values (NPV) and thus make better strategic business decisions. One can think of calculating the proposed *RO-strategic NPV* of a project defined as:

Standard conventional NPV

+

Option premium from active management

=

RO-strategic NPV

A real options approach helps executives quantify the value of active management. Since the conventional NPV calculations typically are based on the discounted value of *average* outcomes, the ability of executives to actively manage a project is not accounted for and therefore the conventional NPV will typically underestimate the true NPV of a project. Active management limits the downside and enhances the upside of the distribution of the NPV outcomes and can change the expected NPV from negative to positive as the graph below illustrates. Moreover the ordering of mutually exclusive projects may not be the same. The upshot is that if the conventional NPV approach is taken, then truly profitable or more profitable projects are not implemented causing shareholder value of the firm to be less than maximal.

Figure 1:

NPV distribution without (dashed curve) and with (continuous curve) real options

NPV distribution without and with real options evaluation
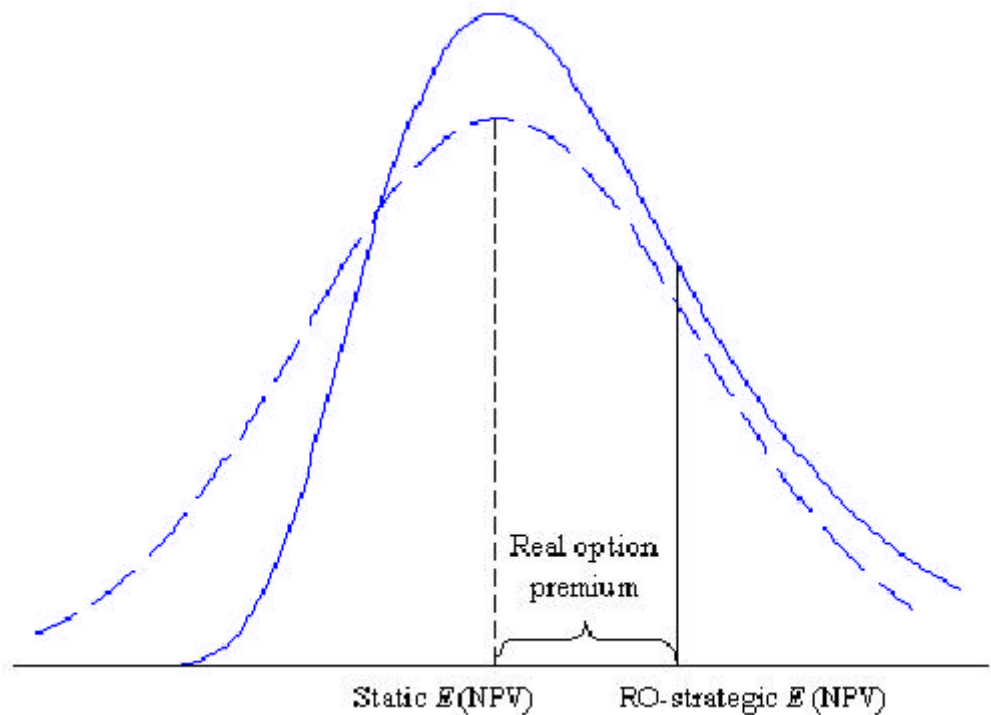
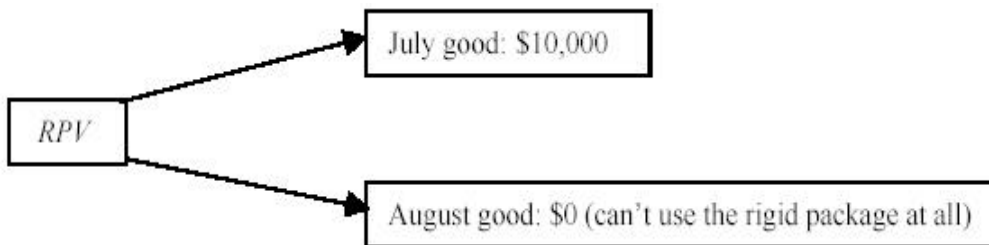
evaluation

Example 1: Vacation packages

Consider the following example: your travel agent offers you two types of vacation packages to the destination of your choice: "rigid" and "flexible". Under the "rigid" package you have to specify exactly the dates of your vacation. Under the "flexible" package, you can go for any seven consecutive days between May 1st and September 30th. Furthermore, the flexible package is 100% refundable while the "rigid" package is not refundable at all. How much more would you be willing to pay for the flexible package? To sim-
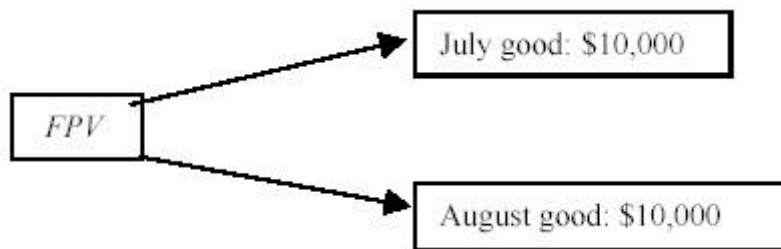
plify the problem, imagine you know for sure you will be able to take a week off this summer, but you don't know whether it will be in July or August. You estimate that each month has an equal probability of being convenient. Assume further that a week's vacation to the destination is worth to you $10,000 more than your next best alternative (a week at the cottage).

Since you don't know which month will be convenient, you toss a coin, and you pick July for the rigid vacation. Here are the payoffs of the rigid package, with *RPV* standing for "rigid package value":

Since both July and August have equal probability of being convenient, ignoring risk, the maximum you would pay for the rigid package is *RPV* = $5,000 = (½ $10,000 + ½ $0).

```
                          ┌─────────────────────────┐
                     ┌───▶│ July good: $10,000       │
        ┌──────┐     │    └─────────────────────────┘
        │ RPV  │─────┤
        └──────┘     │    ┌──────────────────────────────────────────────┐
                     └───▶│ August good: $0 (can't use the rigid package at all) │
                          └──────────────────────────────────────────────┘
```

Consider now the flexible package. It allows you to take your vacation any time this summer. So, the payoffs to the flexible package are, with *FPV* standing for "flexible package value":

```
                          ┌─────────────────────────┐
                     ┌───▶│ July good: $10,000       │
        ┌──────┐     │    └─────────────────────────┘
        │ FPV  │─────┤
        └──────┘     │    ┌─────────────────────────┐
                     └───▶│ August good: $10,000     │
                          └─────────────────────────┘
```

Either way, you take your vacation, so you would be willing to pay *FPV* = $10,000 for the flexible package. In this specific example, the value of flexibility is as big as the value of the inflexible package itself. This is not unrealistically high: a flexible fully refundable airline ticket with open dates may cost as much as five to ten times a non-refundable ticket with fixed dates.

The above example illustrates the basic evaluation method of both financial and real options. Both standard textbook put option evaluations and the vacation package example are overly simplistic. Their main weakness is perhaps that they consider situations where, although valuation is an issue, the decision that confers its value to the option (sell the stock; take the trip) is obvious in each case. In most real situations the decision whether

and when to exercise the option is the outcome of a complex optimization process which maximizes the value of the option.

However simple, these illustrations do demonstrate how the methodology developed for analyzing financial options can be applied to real world problems. In fact the difference between choosing a flexible vacation package and an interruptible power supply scheme or package is not that great. Of course, both the financial and the real options valuation methodologies utilize substantially richer descriptions of the uncertainty and employ more realistic assumptions. In the rest of our discussion, we mention and sometimes analyze several cases when real options have been or could be successfully applied to improve management decision-making. All of those cases are substantially more complicated than the above example. The basic underlying objective remains to optimally manage the creation and use of flexibility as a device to exploit uncertainty. This involves the following steps:

- ✍ identification of the sources of uncertainty and collection of information;
- ✍ identification of the relevant future decisions;
- ✍ construction of optimum decision rules.

4.   Strategic Planning and Real Options

A good strategic plan is a plan that builds real options into the foreseeable future of the firm and sets up an optimized decision making process to fruitfully exploit those options. Again, real options should be recognized, built in and evaluated for each major step of every project: alliances, acquisitions and mergers, spin-offs, technology development and management, organizational restructuring, etc. The value of strategic planning itself is determined by the quality of the real options designed and imbedded in the plan and by the quality of the evaluation procedure of those real options. It is in this precise sense that the design and management of real options, through the exploitation of uncertainty, create value for the firm and that they represent the most important responsibilities of the managers in determining a strategic plan.

Strategic planning is an exercise in managing flexibility. Plans should specify decision nodes, that is to say future steps that may or may not be taken, at dates that may be given but are mostly to be chosen optimally as the future environment of the firm unfolds in a stochastic way. Furthermore, preparing a strategic plan is not a passive exercise in anticipating the future; it is an exercise in shaping the future or, more precisely, an exercise in preparing the way, in due time, the future will unfold to the decision maker's advantage. That is, managers are planting the seeds of future flexibility by identifying and creating real options. This is again a key difference between real options and financial options: with

real options, managers are creating the tool or using existing tools in highly creative ways; in the case of financial options financial executives usually pick their tools in the – sometimes highly exotic – kit of available instruments.

As mentioned above, a financial option cannot have a negative value because its owner has the possibility of exercising it, but never the obligation to do so. Nonetheless, one important characteristic of real options in an oligopolistic environment is that a firm may be less valuable if it holds a real option than if it does not. This paradox arises as follows. The value of real options derives from the active management of a project's steps and variations as uncertainty unfolds over time. However, the possibilities of modifying the planned course of a project imply that the firm's commitment to develop and eventually complete the project is relatively low. This lack of commitment may invite more aggressive behavior from competitors, whose objective may be to drive the firm out of the project or market, or more aggressive attacks from the opponents to the project. Active management means that such options, although valuable in a competitive non reactive business environment, may not be valuable in an oligopolistic reactive business environment: managers must sometimes burn their bridges. It is a major responsibility of higher level managers to identify which options should be closed in favor of strong commitment and which options should be kept open in favor of flexibility.

5.   Real Options: New techniques and Procedures

The real options approach uses all the mathematics of finance. However standard financial techniques and procedures cannot always be applied in the real options context. The most frequent reasons are that real risks cannot always be reproduced by market instruments so that arbitrage or equilibrium methods such as the Black-Scholes-Merton method are not valid; data on the underlying asset (project value) are not available in as convenient forms as financial data; the identification of available options often requires analyses that involve other fields of economics, and other disciplines in management, organization, engineering, etc.

"...real risks cannot always be reproduced by market instruments so that arbitrage or equilibrium methods (...) are not valid..."

Consequently the array of techniques and procedures involved in the real options approach is typically wider than in financial options. Decision tree analysis with optimized decisions at various nodes, and stochastic dynamic programming are prevalent techniques, usually applied numerically. Stochastic dynamic programming, as a mathematical tool, is much in the spirit of the real options approach: it seeks the maximization of a stochastic value function that can be interpreted as the value of the firm or the project, that depends on optimal decisions to be taken in the future upon the arrival of information or the realization of some events still unknown at the time of the evaluation. As an optimization tool it is already widely used in such areas as inventory management, reservoir management, etc., so

that a real options approach may be within the reach of a broad base of management and/or scientific personnel in the firm with a good training in finance and industrial economics.

Stochastic dynamic programming relies on the quality of information. The analyst must identify each step and characterize each decision in terms of its probabilistic effect on the state variables, its cost, its information content, its degree of reversibility or flexibility. Such information is usually highly project specific so that each project may require a substantial investment in data collection and analysis.

"...each project may require a substantial investment in data collection and analysis."

Often the analysis must go beyond data. Fully-fledged industrial analysis is warranted when decisions are truly strategic: competition, preemption, signal extraction motives, asymmetric information, and so on, become key issues. The evaluation of a new "plant" development project should yield different results, other things equal, when the new plant is explicitly considered as an addition to an existing portfolio of "plants", in the firm itself and in the industry as a whole. Similarly the evaluation of a new aircraft project involves strategic choices best addressed by real option evaluations.

Another important tool of the real options approach is simulation. For example, with adequate data on past demand or on past water replenishment rates, one can generate samples of possible future demand trajectories or water levels. A promising new technique consists in drawing econometric inference from such simulated samples[1].

"A promising new technique consists in drawing econometric inference from such simulated samples."

6. More elaborate illustrations

Example 2: A safe known technology versus a promising but uncertain alternative.

Telecommunication service providers serving both the fixed wire and the wireless markets recognize the importance of responding to the growth of the internet, both by adding switching and transmission capacity in the backbone, and by expanding bandwidth into customer sites.

Consider a telecommunication company having an opportunity to expand its data transmission capacity by choosing between the following two technologies:

_____

[1] See Longstaff, F.A. and E. S. Schwartz, "Valuing American Options by Simulation: A Simple Least-Squares Approach", *Review of Financial Studies* 14(1), Spring 2001, 113-47.

? DSL (Digital Subscriber Lines) technology that increases the transfer capacity of the classic telephone lines (formerly designed for voice transfers) to allow higher speed for data transmission.

? Broadband Wireless technology such as MMDS (Multichannel Multipoint Distribution Service) that combines data transfers with voice transfers.

In the case of the wireless MMDS technology, both costs and demand are much more uncertain than in the case of the DSL technology. As a rough approximation of that situation, assume that the future value of the DSL technology is known with certainty, while the future value of the wireless technology is uncertain. One suspects it will increase relative to the value of the DSL technology but there may be accidents and delays along the way.

This may be represented as illustrated in Figure 2 where the values of technologies DSL and MMDS are measured on the vertical axis and time is measured on the horizontal axis. The value *D* of the DSL technology is a constant since it is know with certainty by assumption. The value *V* of the MMDS technology tends to rise with time at a positive rate but in a stochastic way (modeled as a geometric Brownian motion). It may, but need not, dominate the constant-value DSL technology at some time in the future. One illustrative realized path is graphed in Figure 2 but many other paths are also possible ex ante.

The company holds an option to invest. It must choose between the mutually exclusive DSL and MMDS technologies and also the optimal timing of the investment. The analysis of this investment problem leads to an optimal decision rule characterized by two thresholds. It is optimal for the firm to adopt the DSL technology if the value *V* of the MMDS technology is lower than *VL*, and it is optimal to adopt the MMDS technology if *V* is greater than *VH*. For all values of *V* lying between *VL* and *VH*, the firm should rather wait and see before expanding its data transmission capacity. The threshold values *VL* and *VH* must be determined as an optimal decision rule or strategy through a real options analysis.

It is noticeable that the presence of the uncertain MMDS technology, and its analysis in a real options framework, drastically affect the standard evaluation of the DSL technology project: at time zero, in a standard NPV evaluation setting, the latter would be undertaken since, in our example, it yields a higher expected net present value than the MMDS technology. The real options approach emphasizes the arbitrage between foregoing certain current profits by waiting, and avoiding potential future losses from choosing a technology which would turn out later to be a loser. Thus, below the threshold *VL*, the DSL technology is adopted because it dominates the MMDS technology by such a margin that it

"The company holds an option to invest. It must choose between the mutually exclusive DSL and MMDS technologies and also the optimal timing of the investment."

is not likely that the situation will be reversed in the near future (but not impossible, as illustrated in Figure 2, for more distant future dates). Hence, if the value of the MMDS technology were to follow the stochastic path illustrated in Figure 2, the firm waits till period t^*, the first time at which the process leaves the [VL , VH] interval; the firm chooses the DSL technology since at t^* the value of the MMDS technology is below VL.

Figure 2:

**Constant DSL, geometric Brownian motion MMDS, and decision thresholds**
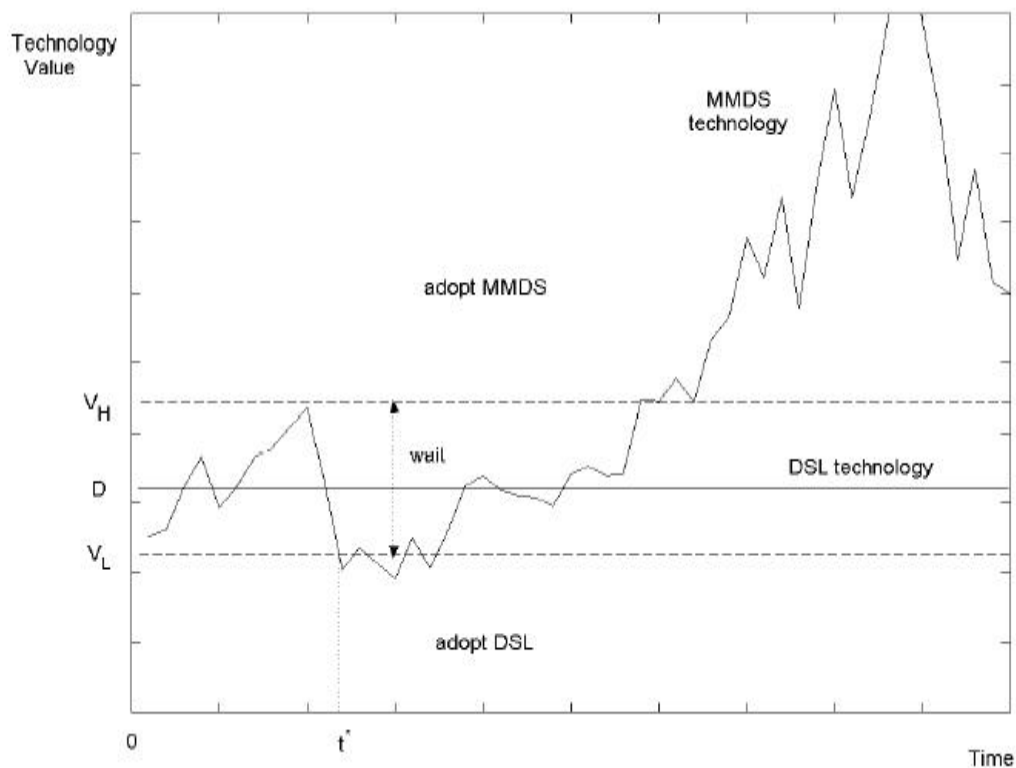
The real option approach provides rigor for the determination of the appropriate decision rule and therefore for the evaluation of the investment option. We can alternatively represent the solution as in Figure 3 where the expected NPV of the two technologies, measured on the vertical axis, are given as functions of the current expected value (or best estimate) V of the MMDS technology, which is known today but stochastic in the future. The net present value of the DSL technology, which is by assumption known with certainty, does not depend on V and is represented as a horizontal straight line at D; the net present value of the MMDS technology is illustrated as a 45-degree line with the negative intercept representing the cost of the investment.

Figure 3:

Values of investing in the MMDS technology, of investing in the DSL technology, or to wait, according to the current value of the MMDS
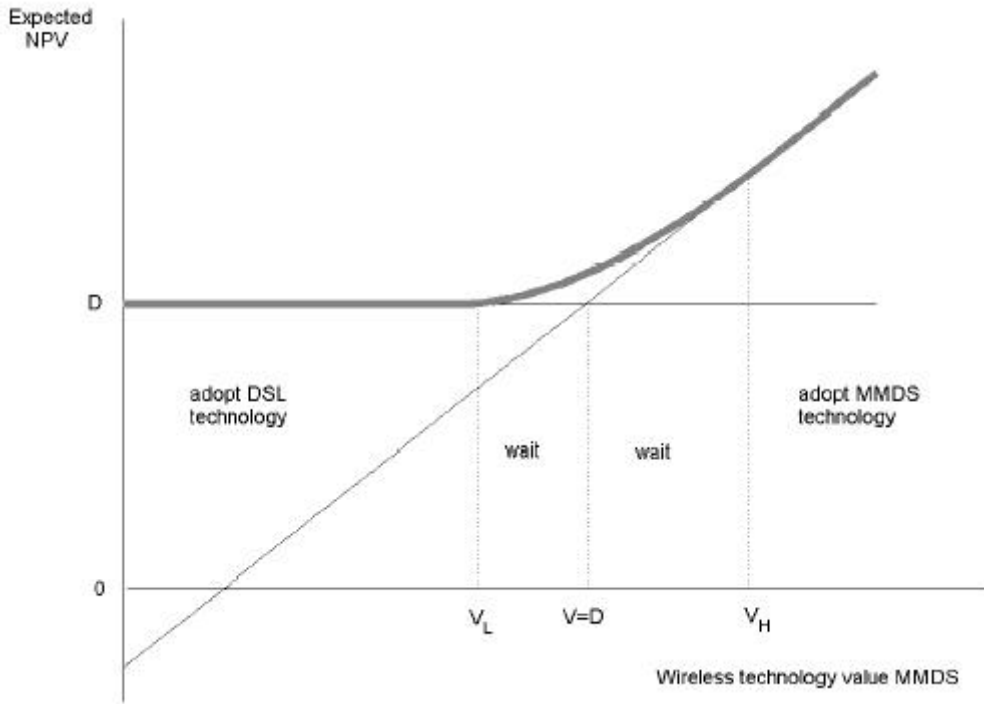
An investment decision based on an NPV analysis would require the DSL technology to be acquired immediately if $V<D$, while the MMDS technology would be acquired whenever $V>D$. However, by holding on to its option to invest in either technology when V lies between the lower and the upper limits VL and VH, the firm raises its net value to the level indicated by the thick gray curve which includes the option value. The value of the firm or project coincides with the values given by the NPV analysis in situations where the decision is clear-cut (outside the [VL , VH] interval) but it is higher than the NPV of both technologies in situations where managerial discretion requires waiting (when V is inside the [VL , VH] interval) because of the value of the option to wait.

Of course the current example could be extended to account for the fact that investment in either technology creates different options for subsequent developments.

Example 3 (general): Stochastic input costs and flexible technologies

The following integrated example of a specific manufacturing problem involves several real options that are identified and described briefly in the foregoing section. Example 3 (specific) below provides a more detailed analysis for the interested reader.

"...investment in either technology creates different options for subsequent developments."

Manufacturing companies often have the option to produce some of the energy they need. In the present example, a firm faces a choice between three industrial boilers to generate steam and electricity. The first boiler burns natural gas, the second burns fuel oil, and the third can switch between the two inputs.

The first two boilers illustrate the traditional trade-off between operating costs and acquisition cost. Whether or not one dominates the other depends on future fuel prices. Evaluating and comparing them for immediate acquisition requires forecasting future input prices but does not require investigating any particular future decision: once acquired, there is only one way to operate either technology.

The value of technological flexibility: the fuel switching option.

The third boiler involves additional flexibility. As the first two, its value depends on future fuel prices; but in addition its value depends on the rule that will be used for switching between fuels in the future; that rule must be optimized and its proper choice confers value to the technology. In contrast with the acquisition of either one of the first two technologies, acquiring the flexible technology creates the option to switch between fuels in the future according to future fuel prices. Note that this is not an option to invest, but an option to manage (switch). Since future fuel prices are not currently known, future switching dates cannot be built into the project for evaluation. However the rule determining switching may be selected and the expected value of owning the boiler, conditional on that rule being used in the future, may be determined.

The value of waiting: the timing option.

While acquiring one of the first two technologies does not create any option, the real options approach applies to them nevertheless. This is because their acquisition uses up an option: before acquiring a boiler, the firm has the flexibility to buy any boiler, or to wait and see; once the boiler is purchased, the option is exercised and there is no way back, whatever the future prices of gas and oil may turn out to be. The timing of the acquisition, together with the choice of one particular technology, need to be optimized. As with the switching option, the decision maker does not choose a date but an optimal decision rule that will be used for the choice of the stochastic acquisition date.

From the single machine to the plant portfolio.

In the decision sequence presented above, the real options approach helps evaluate the value of flexibility in a boiler. The operating rule is described in a rigorous fashion, and the decision whether or not to invest in such a boiler is optimized.

The real options approach can be applied in the same spirit to decisions of a much wider scope. Acquiring a gas-fired power plant may have a different value for one utility that dif-

"The timing of the acquisition, together with the choice of one particular technology, need to be optimized."

fers from the value it may have for another utility, depending on the existing portfolio of plants of each firm. Conventional NPV evaluation would not capture such a difference. For example if one power plant technology is affected by climate change (hydro power) while another technology is affected by fossil fuel cost (gas-fired plant), the same plant, to be used to serve the same market will probably be worth less to a firm that already owns several plants of the same type than to a firm that does not.

This is so for two reasons. The first one is the conventional reason associated with financial portfolio construction reinterpreted in the context of real assets: given any operation rule, the correlation between the value of the new plant and the other assets of one firm is likely to be different from the correlation between the value of this same new plant and the other assets of another firm. The second reason, emphasized by real options, is that each firm would choose a different operation rule to manage the new plant if it acquired it. Under conditions unfavorable to operating that plant, the firm with few similar plants could switch it off while serving demand with other equipment, while the other firm could not. The real options approach helps determine more precisely how this should be done and what the implications for plant and firm evaluation are.

Example 3 (specific): Stochastic input costs and flexible technologies

The value of technological flexibility: The fuel switching option

When a project involves several options, each future option confers value to earlier ones. Hence the evaluation of future options must precede the evaluation of current options. We start with the fuel switching option, focusing on the following question. If the firm acquires the third boiler now, then what is the value of its flexibility? What is the switching rule that confers its value to that flexibility? The answer to both questions depends on currently known parameters such as current prices, discount rate, and uncertainty, as described now.

The boilers may be described by their acquisition price and their efficiency-adjusted price of fuel. The efficiency-adjusted price of fuel is the spot price of the relevant fuel, that is $Pgaz$ or $Poil$, times a factor that reflects the thermal efficiency of the boiler. Suppose that the price of the first boiler is $63,500 and its efficiency-adjusted price of fuel is $1469 Pgaz$, that the price of the second boiler is $66,600 and its efficiency-adjusted price of fuel is $1408 Poil$, and finally that the price of the third boiler is $68,700 with the same thermal efficiencies as the single-fuel boilers: its efficiency-adjusted price of fuel is $1469 Pgaz$ when it burns gas and $1408 Poil$ when it burns oil. Therefore, the price of natural gas equals the price of fuel oil, on an efficiency-adjusted basis, when the price ratio ($Poil$ / $Pgas$) equals 1.04 (=1469/1408). Moreover, the option to switch fuel inputs is more valuable if the efficiencyadjusted price ratio frequently crosses the point of equality.

"When a project involves several options, each future option confers value to earlier ones. Hence the evaluation of future options must precede the evaluation of current options."

When the ratio of the price of oil over the price of gas ($Poil$ / $Pgas$) is higher than 1.04, it would be less costly to operate the gas boiler than the oil boiler, or to operate the flexible dual boiler in the gas mode rather than in the oil mode. If the price ratio is lower than 1.04, the reverse is true.

Let us suppose that there is a fixed cost S to switch fuels in any direction when the flexible dual boiler is used. What additional value does the dual-fuel technology confer to the firm? In practice the fuel price ratio typically behaves as in Figure 4: it often crosses the 1.04 value. However it is not clear that the price ratio stays on either side of 1.04 for a long enough time to justify incurring the fixed switching cost, nor is it clear that it ever stays far enough on either side of 1.04 for substantial cost differences to arise between the oil and the gas regimes. Intuitively the higher the switching cost S, the further the price ratio must move away from the critical 1.04 value and the longer it needs to stay away from 1.04, for a switch to be warranted.

"...the two trigger price ratios move further away from the 1.04 value as uncertainty (volatility) increases."

A formal analysis gives a precise content to that intuition: as illustrated in Figure 4, there are two critical values of the price ratio. One of them, Pg, governs switches from oil to gas; it is higher than 1.04 and lies further away from that value, the higher the switching cost. The other critical value, Po, of the price ratio governs switches from gas to oil; it is lower than 1.04 and lies further away from that value, the higher the switching cost. Not surprisingly for users of the real options approach, the two trigger price ratios move further away from the 1.04 value as uncertainty (volatility) increases[2].

The decision rule just described maximizes the profit derived from the dual technology. By comparing this profit with the profit achieved if the best single-fuel technology at the current price ratio is used, one can compute the additional value conferred to the firm by the dual-fuel technology. The difference is the value of the flexibility option contained in the dual-fuel technology.

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[2] Decisions to sell or purchase electricity on the spot markets can be shown to obey similar rules.

Figure 4: Switching Rules and Sample History of the Price Ratio

Clearly, if the price ratio were constant, one of the single-fuel technologies would be best and the value of flexibility would be zero. Generally, the higher the volatility in prices, the higher the value of the flexibility option. Uncertainty is usually seen as depressing profits as well as minds. The real options approach emphasizes the opposite. A firm may be modeled as holding various options. As in the above example, these options are more valuable when uncertainty increases and so does the value of the firm. As a matter of fact, flexibility is not limited to technological and operational flexibility. Most business decisions, especially strategic decisions, involve trading resources against flexibility. The real options approach may help evaluate them.

The value of waiting: the timing option

The analysis of the fuel switching option has established, at any time or, equivalently, at any fuel prices, the value of the ability to switch in the future. Thus a firm considering the purchase of a boiler can compare at any date the value of the flexibility option with the acquisition cost premium associated with the dual-fuel technology and decide which is best.

If the flexibility option is worth more than the difference between the cost of acquisition of the dual-fuel burner and the cost of acquiring the alternative single-fuel burner, it does not follow that the firm must go ahead with the investment. At any date the manager must decide whether it is time to buy, or whether it is preferable to wait in order to avoid regretting the decision in case the price ratio evolves unfavorably. Once the investment is realized it is irreversible: realizing the investment involves a loss of valuable flexibility.

"Generally, the higher the volatility in prices, the higher the value of the flexibility option."

"Once the investment is realized it is irreversible: realizing the investment involves a loss of valuable flexibility. The foregone option to wait must be included as a cost of the project."

The foregone option to wait must be included as a cost of the project. This is where the real options approach again modifies the conventional NPV approach.

More contextual information is necessary to address this issue. We need to know the value of the production of the proposed boiler in order to evaluate the opportunity cost of waiting. Here the boiler allows the firm to substitute its own energy production for purchased electricity. There may be two main reasons to buy a boiler: purchased electricity is becoming more expensive; or boilers are becoming cheaper to acquire or operate.

Let us focus on the price of purchased electricity Pe. If that price is very low, it is clear that no boiler needs to be purchased. This suggests that there is a threshold price of electricity below which the manager should wait and above which the manager should go ahead with the acquisition of a boiler. In that case the analysis of the previous section indicates that the choice between the three types of boilers depend on the fuel price ratio, as indicated in Figure 4.

When the relative price of electricity is low, it is preferable to buy electricity rather than produce it from one's own boiler while at high relative prices of electricity it is preferable to operate a boiler. Which boiler? Above which electricity price? When the price of oil is low relative to the price of gas ($Poil / Pgas$ is low), chances of buying the wrong boiler are low; thus the oil boiler should be bought if the ratio of electricity price over oil price ($Pelect / Poil$) is above some benchmark as illustrated in Figure 5. However, when the price ratio ($Poil / Pgas$) is closer to PPo, it is more likely to cross the PPo line in the future, which would imply that the manager would prefer owning a dual boiler and would regret having acquired an oil boiler. To avoid the mistake of buying the wrong boiler, the manager requires a higher relative electricity price to make the irreversible decision. Thus the boundary separating the "wait" locus from the "buy oil boiler" locus is upward slopping. Similarly when the ratio ($Poil / Pgas$) is only slightly below PPg, buying a dual boiler might turn out to be a mistake if the ratio increases above PPg: thus the manager cautiously requires a higher relative electricity price before deciding.

Clearly, since the dual fuel boiler is more expensive, the threshold of the ratio ($Pelect / Poil$) warranting its acquisition is generally higher than in the case of single fuel boilers. This suggests that the threshold electricity price depends on the fuel price ratio, as drawn in Figure 5.

"To avoid the mistake of buying the wrong boiler, the manager requires a higher relative electricity price to make the irreversible decision."
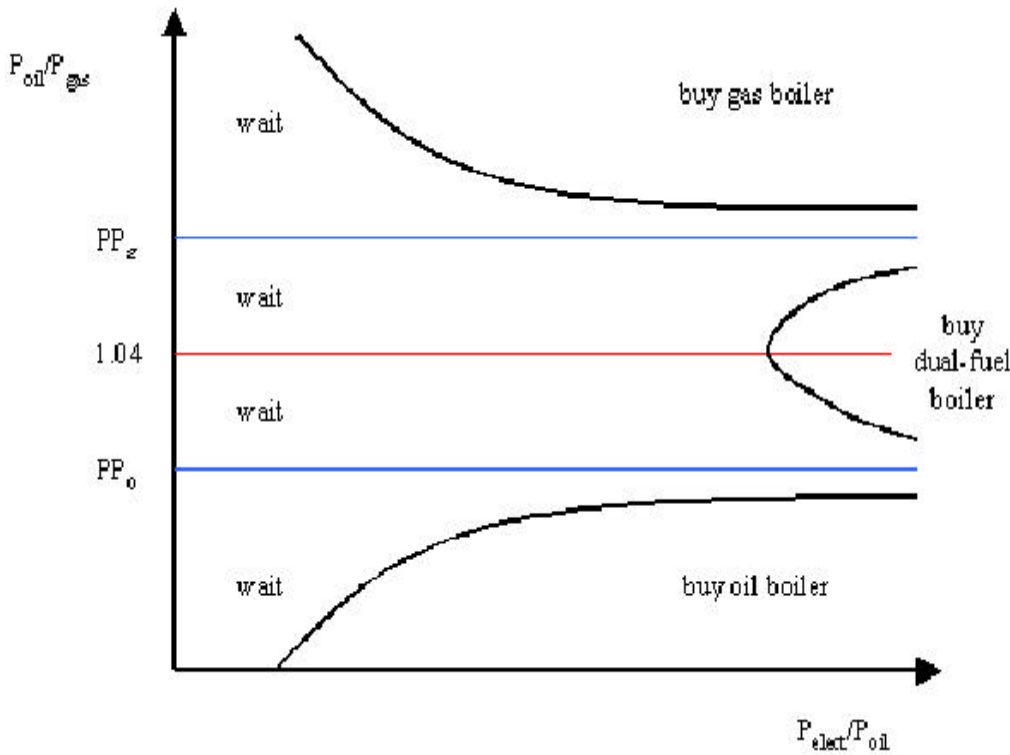
Figure 5: Boiler Buying Rule

Figure 5 is based on a conjecture that could only be confirmed and made precise through a complete real options analysis. The curve that separates the 'wait' domain from the 'Buy gas boiler' domain is downward sloping because, the closer the fuel price ratio is to the *PPg* value below which the dual boiler is a better buy than the gas boiler, the more likely it is that the fuel price ratio will go over the line in the future: if this happens and the manager has purchased a gas boiler, that decision will turn out to be a mistake. To protect himself against such mistake, the manager extends the waiting period by requiring a higher relative electricity price when the fuel price ratio is close to *PPg*.

7. Real Options and Risk Management

A financial option is the right but not the obligation to a payment, positive or negative, in the future based on the value of an underlying asset. Financial options are hugely important securities since they allow investors to construct portfolios with virtually any desired payoff profile, and thus enable investors to implement any view of the market, however sophisticated, and therefore manage the financial risks they face. Examples include Bull and Bear spreads (market will go up or down), Butterfly spreads (market will be tranquil), Straddle combinations (market will be volatile), Strips and Straps (market will be volatile but is more likely to go down than up and vice versa) and so on. A key feature of all these strategies is that the downside risk is limited when a long position is taken. This illustrates another key feature: options not only can help in taking speculative positions in

"A financial option is the right but not the obligation to a payment, positive or negative, in the future based on the value of an underlying asset."

"...options not only can help in taking speculative positions in the market, but they also can help in managing risk as well."

"...the better the available financial contracts, the lower the value of real flexibility."

the market, but they also can help in managing risk as well. If one is long in equity and worried about an impending stock market crash, buying out-of-the money puts could be an effective and insurance policy.

Combining real and financial options.

A firm that owns a single-fuel burner may use financial instruments to insure itself against fuel price fluctuations. For example if it owns a gas burner, it may buy a hedge that guarantees it to be able to purchase gas at some prescribed price should the spot price exceed that prescribed price.

Such hedges may also be considered if the firm owns a dual-fuel burner. They would be used as an insurance against the risk of incurring the fuel switching cost. If such insurance or hedging contracts are available at reasonable costs, it will affect the optimal switching rule determined in the absence of such financial instrument. The firm will be able to let the gas/oil price ratio increase to a value higher before switching to oil and vice-versa for gas.

Thus the availability of financial instruments may alter real management, just as insurance may alter management in general. This in turns affects the value of the flexible technology: the better the available financial contracts, the lower the value of real flexibility. Similarly, the more flexibility, the less insurance is needed. Flexible technology, flexible organization, flexible activities, etc. are all possible substitutes for insurance combined with some rigidity. Self insurance is not only the ability to withstand adverse occurrences, but also the ability to reduce their impact through adequate management decisions.

The relevance of financial options to risk management is well established. However, financial options are just one of many instruments of real risk management. Real options, as the main tool to manage and value real asset flexibility, is probably the most important tool. As we have stressed earlier, real options analysis focuses on management rules that avoid bad outcomes while seeking exposure to good opportunities. By so doing the approach establishes that risky projects have more value, but also require a premium in order to be undertaken. This may sound very similar to finance, where investors trade volatility for expected return, except for a major difference: while the owner of a financial portfolio is passive once portfolio content has been established, the manager of a real portfolio must apply a particular management decision rule in order to realize the potential of real options.

Also, real managers often face decisions where the benefits of a project are relatively well known, while its costs are highly volatile and uncertain. For example, if the issue of climate change is how costly it may be to avoid a given temperature change, then

real options indicate that the precautionary principle should be applied: undertake avoidance projects whose expected net present value may be negative, provided it does not lie below some threshold value. In such cases, uncertainty do not delay, but speed up, investment.

There are other situations where volatility is not a cause for walking away from an investment. If a project is highly volatile, but tends to be negatively correlated with other projects held by the firm, then the former derives value, not only from the option to undertake it in case of "good news" while leaving it aside when its prospects are not high enough, but also from the possibility to use it as insurance in case other projects fail. This is reminiscent of the Beta of a financial asset. Just like an asset with a negative Beta derives additional value from the fact that it can provide insurance against fluctuations in the market portfolio, a real option whose value tends to move in the opposite direction as other options derives additional value from this ability.

However, the potential of real options to project evaluation, real management, and risk management can only be realized if the relevant variables (sources of risk, processes for the relevant variables, and correlations) are well identified and measured. This requires firms to gear themselves up in the same way as they have learned to be aware of and exploit financial volatilities and beta values.

In fact there is also an analogy between the single asset mean-variance model and the single asset real options model on one hand, and between the several assets CAPM model and the several assets real options model on the other hand. In the first two instances, volatility is what matters; the value of a financial asset is lower, the higher its volatility. In the second two instances the correlation between assets is just as important as their volatility; a low beta, or a low coefficient of correlation between asset values, improves the ability of an asset (whether real or financial) to be used as insurance, thus giving it additional value.

As mentioned in the introduction, the efficiency of financial systems rests on their ability to assess the real sector on which they are based. Real options will allow financial institutions to apply to the real sector techniques and approaches that are similar in spirit to those used and developed for the financial sector, thereby meeting the requirements of the Basel accords.

"There are other situations where volatility is not a cause for walking away from an investment."

8. Conclusion

The real options approach may bring the discipline and accuracy of finance into various areas of decision-making. The approach is relevant to a very large array of management and strategic decisions involving uncertainty and irreversibility. This is why many pioneer firms are starting to use it to take better advantage of a proactive type of management and create value.

Implementing a real options approach is not easy however. The standard procedures used in finance must often be adapted or replaced with other techniques. Each application of the real options approach is likely to be context specific. The available options must be envisaged and described; the relevant information must be identified and collected carefully; the executive using a real options approach must have the required knowledge and training to adapt standard procedures to each particular situation. Perhaps most importantly the real options approach is a state of mind, a capacity and willingness to detect decisions that create opportunities or protect against mishaps, and act upon them in order to create value for the firm.

For managers with such a state of mind, the real options approach is a tool that allows them to bring intuition in line with the prescriptions of rigorous decision-making procedures. More importantly it allows them to give a more accurate quantitative content and value to intuitive rules, thus gaining an edge over competitors.

"The real options approach may bring the discipline and accuracy of finance into various areas of decision-making."