



# NATIONAL BANK OF BELGIUM

## WORKING PAPERS - RESEARCH SERIES

### REAL OPTIONS AND INVESTMENT UNDER UNCERTAINTY: WHAT DO WE KNOW?

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The views expressed in this paper are those of the author and do not necessarily reflect the views of the National Bank of Belgium.

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### **Editorial**

On May 27-28, 2002 the National Bank of Belgium hosted a Conference on "*New views on firms' investment and finance decisions*". Papers presented at this conference are made available to a broader audience in the NBB Working Papers no 21 to 33.



## **TABLE OF CONTENTS**

<b>1. INTRODUCTION.....</b>	<b>1</b>
<b>2. OVERVIEW OF COMMON REAL OPTIONS: A COMPREHENSIVE EXAMPLE .....</b>	<b>2</b>
<b>3. SIMPLIFYING REAL-LIFE PROBLEMS .....</b>	<b>9</b>
<b>4. MAIN IMPLICATIONS: WHAT WE KNOW ABOUT REAL OPTIONS AND INVESTMENT UNDER UNCERTAINTY .....</b>	<b>10</b>
<b>5. FUTURE RESEARCH FOCUS: WHAT WE STILL DON'T KNOW .....</b>	<b>17</b>



## 1. Introduction

In an increasingly uncertain and dynamic global market place managerial flexibility has become essential for firms to successfully take advantage of favorable future investment opportunities, respond effectively to technological changes or competitive moves, or otherwise limit losses from adverse market developments. Thinking of future investment opportunities as “real options” has provided powerful new insights that in many ways revolutionized modern corporate resource allocation. Real options emphasizes the importance of waiting or staging flexibility, suggesting that managers should either “wait and see” until substantial uncertainty is resolved and the project is more clearly successful, requiring a premium over the zero-NPV critical value, or they should stage the decision so that they can revise the situation at critical milestones to either proceed to the next stage or abandon. During the waiting or staging period, new information can be revealed that might affect the desirability of the project; if future developments turn out worse than expected, the firm has implicit insurance protecting it against downside losses by choosing not to proceed with the project.

Real options also introduces a new insight with respect to the role and impact of uncertainty on investment opportunity value that runs counter to conventional thinking. Since management is asymmetrically positioned to capitalize fully on upside opportunities while it can limit losses on the downside, more uncertainty can be beneficial for option value. More can be gained from opportunities in highly uncertain or volatile markets because of the exceptional upside potential and limited downside losses that result from management’s flexibility to continue or not proceed with the project.

From a strategic perspective, of course, it may not always be beneficial to “wait and see.” For example, by making an early strategic R&D investment, a firm may not only develop more cost-efficient or higher-quality products or processes that can result in a sustainable cost or other competitive advantage, but may be able to positively influence competitive behavior and earn a higher market share down the road. In some cases a firm

anticipating competitive entry may make a strategic investment commitment (e.g., in excess production capacity) early on such that it can preempt competition altogether. Therefore, optimal investment timing generally involves a trade-off between wait-and-see flexibility and the “strategic value” of early commitment. Moreover, early investing may itself open up a set of new options embedded in the commercial project (e.g., to later expand, abandon, or switch to alternative uses), whose value may also be enhanced by higher uncertainty, but is realized through early investing. Thus, the presumed depressive impact of uncertainty on investment is not that clear cut. The above new considerations of investment under uncertainty suggest the need to adopt an expanded or strategic NPV criterion, able to capture management’s flexibility to alter planned investment decisions as future market conditions change as well as the strategic value of competitive interactions – besides the value of expected cash flows from committed assets.

The rest of the paper is organized as follows. Section 2 provides an overview of some common real options through a comprehensive example. Section 3 discusses briefly simplifying real-life problems and reducing them to a basic problem structure. What we know about real options in terms of main insights and implications is discussed in section 4. Section 5 catalogues what we still don’t know that future research must focus more on.

## **2. Overview of Common Real Options: A Comprehensive Example**

The following example involving a mineral resource extraction and processing facility serves to review many of the most common options encountered in long-term capital investment opportunities. A large natural resources company has a one-year lease to start extracting on undeveloped land with potential mineral reserves. Initiating the project may require certain exploration costs, to be followed by construction of roads and other infrastructure outlays. Planned investment outlays are indicated as  $I_t$ , while  $V_t$  indicates the value of the project’s expected operating cash flows at time  $t$ . The initial investment in exploration is  $I_0$ , and the investment in roads and other infrastructure in the first period is  $I_1$ .



This is expected to be followed by capital outlays,  $I_2$ , for the construction of a new processing facility. Extraction can begin only after construction is completed, i.e., cash flows are generated only during the operating stage that follows the last outlay. During construction, if market conditions deteriorate, management can choose to forego future planned outlays past the current stage. Management may also choose to reduce the scale of operation by  $c\%$ , saving a portion,  $I_c$ , of the last outlay ( $I_2$ ) if the market is weak.

The processing plant can also be designed up front such that, if mineral prices turn out unexpectedly high, the rate of production can be enhanced by  $x\%$  with a follow-up outlay of  $I_E$  to install extra capacity. At any time, management may salvage a portion of its investment by selling the processing plant and equipment for their salvage value or switch them to an alternative use value,  $A_t$ . An associated refinery plant --that may be designed to operate with alternative sources of energy inputs -- can convert the raw mineral into a variety of refined by-products. This type of project has embedded in it the following package of real options:

1. *The option to defer investment.*

The lease enables management to defer investment for up to one year and benefit from the resolution of uncertainty about mineral prices during this period. Management would invest  $I_1$  (i.e., exercise its option to extract the mineral) only if mineral prices are sufficiently high, but would not commit to the project, saving the planned outlays, if prices decline. Just before expiration of the lease, the value added will be the greater of the net value created (that is,  $V_1 - I_1$ ) or \$0, with value-added represented as  $\max(V_1 - I_1, \$0)$ . The option to defer is thus analogous to an American call option on the gross present value of the completed project's expected operating cash flows,  $V_1$ , with the exercise price being equal to the required outlay,  $I_1$ . Since early investment implies sacrificing the option to wait, this option value loss is like an additional investment opportunity cost, justifying investment only if the value of cash benefits, actually exceeds the initial outlay by a substantial premium. The option

to wait is particularly valuable in such resource extraction industries, as well as in farming, paper products, and real estate development due to high uncertainties and long investment horizons.

2. *The option to abandon staged investment.*

In most real-life projects, the required investment is not incurred as a single up-front outlay. The actual staging of capital investment as a series of outlays over time creates valuable options to abandon at any given stage (e.g., after exploration if the reserves or mineral prices turn out very low). Thus, each stage (e.g., building necessary infrastructure) can be viewed as an option on the value of subsequent stages by incurring the next cost outlay (e.g.,  $I_1$ ) required to proceed to the next stage, and can therefore be valued similar to compound options. This option is valuable in all R & D intensive industries, especially pharmaceuticals, in highly uncertain, long-development capital-intensive industries, such as energy-generating plants or large-scale construction, high-tech start ups and venture capital.

3. *The option to expand.*

If mineral prices or other market conditions turn out more favorable than expected, management can accelerate the rate or expand the scale of production (by  $x\%$ ) by incurring a follow-up cost outlay ( $I_E$ ). This is similar to a call option to acquire an additional part ( $x\%$ ) of the base-scale project, paying  $I_E$  as exercise price. The investment opportunity with the option to expand can be viewed as the base-scale project plus a call option on future investment [i.e.,  $V + \max(xV - I_E, 0)$ ]. Given an initial design choice, management may purposefully select a more expensive technology with a built-in flexibility to expand production if and when it becomes desirable. As discussed further below, the option to expand may also be of strategic importance, particularly if it enables the firm to capitalize on new or future market

growth opportunities. When the firm buys vacant undeveloped land, or when it builds a flexible plant in a new geographic location (domestic or overseas) to position itself to take advantage of a developing potentially-large market, it essentially installs an expansion or growth option. This option, which will be exercised only if future market developments turn out favourable, but not otherwise, can oftentimes make a seemingly unprofitable (based on passive NPV) base-case investment worth undertaking.

4. *The option to contract.*

If market conditions turn out weaker than originally expected, management can operate below capacity or even reduce the scale of operations (by  $c\%$ ), thereby saving part of the planned investment outlays ( $I_C$ ). This flexibility to mitigate loss is analogous to a put option on part ( $c\%$ ) of the base-scale project, with exercise price equal to the potential cost savings ( $I_C$ ), giving  $\max(I_C - cV, \$0)$ . The option to contract, just as the option to expand, may be particularly valuable in the case of new product introductions in uncertain markets. The option to contract may also be important in choosing among technologies or plants with a different construction to maintenance cost mix, where it may be preferable to build a plant with lower initial construction costs and higher maintenance expenditures in order to acquire the flexibility to contract operations by cutting down on maintenance if market conditions turn out unfavourable.

5. *The option to temporarily shut down (and re-start) operations.*

In real life, the plant does not have to operate (i.e., extract the mineral) in each and every period automatically. In fact, if mineral prices are such that cash revenues are not sufficient to cover variable operating (e.g., maintenance) costs, it might be better not to operate temporarily, especially if the costs of switching between the operating

and idle modes are relatively small. If prices rise sufficiently, operations can start again. Thus, operation in each year can be seen as a call option to acquire that year's cash revenues (C) by paying the variable costs of operating ( $I_V$ ) as exercise price, i.e.,  $\max(C - I_V, 0)$ . Options to alter the operating scale (i.e., expand, contract, or shut down) are typically found in natural resource industries, such as mine operations, facilities planning and construction in cyclical industries, fashion apparel, consumer goods, and commercial real estate.

6. *The option to abandon for salvage value.*

If reserves turn out low, if mineral prices suffer a sustainable decline or the operation does poorly for some other reason, management does not have to continue incurring the fixed costs. Instead, management may have a valuable option to abandon the project permanently in exchange for its salvage value (i.e., the resale value of its capital equipment and other assets in second-hand markets). This option can be valued as an American put option on current project value with exercise price the salvage or best alternative use value, entitling management to receive  $V + \max(A - V, 0)$  or  $\max(V, A)$ . Naturally, more general-purpose capital assets would have a higher salvage and option abandonment value than special-purpose assets. Valuable abandonment options are generally found in capital-intensive industries, such as in airlines and railroads, in financial services, as well as in new product introductions in uncertain markets.

7. *The option to switch use (e.g., inputs or outputs).*

Suppose the associated mineral processing operation can be designed to use alternative forms of energy inputs (e.g., fuel oil, gas, or electricity) to convert the raw mineral into a variety of output by-products. This would provide valuable built-in flexibility to switch from the current input to the cheapest future input, or from the

current output to the most profitable future product mix, as the relative prices of the inputs or outputs fluctuate over time. In fact, the firm should be willing to pay a certain positive premium for such a flexible technology over a rigid alternative that confers no or less flexibility. Indeed, if the firm can in this way develop more uses for its assets relative to its competitors, it may be at a significant comparative advantage. Generally, *process* flexibility can be achieved not only via technology (e.g., by building a flexible facility that can switch among alternative energy *inputs*), but also by maintaining relationships with a variety of suppliers, changing the mix as their relative rates change. Subcontracting policies may allow further flexibility to contract the scale of future operations at a low cost in case of unfavourable market developments. A multinational company may similarly locate production facilities in various countries in order to acquire the flexibility to shift production to the lowest-cost producing facilities, as the relative costs, other local market conditions, or exchange rates change over time. Process flexibility is valuable in feedstock-dependent facilities, such as oil and minerals, electric power, chemicals, and crop switching. *Product* flexibility, enabling the firm to switch among alternative *outputs*, is more valuable in industries such as automobiles, consumer electronics, toys or pharmaceuticals, where product differentiation and diversity are important and/or product demand is volatile. In such cases, it may be worthwhile to install a more costly flexible capacity to acquire the ability to alter product mix or production scale in response to changing market demands.

8. *Corporate growth options.*

As noted, another version of the earlier option to expand of considerable strategic importance are *corporate growth options* that set the path of future opportunities. Suppose, in the above example, that the proposed processing facility is based on a new, technologically superior *process* for mineral refinement developed and tested

internally on a pilot plant basis. Although the proposed facility in isolation may appear unattractive, it could be only the first in a series of similar facilities if the process is successfully developed and commercialized, and may even lead to entirely new mineral by-products. More generally, many early investments (e.g., R & D, a lease on undeveloped land or a tract with potential oil reserves, a strategic acquisition, or an information technology network) can be seen as prerequisites or links in a chain of interrelated projects. The value of these projects may derive not so much from their expected directly-measurable cash flows, but rather from unlocking future growth opportunities (e.g., a new-generation product or process, related mineral reserves, access to a new or expanding market, strengthening of the firm's core capabilities or strategic positioning). An opportunity to invest in a first-generation high-tech product, for example, is analogous to an option on options (an inter-project compound option). Despite a seemingly negative NPV, the infrastructure, experience, and potential by-products generated during the development of the first-generation product may serve as spring-boards for developing lower-cost or improved-quality future generations of that product, or even for generating new applications into other areas. But unless the firm makes that initial investment, subsequent generations or other applications would not even be feasible. The infrastructure and experience gained can be proprietary and can place the firm at a competitive advantage, which may even reinforce itself if learning cost curve effects are present. Growth options are found in all infrastructure-based or strategic industries, especially in high tech, R & D, or industries with multiple product generations or applications (e.g., semiconductors, computers, pharmaceuticals), in multi-national operations, and in strategic acquisitions.

In a more general context, such operating and strategic adaptability represented by such a set of corporate real options can be achieved at various stages during the value chain, from switching the factor input mix among various suppliers and subcontracting practices, to rapid product design and modularity in design, to

shifting production among various products rapidly and cost-efficiently in a flexible system or network.

### **3. Simplifying Real-life Problems**

Most real-life problems involve more complex combinations of the above (and occasionally other) options. However, one can simplify a complex investment/ decision problem by decomposing it into a few basic building blocks (such as the standard options in the previous section) connected by some basic decision operations. The four basic decision operations commonly encountered are: choice of the best among several mutually exclusive alternatives (OR), the sum of several (parallel) options (AND), taking the probabilistic average (AVG) of follow-on options across some technical outcome scenarios weighted by the corresponding (actual) probabilities, or investing a portion of a budget in a subset of a range of technological options, and a recursive multi-stage option on an option (or COMPOUND option). Valuation proceeds in a recurring (even modular) manner following standard backward risk-neutral option valuation. Exhibit 1 illustrates a similar basic structure (combination of standard options and decision operators) for two real-life applications taken from entirely different industries. Powergen involves a staged powerplant construction (with options to abandon and later expand), while Glaxo involves valuing R&D during the clinical trials phase and determining the value of the patent rights for a new drug (also involving abandonment and expansion options into related niches). The problem structure and related option maps (shown in Exhibit 1) are remarkably similar, despite differences in problem context and industry characteristics. In both situations each firm faces a compound or multi-stage option to complete a development process (building a plant or completing clinical trials), followed by an option to either continue with commercial operations (also involving a later option to expand) or abandon for a salvage or sale value.

#### 4. Main Implications: What We Know About Real Options and Investment Under Uncertainty

The insight and implications of viewing investment opportunities through a real options lens can be quite powerful. Below I summarize a dozen insights or important main implications of now-standard real options analysis:

1. Uncertainty and flexibility are key determinants of the value of an asset or firm and call for an expanded valuation criterion.

The traditional valuation paradigm based on cash flows from *expected* plans under the implicit assumption of passive management has proven inadequate. The role of uncertainty in the presence of managerial flexibility is not necessarily penalizing as conventional wisdom would have us believe. Greater variability of potential outcomes around the expected (mean) result may be beneficial in the presence of options. Managerial flexibility to revise decisions when there are deviations from the expected plans introduces beneficial asymmetry in the distribution of project value returns by enabling upside (value-creation) opportunities to be exploited fully while limiting downside losses by choosing not to proceed or abandon. The resulting skewing of the probability distribution of expected project returns toward a more positive outcome calls for an expanded (strategic) NPV criterion to also capture the additional value of managerial operating flexibility and other strategic interactions:

$$\text{Expanded (or Strategic) NPV} = \text{passive NPV} + \text{Option Premium (ROV)}$$

(Flexibility value + Strategic value)

Based on this expanded criterion, it can be seen that it may now be justified to accept projects with negative passive NPV of expected cash flows (if this is offset by a larger option premium or real option value as a result of additional flexibility



and strategic value), or delay projects with positive NPV until a later time when Expanded NPV can be maximized under uncertainty.

2. Managerial flexibility or real option value (ROV) may be higher (other things the same)
  - for industries with higher uncertainty;
  - for investment opportunities with longer horizons or that can be delayed longer;
  - when (real) interest rates are higher;
  - for multi-stage (compound) options.
  
3. Higher uncertainty tends to increase the value of the option to defer (a single, irreversible, proprietary) investment -- provided there are no “dividends” or other early-exercise benefits, strategic interactions or other embedded options.

The flexibility to delay or “wait and see” enables acquiring more or better information and making a more informed future decision, potentially avoiding a mistake from premature investment in case things develop unfavorably. This higher value to “wait-and-see” necessitates a higher critical investment threshold, i.e., project value,  $V$ , must be at a significant premium above the required investment cost,  $I$ , before investing and sacrificing the option to wait is justified. The implication of this is that higher uncertainty would presumably lead to investing less or later (other things the same), with potentially significant macroeconomic implications. I should caution, however, that this holds under the provisional statements made above (and relaxed later) and may be different in different contexts, so it is questionable whether empirical studies on investment based on macro data can verify the presumed depressive role of uncertainty on investment (in terms of lower or delayed investment) if the provisional conditions are not confirmed to be carefully satisfied.

4. If one can reverse a decision (with ease or little cost), it is easier to make it (e.g., invest) in the first place.

A multinational corporation would find the decision to enter a new foreign country easier if it can get out with limited damage in case of unfavorable developments. This principle holds in general contexts beyond business investment. For example, the decision to get married might be easier in societies where it is easier to receive divorce (in Moslem parts of India men could obtain divorce simply by proclaiming the word 3 times). In deciding whether to move from the US to a smaller, more risky country, it helps to make the decision if one has US citizenship rights. These rights give the individual the option to reverse the decision and operate in the best of the two countries over time, just as locating plants in several countries enables a multinational corporation to operate in the best subset of several countries and shift production from one country to another to take advantage of fluctuations or differences in exchange rates, labor costs or other production inputs, tax regimes etc.

5. Under uncertainty, it is prudent to stage an investment or proceed with decision plans in stages.

Staging the investment or decision plans provides valuable flexibility to continue to the next stage (receiving the option value from continuing) or to abandon (exit) midway. Continuation (e.g., financing of subsequent stages in Venture Capital) should be contingent on the success of earlier stages.

6. Multi-stage opportunities may have significant growth (compound) option value that may justify making strategic investments despite having negative NPV.

Consider, for example, a two-stage growth option. The first stage involves investing in a manufacturing facility in Spain to introduce a new product that is expected to generate moderate cash flows from the Spanish market. The second stage would involve a 10-fold expansion into the broader European market 3 years later. The first-stage NPV of the expected cash flows from investing in the Spanish market is negative, and committing now to enter the European market on an expanded scale seems ten times as bad. But the company does not have to commit now. Instead, it has an option to “wait and see” how the Spanish and European demand develops and expand to the European market if and only if it appears favorable to do so 3 years from now. The opportunity to expand in Europe, valued as an option, may well offset the negative NPV of the first-stage investment (in effect the option premium or exercise price that needs to be paid to acquire the European expansion option) and justify making this strategic multi-stage investment on strategic grounds.

Empirically, companies in industries with higher uncertainty that involve multi-stage (compound) options tend to have a higher proportion of their stock price deriving from growth opportunities (PVGO/P), providing an indirect confirmation of the validity of real option predictions.

7. If investing creates other options within the project (e.g., to later expand, abandon, or switch to alternative uses), then more uncertainty would also increase the flexibility value of these other embedded options –increasing the value of early investing in the first place. For this reason (and the other reasons listed below), higher uncertainty would not necessarily suppress or delay investment.

8. In the presence of competition in an oligopoly setting, early investment may have strategic value by influencing the equilibrium actions (quantity or price setting) of competitors in a way beneficial to the investing firm or even by preempting competitive entry in some cases. Thus the option value of waiting must be traded off against the strategic value of early investing. Again, the impact of higher uncertainty on investment is not clear cut -- in fact it may not even vary monotonically with demand as shifts in demand may lead to shifts in the type of equilibrium games and different market structure outcomes (e.g., from a Nash duopoly to a Stackelberg leader/follower game or a monopoly) in different demand zones leading to value discontinuities as a function of demand.

The value of the strategic investment and the optimal competitive strategy (e.g., to invest now or wait) depends on whether the resulting benefits of the investment are proprietary or shared and whether they are damaging or benefiting the competitor, as well as whether competitive reaction is contrarian (opposite to the action of the investing firm) or reciprocating (similar to the action of the investing firm).

When the investment benefits are proprietary and the pioneer can get stronger at the expense of its competitor, it should commit to an early investment (aggressive) strategy if the competitor's reaction is contrarian, e.g., if it will retreat and cut its market share under quantity competition as the pioneer expands its own market share. However, when the benefits are shared, thereby benefiting the competitor as well, and a contrarian competitor would respond aggressively, it should follow a flexible "wait and see" strategy rather than subsidizing an aggressive competitor while itself paying the full cost. The above can be reversed under reciprocating (e.g., price) competition. If the benefits are shared and will benefit a competitor who will reciprocate when treated nicely (e.g., by maintaining high prices) the optimal strategy might be to invest early but not aggressively. On

the contrary, if the benefits are proprietary and will hurt a competitor who will retaliate by entering into a price war, it may make better sense to wait or not invest.

9. Competitive pressure may induce firms (e.g., in a “winner takes all” innovation race) to invest prematurely resulting in a suboptimal prisoner’s dilemma situation. Each of the two firms (like prisoners), being afraid that it may be preempted by the other and lose all (the most severe punishment), would rush to invest prematurely (give in), rather than wait (hold out) which may be the preferred outcome.

A joint research venture may enable the two firms to more fully appropriate the flexibility value from waiting (avoiding the prisoner’s dilemma) by coordinating and jointly optimizing against demand uncertainty – besides sharing and saving on the investment cost. A limitation is that in collaborating a firm gives up the possibility to outwit its rivals and gain a competitive advantage or strategic value over the other firm.

10. Multiple options embedded in a project may interact, i.e., option value additivity may break down. The presence of a later option enhances the value of the underlying asset for a prior option, while exercising an earlier option may alter the scale of (and in the case of the option to abandon, may extinguish) a later option. The value of a portfolio or combination of embedded options typically is less than the sum of separate or independent option values. Therefore, using an analytic formula like Black-Scholes to determine the value of separate options and then add them up may be misleading. The error from adding up separate option values may be of the same order of magnitude –but in the opposite direction - as the

error from ignoring options altogether. That is, a wrongly executed options analysis can be as dangerous as a naïve NPV analysis.

11. Options to switch (receive the cheapest of several inputs, best of several outputs, or most profitable countries of operation) provide valuable flexibility and risk management value.

Traditional mean-variance portfolio theory based on the notion that risk is undesirable and must therefore be minimized (for a given expected return) is inadequate; it needs to be extended for portfolios of (potentially interdependent) options, incorporating higher moments. The flexibility to adjust plans when deviating from expectations by improving the upside potential while limiting the downside risk adds skewness (third moment), while potential volatility dependence on project value, competitive jumps and technological disruptions may introduce kurtosis (fourth moment).

The very notion and role of risk must also be revisited when flexibility is present. With options to choose the best of several alternatives (or on the maximum or minimum of several assets) or options to switch from one “mode” of operation or being to another, lower correlation tends to increase the relative volatility and option value of a flexible system. When the value of one alternative drops, an option to choose the best or switch to another alternative is worth more if the value of that second alternative tends to increase (i.e., is negatively correlated with the first). For this reason, multinational corporations (MNC's) operating in several countries would prefer to select the next strategic location (to be added to the multinational network) so as to have lower correlation (with the existing structure) not so much in order to diversify and reduce risk, but rather so as to increase the relative volatility and option value of the flexible network. Risk is not necessarily something bad to be avoided, but rather can be seen as a window of

opportunity for the more flexible and innovative corporations to create more value by leveraging on opportunities while limiting losses.

12. When switching among operating “modes” or strategies, the presence of significant switching costs (e.g., to enter, exit, or shut down) may induce a “hysteresis,” inertia or delay/lag effect. Even though immediate switching may be attractive based on short-term cash-flow considerations, it may be long-term optimal to wait, e.g., due to a high cost or probability of switching back later. Examples involving hysteresis effects include continuing operation of a currently unprofitable mine or oil field despite temporarily suppressed prices, the Japanese auto producers who once they entered the US market in profitable times kept hanging-on in the US despite incurring losses in subsequent years, lags in hiring and firing by companies as business moves to an up and down cycle, delays in seeking divorce despite an unhappy marriage etc. All these cases involve irreversible or costly-to-reverse decisions which justify delaying a switch for a while since a re-switch back to the current situation is either infeasible or would occur only after a costly impairment of infrastructure, goodwill etc.

## **5. Future Research Focus: What We Still Don't Know**

Despite significant progresses in recent years, some long-standing gaps remain. Here is my list of ten pending issues that future research must still focus on:

- (1) More actual case applications and tackling real-life implementation issues and problems.
- (2) Investments (such as in R & D, pilot or market tests, or excavations) that can generate information and learning (e.g., about the project's prospects) by extending/adjusting option pricing and risk-neutral valuation with Bayesian analysis or alternative (e.g., jump) processes.

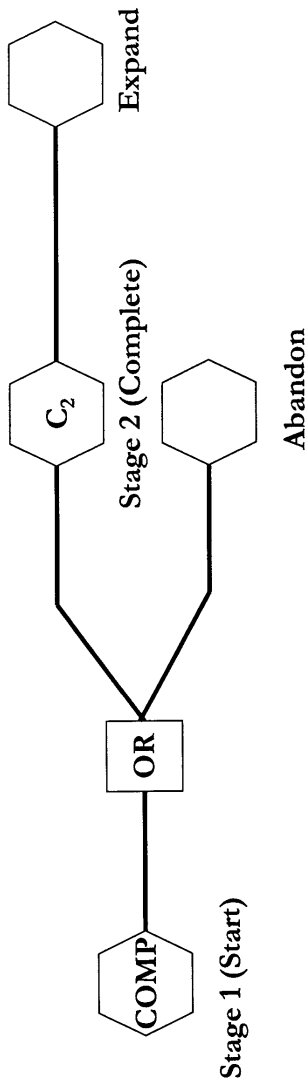
- (3) Exploring in more depth endogenous competitive counteractions and a variety of competitive/market structure and strategic issues using a combination of game theoretic industrial organization with option valuation tools.
- (4) Modelling better the various strategic and growth options.
- (5) Extending real options in an agency context recognizing that the potential (theoretical) value of real options may not be realized in practice if managers, in pursuing their own agenda (e.g., expansion or growth, rather than firm value maximization), misuse their discretion and do not follow the optimal exercise policies implicit in option valuation. This raises the need to design proper incentive contracts by the firm (taking also into account asymmetric information) and develop a more dynamic, option-based extension of economic value added.
- (6) Recognizing better that real options may interact not only among themselves but with financial flexibility options as well, and understanding the resulting implications for the combined, interdependent corporate investment and financing decisions.
- (7) On the practical side, applying real options to the valuation of flexibility in related areas, such as in competitive bidding, information technology or other platform investments, international finance options, and so on.
- (8) Using real options to explain empirical phenomena that are amenable to observation or statistical testing, such as examining empirically whether the management of firms that are targets for acquisition may sometimes turn down tender offers in part due to the option to wait in anticipation of receiving better future offers. We also need more empirical studies to confirm other qualified predictions of options theory, such as the impact of uncertainty on investment.
- (9) Doing more field or survey studies to test the conformity of theoretical real option valuation and its implications with management's intuition and experience, as well as with actual data when available.



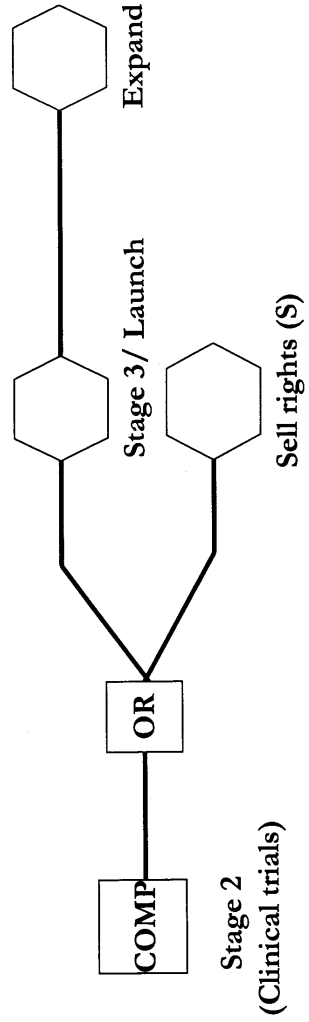
(10) Developing a more credible portfolio theory for (possibly interdependent) options under budget or other constraints that recognizes the potentially beneficial role of uncertainty in the presence of flexibility to select the best (subset) of [or switch among] alternatives. Apply this to address important strategic contexts, such as management of a portfolio of start-up ventures by a venture capitalist, running a portfolio of R&D opportunities by a pharmaceutical company, or selection of a subset of technologies to invest in by a telecom company and dynamic revision of the subset of invested technologies as uncertainties and their relative merits change over time.

# Exhibit 1

## POWERGEN: STAGED POWERPLANT CONSTRUCTION



## GLAXO: VALUING R&D/PATENT RIGHTS



## NATIONAL BANK OF BELGIUM - WORKING PAPERS SERIES

1. "Model-based inflation forecasts and monetary policy rules" by M. Dombrecht and R. Wouters, *Research Series*, February 2000.
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