

Real Options: Still Looking for Evidence?*

Henri PHILIPPE**

CEREG (CNRS-UMR 7088), Université Paris-Dauphine

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Abstract:

Despite a large body of literature on the topic, empirical tests of real option models are scarce. The lack of empirical data offers an initial explanation for this. However other intrinsic reasons could well explain why real options are difficult to test on large-scale studies. We show that the use of case studies is a partial solution to this problem since it improves our understanding of management's behavior but not test the validity of real option models. We support our argument by the analysis of 4 empirical studies traditionally quoted in the real options literature as well as on a real-life case study.

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** The author is a manager of Dome Close Brothers Fairness. This working paper reflects the opinions of the author and does not necessarily express the views of Dome Close Brothers Fairness.

Correspondence: CEREG, Université Paris-Dauphine, place du Maréchal de Lattre de Tassigny, 75775 Paris cedex 16

E-mail: h.philippe@dcbfairness.com

1 Introduction

For the past ten years, research on real options has significantly expanded in various directions, leading to quantitative as well as analytical developments. Real options are now widely present in corporate finance literature, academic journals, financial books, and even the financial pressⁱ. They form a consistent theory to answer some crucial questions of corporate finance (Lander and Pinches [1998]): How to include flexibility in the value, why risk can be valuable for firms, how finance may reconcile with strategy, etc. This academic success also has its roots in the quantitative finance interest for these new exotic options.

Beside this prolific body of research, several articles and papers have recently tried to set up a framework to use real options (Durand, Gomez and Monin [2000], Borison [2003]), and a few have even debated on the relevance of the theory (Kobrak and Spieser [2000]).

While publications in professional journals, introductory articles and case studies on real options are numerousⁱⁱ, implementations by professionals seem limited (Graham and Harvey [2001])ⁱⁱⁱ. At the same time, authors have searched for the emerging use of practitioners (Busby and Pitts [1996], Triantis and Borison [2001]), as well as the empirical validity of real option models (Berger, Ofek and Swary [1996], Quigg [1993]). However the number of these empirical studies is still rather limited.

The goal of this paper is to show why empirical studies on real options are difficult to conduct. The scientific nature of financial theory is grounded on its ability to test empirically its models on market data in large-scale statistic studies (Rainelli-Le Montagner [2003]). In that sense, real options, a field where these studies are rather limited, are an exception.

A first explanation might be the difficulty in gathering the massive quantity of information that is necessary to value real options. However the goal of this paper is to show that there might be other reasons intrinsic to real options to explain these difficulties.

It is important to find evidence of the existence of real options in market data, because real options are difficult to value with the tools used to value financial options. The main concern is the

arbitrage reasoning, which is rather unsatisfying since real assets are usually not traded. Some authors argue that we can use arbitrage reasoning ‘as if’ the assets were traded. Therefore if we were to find evidence of real options value consistent with a result from an arbitrage-based method, this would support this argument.

This paper is based on the analysis of empirical studies conducted on real options and traditionally quoted in the literature (Paddock et al. [1988], Quigg [1993], Berger et al. [1996], Moel and Tufano [2002]). The analysis of this sample highlights common difficulties encountered when real option models are tested empirically.

Our analysis of this sample shows that they have been conducted mostly in the natural resources sector. Moreover, in most cases, they concern simple assets where the option valued is obvious, i.e. the flexibility is inherent to the asset. This paper shows that real options are intrinsically difficult to test empirically if the approach is extended to more complex assets or options. This difficulty is explained by the subjectivity implied by the approach. In that context, case studies can only partially solve this problem. We support this conclusion by the study of a real-life case study.

The remainder of this paper is structured as follows. Section 2 describes briefly the different empirical studies of real options that have been analyzed. Section 3 highlights the main questions and issues raised by these studies. Section 4 details why real options should be empirically tested with other tools, such as case studies. Section 5 concludes on new research opportunities in the field of real options.

2 Review of a Sample of Studies

Different methods are used to test evidence of the existence and value of real options in financial market data. This paper examines a sample of empirical studies (Paddock et al. [1988], Quigg [1993], Berger et al. [1996], Moel and Tufano [2002]), traditionally quoted in the literature. This sample is not exhaustive but it provides an overview of the difficulties and issues with the use

of empirical tests in the area of real options. It is worth noting that these tests are common in corporate finance. Therefore the study should show why real option models are more difficult to test empirically and how real options differ from other financial assets.

2.1 Paddock et al. [1988]

Paddock et al. [1988] have empirically tested a real option model to value undeveloped oil reserves.

The authors consider that there is an embedded option in any undeveloped field. This option is equivalent to a call option on a dividend-paying stock. The owner of an undeveloped field has the opportunity to develop the field in the future, if he spends the development costs (i.e. the exercise price). In the meantime, if he does not exercise the option, he loses the production revenues (i.e. the 'dividend' of the asset). The developed reserve value is supposed to follow a Brownian motion.

The model results in a set of partial differential equations. The main parameters of the model are the value of the reserves and the standard deviation of the rate of change of the value of the reserves, the development costs, the risk free rate and the production revenues. The most difficult to value are the first two: the developed reserve value was assessed with actual transactions observed on the market (reported as a price per barrel). Since the standard deviation of the rate of change of this value can not be observed directly on the market (due to the limited number of transactions), it was estimated based on historical oil prices.

The model was tested on a limited number of contracts for offshore oil leases in the US, awarded in September 1980. The data was provided by an anonymous company that had bid for the leases. Then the model results were compared to actual bids offered by the company, to government estimates as well as to the industry average bids. The bid prices based on option value are lower than average bid prices observed. The authors conclude that a strategy based on option value could be more cost effective in a competitive bidding process.

2.2 Quigg [1993]

Quigg [1993] studied the value of an option to wait before investing in the real estate sector. Her research question was to test '*the empirical predictions of a real option-pricing model using large sample of market prices.*'

Each land is valued as an option whose underlying asset is the value of the building that could be built over it. Development costs as well as the price of the building (underlying assets) are following Brownian motions.

The value of the building is based on a hedonic estimation (i.e. a function that defines the value of the asset as a function of different parameters). Some of the parameters are the square footage of the land, its height and age, type, etc. These parameters were estimated on the basis of data available on developed properties.

The model defines a set of partial differential equations for which the author seeks the equilibrium point where it is optimal to build (building price vs. development costs). This assumption offers a closed form solution to the model. It results on an option-based value of the land as well as implicit estimates of the standard deviation of the rate of change of the undeveloped land value.

This test is based on market data for local transactions in Seattle (2,700 observations of undeveloped properties and 3,200 concerning developed properties) over the 1976-1979 period. It confirms that actual prices observed in transactions include a premium that could account for the option to wait.

2.3 Berger et al. [1996]

Berger et al. [1996] examined the empirical implications of a real option model to price an abandonment option.

The research question was '*whether investors use balance sheet information about a firm's assets to value their option to abandon the continuing business in exchange for the asset's exit value.*' The authors consider this option to be equivalent to an American put option on a dividend-paying stock. All other things

being equal, the authors consider that, assuming that the market values this option, firms with a greater exit value should worth more.

Since exit values are not directly observed on markets, the authors value them based on average amounts extracted from the balance sheets footnotes on 'discontinued operations'. The main parameter of the abandonment option is the underlying asset value, which equals the present value of future cash flows of the company. The authors assume that analysts' earnings forecasts are a good proxy for those cash flows.

This translates into the following equations (Berger et al. [1996, eq. (1), (2)]):

$$VALUE = PVCF + P(PVCF, EXIT, SDEV)$$

$$\left(\frac{VALUE}{PVCF} - 1 \right) = P \left(1, \frac{EXIT}{PVCF}, SDEV \right)$$

VALUE is the firm's market value, PVCF is the present value of the firm's expected operating cash flows, P is an operator representing an American option value, EXIT is the exit value of the firm's assets, SDEV is the standard deviation of $\frac{VALUE}{EXIT}$.

Myers and Majd [1990] have shown that there is no closed-form solution to this general form of the abandonment option. However the second equation offers a representation of its value as a percentage of the PVCF, which can be empirically observed. Thus, with this ratio, exit values may be tested on a sample of data.

A main difference with other studies is that authors in this article are testing the relation presented in the second equation above by different regression analyses. Hence, they are not trying to directly solve the partial differential equations as in other papers.

This test was based on market data for companies (sales above \$20 million) for which analysts' forecasts were available (on the IBES database - Institutional Brokers Estimate System) as well as CRSP and Compustat data over the 1984-1990 period. This resulted in 7,102 observations. The authors find strong relations anticipated by the abandonment option theory (e.g., between market values and estimated exit prices as well as on the factors affecting the probability of exercise of the option).

2.4 Moel and Tufano [2002]

Moel and Tufano [2002] studied the decision pattern of closing and reopening gold mines in North America. The option valued is the flexibility to open, to temporarily shut down or to permanently abandon a mine based on the evolution of the commodity extracted from the mine. Brennan and Schwartz [1985] have studied previously this problem.

The research question is to test whether the actual management decisions to close/open mines have been in accordance with the predictions of real option models. Therefore the authors test with multiple regression analyses various assumptions (i.e. relationships between variables and option value) drawn from real option theory (Brennan and Schwartz [1985]).

The parameters used in the analysis are gold prices, their volatility, the interest rate, the mine cost structure in the various states (closed, opened, in production), the prior state of the mines (open or closed).

This test is based on data constructed by the authors based on various database and public information. Their sample is composed of 285 gold mines in North America over the 1988-1997 period. Their study confirms that management decisions have been taken in accordance with real option model predictions. Colwell et al. [2002] have recently conducted a similar study on Australian gold mines over the 1992-1995 period that confirms these conclusions.

3 Comments on the Sample

This sample of empirical studies raises a number of comments and issues.

The studies cover a limited number of sectors, principally natural resources^{iv}. This is no surprise (Slade [2001, p. 194]) since real options originally developed in this field (Henry [1974] and later Brennan and Schwartz [1985], McDonald and Siegel [1986]). However many authors have highlighted the potential use of real options in many different sectors (Lander and Pinches [1998]). Therefore the lack of empirical studies in other sectors is a first concern. It could be explained by the lack of empirical data. Natural resources are usually traded commodities and hence have an

obvious advantage for researchers: this context is appropriate for arbitrage reasoning. The use of this kind of reasoning is more questionable for R&D projects or high-growth Internet start-ups (Schwartz and Moon [2000]).

A second comment relates to the objectives of these studies. There is a difference between the study of patterns (*'are the actual behaviors of managers consistent with real option model'*) and values (*'are the values resulting from the model different from the prices observed on the market'*). It seems that the latter is difficult in most cases since actual prices for the assets are usually not directly observed in markets (the exception being Quigg [1993]). In some cases (Paddock et al. [1988]), authors compare their real options values with static values (i.e. obtained from traditional discounted cash flows models) or values extracted from private data. The issue is that even if real option models are good predictors of managers' behavior, it doesn't necessarily mean that they value the assets properly. Moreover testing behaviors rather than values is a sign that there is a difficulty to observe actual prices of assets in most cases and to compare them to the models' results. As shown later, it is also a sign of the difficulty to design and populate real option models.

The analysis of the studies also shows difficulties in modeling the real options themselves. Since they are not formally contracted between different parties, authors have to 'define' and to 'model' the real options they perceive in the firm. Most of the difficulties lie in the modeling of the underlying asset but also of the exercise decision. To circumvent these difficulties, most authors simplify the exercise decision. Quigg's [1993] value of an undeveloped land is based on an estimation of the building value that could be erected over it. This 'underlying asset' value is the result of a hedonistic function to value a building based on various criteria. Even if the ability to erect (and delay the decision) seems significant in this case, the issue at stake is more complex. For example, the impact of regulations and other stakeholders (e.g., public opinion) could explain partly the decision to delay the erection of the building. Moreover, there are some path-dependency issues in this real estate case. For example, because a first building has been erected in an area it could alter significantly the opportunity to erect a subsequent one in the neighborhood.

The difficulty to obtain a tractable model is also a concern when testing models empirically. Usually, real option analyses result in a set of partial differential equations with no closed form

solutions. In Berger et al. [1996], the authors test with several regression analyses the relations predicted by the real option model rather the model itself. Even when a closed-form solution for these equations is obtained, it usually requires the assessment of exotic parameters. These parameters might be described as 'exotic' since they are not directly observable on the market. Moreover the assessment of several of these parameters is not required when valuing a project with traditional tools. For example, Paddock et al. [1988] have difficulties estimating the standard deviation of the rate of change of the value of the undeveloped reserves. To get around this difficulty they base their assessment on rough assumptions (e.g. Paddock et al. [1988] use oil price data as a proxy).

The main question for researchers empirically testing real option models is to find samples of data large enough to draw valid conclusions. The first solution is to conduct studies on assets relating to commodities, where large samples of data are available, and on simple assets. In that sense, 'simple' means assets for which the production function can be easily modeled (e.g., a pipeline, an oil field) and options for which the exercise decision modeling and underlying assets are obvious. This is consistent with the trend to develop real options theory on less mature, simple projects: R&D and patents (Schwartz [2001], high-growth companies (Schwartz and Moon [2000]). This doesn't mean there are no options embedded in other projects. It seems that they are just more difficult to value "objectively" and consequently to test empirically.

4 Real Options: Strategy Translated in Financial Language?

In most cases, real options, as reflected in the sample, concern assets whose value is heavily contingent on traded commodity prices and that are based on simple projects (i.e. simple exercise decision of the option and simple production function). Through these empirical tests, it seems that the underlying argument is that real option theory is appropriate in a limited area. In other sectors,

empirical studies show empirical evidence of their existence and of the relations presented in the theory (e.g., Berger et al. [1996]), but not of their value. However this narrow approach of real options empirical testing does not seem to be consistent with the overall use of real options: there are many different kinds of real options that should also be tested and real options are useful for many reasons and not just for valuing. Hence the focus of empirical tests should not necessarily be on testing value but more on understanding investors' behaviors.

4.1 Many different kinds of real options

Real options theory results from the transposition of option pricing models outside financial markets. Therefore, the use of real options on flexible commodity-like assets is understandable. However the scope of real options is broader (Lander and Pinches [1998]), in terms of both industry sectors and type of options. Amram and Kulatilaka [1999] present case studies in a wide variety of industries: start-up, oil industry, drug development, infrastructure, real estate, licensing, gas/oil turbines and technology industry. Moreover there is a wide variety of real options identified in the literature:

- Investment options are available in any asset investment (to wait before investing, to decrease the scope of the investment, etc.);
- Operating options exist in most projects (to abandon the project, to shut/restart a production, to switch inputs and/or outputs, etc.);
- There are also other kinds of options that could be defined as 'strategic' (i.e. growth options, inter-related options, etc.).

This classification is neither exhaustive nor restrictive since many options belong to different classes. It offers an overview of the trend from the simplest options to the most complex ones. It has been shown earlier that real options have to be 'designed' by the valuer since they are not contracted in the market. The above classification shows the degrees of simplification needed to model different kinds of real options.

The first two types are the easiest to assess and to test empirically since they are consistent with the view of a simple asset exposed above. The third one is more difficult to assess since strategic

options have broad implications on the firm. For instance, Kellog and Charnes [2000] value a new drug as series of growth options. Each option is contingent on the size of the market as well as on the regulator's decision to let the clinical experimentation continue. In this case, there are several inter-related growth options: each option offers an opportunity to go one step further and obtain a new growth option, until the final one, which gives the opportunity to launch a new drug. But the more options are complex, the more difficult they are to design and hence to value.

4.2 Real options: not just a valuation tool

Besides the traditional use as a valuation tool, there are also different other possible uses of real options. Many authors (Amram and Kulatilaka [1999], Chatwin et al. [1999], Triantis and Borison [2001]), real options may help in conducting and planning a strategy. Chatwin et al. [1999] present a general framework to analyze strategic issues and translate them in terms of real options:

'OpenFraming is a structured discussion process that aims to define the Real Option Valuation (ROV) problem for a company by identifying business risks, as well as the options available for converting those threats into opportunities, and then establishing a framework for analyzing the risks and options. ROV involves an ongoing dialogue between decision makers and the valuation team...'

This tool is based on interactions with management, but also requires the involvement of a team comprising the staff from each of the main departments of the firm (finance, operations, sales, marketing, human resources, etc.). A workshop is set up to facilitate dialogues between experts, management and the valuation team: therefore it is neither a top-down nor a bottom-up approach, it might be better described as a cross-functional approach. The goal is to offer the best knowledge of the firm at one point in time.

Therefore real options build an open area where different functions of the firm can debate about their future. It also offers a toolbox with useful concepts to translate part of the strategic initiatives into a formal financial business plan. In that sense, the analogy with financial options may be particularly helpful since it highlights concepts to formalize the rather vague notion of strategic flexibility within the firm (e.g., underlying asset value, strike price, maturity, etc.). The firm might not be able to attribute a financial value to these options, but real options offer the tools to discuss

the future strategies of the firm with shared concepts. Hence it could generate new ideas and debates within the firm.

In that broader context, real options translate part of the 'knowledge' available in the firm. This move from information-based models to knowledge-based model has significant implications on the empirical study of real option models. Information is defined by Fransmann [1998]^{vi} as '*data relating to states of the world and the state-contingent consequences that follow from events in the world that are either naturally or socially caused*'. According to the same author, 'knowledge' is the fruit of an interpretation of the information available and therefore is contingent on individual's cognitive models.

On one hand, Paddock et al. [1988] develop an information-based model since they rely heavily on market data and because the asset they value (undeveloped oil reserve) has one major obvious option. On the other hand, Chatwin et al. [1999] present a knowledge-based model that relies on the knowledge gathered during workshops with management more than on information gathered on the financial market.

The use of knowledge-based models raises questions about their subjectivity and on how to test them empirically. When designing a real option model with the objective to test it empirically, authors have to find obvious (i.e. indisputable) strategy: anybody would agree on the existing real options and uncertainties, as in the case of Paddock et al. [1988]. This explains why the empirical studies analyzed above concern simple flexible assets with obvious decisions available (e.g., to abandon the asset in certain circumstances). If this is not the case and if there are multiple options available and existing risks associated, there would be some subjectivity involved that could impact the modeling of the issue. Consequently, real options would provide a subjective value in that case when we are testing a market (objective) value.

4.3 Are we looking for evidence or testing values?

Empirical tests of real options may either provide evidence of the existence of real options, at least of the consistency of managers' behavior with the theory, or test the results of real option models compared to actual prices observed on market data. As discussed above, the latter are more easily conducted on commodity-like simple assets. These studies present the most convincing proof

of the contribution of real option models. On the other hand, the former type of studies offer only indications of the possible existence of real options, but no direct evidence concerning their ability to value assets. Berger et al. [1996] have shown that evidence of the existence of abandonment options might be found on large-scale studies. In another study, Smith and Watts [1993] present various potential measures (indices) of the investment opportunity set (growth options portfolio) of the firm: the ratio of book value of assets to firm value, the ratio depreciation to firm value, the ratio of R&D costs to firm value, the variance of the rate of return of the firm, the price/earnings ratio, the capital expenditures/firm value ratio.

These studies may help to confirm that real options exist, or, more precisely, that managers behave in a manner consistent with real options theory. However these kinds of studies are unable to quantify the options studied, since this would require a deeper analysis of the issues at stake and hence require a move towards a more 'subjective' value. At the same time, this need for a deeper analysis would remove the possibility to study a large sample of cases. It seems also that real options have broader uses than just valuing assets, and could also be useful as a way of thinking or as a strategic tool. As such there is a need to identify a research method to 'test' the validity of the tool in these new contexts.

5 Cases studies as a tool for real options empirical tests?

When considering methods available to test empirically real option models, if we exclude large-scale studies, researchers may turn to case studies. Tufano [2001] has shown the potential interest of case studies as a research tool in finance.

The real options literature presents a large number of case studies (e.g. Amram and Kulatilaka [1999], Chatwin et al. [1999], Kellog and Charnes [2000]). However most of these may be considered more as 'examples' of how to use real options than as 'empirical studies' of real options.

When considering complex real options, we have to rely on subjective analysis to frame the issue and develop a real option model: some options might be included, others disregarded, etc. By

conducting case studies, the researcher builds a rationale to justify and/or explain his subjective valuation. This approach is common when defining parameters in finance, it is more original when it comes to defining the object valued, its boundaries, its prospects. These elements are usually taken as given data in traditional financial research while they have to be built in the case of real options (Chatwin et al. [1999]). Hence, in that context, case studies on real options bridge the traditional distinction in corporate finance between investment strategy (*'where are the growth options coming from?'*) and financing strategy (*'what is the value of these growth options?'*).

Therefore, this method presents a new axis of research in corporate finance. Case studies develop a different kind of evidence on the consistency of management behavior with the real option theory based on detailed in-depth analyses of particular situations: case studies may be helpful to understand whether the design of real options in the model is appropriate or not. They offer a field analysis of the set of assumptions built during the designing process, such as:

- What is the underlying asset? How is it valued? How does it evolve? How is the option value shared between the different stakeholders of the firm?
- What is the exercise decision of the option? Who is actually making the decision within the firm?
- What is the premium paid to 'acquire' the real option?
- What are the main factors affecting these parameters?

These arguments in favor of case studies should not hide the difficulties of the method. In particular, the empirical test of real options ability to value assets is still debatable. In particular, when valuing specific cases, we compare real option models results with actual market and/or transactions prices, as well as with other methods' results (e.g., discounted cash flows or market multiples). However the conclusions drawn from these comparisons are not clear and, more importantly, cannot be generalized since they are based on subjective analyses.

By definition it seems impossible to answer the question of real option models' ability to value assets in accordance with market data, because real options in most cases imply some kind of subjectivity in the analysis. However case studies could provide further evidence that managers

behave consistently with real options theory. Moreover case studies should improve our understanding of the firm's value through the real options' lenses.

5.1 An example of case study research (and, hopefully, some insights...)

We illustrate our discussion on case study research in the field of real options by the analysis of a real-life case study: Nikopol^{vi}. This company, founded by a team of 15 researchers is a Research and Development firm specialized in chemical research. Its founders have a long experience in both fundamental and applied research. The main assets of the firm, besides its human capital, are the various international patents it has developed. The main growth opportunities of the firm directly rely on both kinds of assets. In particular, Nikopol has discovered a new chemical formula called "Pi", which could be useful in mass markets (food and chemical business). Pi key characteristics are that Pi is less dangerous than existing formulas (called "Y-type") and cheaper to mass-produce than existing formulas (called "Z-type").

We met Nikopol's shareholders in a transaction context. Nikopol is managed by researchers, which have already been successful in the business: a few years ago, they already experienced the same story, and launched a successful start-up and went through the whole industrial implementation process of their discovery. Because of their past experience, and of their age, they are not ready to repeat the experience ago and so they are eager to sell their company. Therefore, the objective of our mission was to value the business, but also to create a selling business plan and prepare shareholders to answer questions from potential buyers.

The 2002-2015 business plan was designed in a long lasting process (several months), during which most business plan assumptions were proposed, discussed, etc. At the end of the process, many different sources of information have been used: market analysis, industrial forecasts, expert interviews and weekly meetings with Nikopol's management.

The main difficulties in valuing Nikopol are linked to the projections of the company's future revenues. Nikopol's balance sheet presents almost no assets and liabilities. Like most R&D companies, its investments are expensed and not capitalized. Most of Nikopol's future revenues will be generated future opportunities, and hence subject to numerous uncertainties, and almost nothing

by current assets-in-place. A wide range of uncertainties might affect the future of Nikopol in terms of market acceptance, delays, market shares, competition, patents life, price, ability to license, etc. All these have been in the original business plan through the use of discrete-state uncertainty (basically High/Nominal/Low scenarios for each uncertainty).

A few of these uncertainties were finally modeled in the following decision tree:

INSERT FIGURE 1 ABOUT HERE

The uncertainties were modeled in a dynamic spreadsheet on Microsoft Excel. The model computes discounted cash flow calculations for each scenario. A terminal value was estimated based on the Gordon-Shapiro formula assuming 2015 would be the first 'normative' year for Nikopol. We considered that, in a transaction context, the cost of capital could be based on the return expected by venture capital investors (20% - 25%).

The optional value of Nikopol was approached through an option to abandon: if Nikopol's results are lower than expected, or if the management receives disappointing information from the market, it has the opportunity to go bankrupt (i.e. an option to abandon). This option is common to all shareholders and was described by Myers (1977). By 1st January, 2005, at the latest, Nikopol's management must decide whether or not to build the plant to produce Pi on a mass scale. Management assumes that at this date they will have a better knowledge of the market, and especially of the price they might offer on the market and based on the sole knowledge of the uncertainty on price, management will exercise or not their option to abandon^{viii}. The uncertainty on price is solved in 2005 before the decision regarding construction.

We used backward induction to include this flexibility in the decision tree: We begun the analysis with the final branches, and computed the value backward, by assuming that each time we encounter a decision node management will make the decision that maximizes the NPV.

The graph below shows the sensitivities of the static value to the uncertainties, all other things being equal. There is a clear asymmetry between gains and losses due to the option to abandon if things turn sour for shareholders:

INSERT FIGURE 2 ABOUT HERE

Based on the decision tree, the expected value of Nikopol is 2.2 million Euro including the option to abandon, and 1.6 million Euros excluding the option. The risk profile of the value is shown in the following graph (the dotted graph corresponds to the value without the option to abandon, the vertical bar to the expected value):

INSERT FIGURE 3 ABOUT HERE

The option to abandon offers a valuable flexibility to Nikopol's owners (around 34% of the total value).

It is worth noting that the main uncertainties that Nikopol is facing are market- and competition-related. These uncertainties were modeled in a simple manner (based on scenarios) and, in particular, the complex relations between the option value and the competitors' behavior were ignored in the financial model. The matrix developed below will offer an explanation to justify this assumption. It was also assumed that the uncertainty on the researchers' ability to finalize the project is accounted for in the discount rate. Moreover, it was assumed that the implicit risk of default of researchers is nil since Nikopol's and researchers' interests are supposed to be the same.

Numerous criticisms might be raised against the method used to solve the case (how we came up with the discount rate, how we assessed the probabilities, how we valued the flexibility, etc.). We concentrate in the following paragraphs on why case study has been a valuable research tool in this context and some evidence from the case that managers/investors behave consistently with the existence of real options.

5.2 Case study insights: from model to reality

5.2.1 Corporate governance matters...

After this round of preparation of the current shareholders and a preliminary valuation of Nikopol, we have been through a formal acquisition process. What is striking is that investors were more concerned by legal issues than by the business plan itself. Financial investors were in fact behaving consistently with Myers' (1977), and Miller and Modigliani's (1961) view that firms' value is generated both by growth opportunities and by assets-in-place. Hence, in Nikopol's case, because

revenues generated assets-in-place were nil, all concerns were dedicated to growth opportunities and in first place to the understanding of their protection.

The consequence of this was twofold: firstly, investors were feeling that their assessment of Nikopol's value based on a single business plan was inappropriate, either over-optimistic or too conservative. They also understood quickly the risks associated with the projects as well the fact that the risk would severely decrease in the near future based on incoming information (hence this was an incentive to increase the length the transaction process).

At the same time, in the due diligence process (pre-acquisition audit), the earliest questions (from financial investors) concerned the project's legal protections, but also the incentive schemes of the researchers. Investors were feeling that researchers could in a sense "steal" or at least significantly influence the value of Nikopol's growth opportunities. It seems that the possibility of the capture of growth options value by researchers has justified in potential investors' minds the design of specific incentives mechanisms.

When a researcher foresees a project that has such a value on a stand-alone basis that it could be worthwhile for him/her to pursue this project outside the firm, he/she could still abandon the value of its stake in the firm (shares, revenues, benefits, but also social position, image, etc.). Therefore, employees may compete for the value with the firm. It has already been the case in the past: Nikopol was founded by researchers from various institutions (i.e. companies, government agencies) that left these institutions when they understood the potential value of their discovery on a stand-alone basis. This capture of value is made possible in this sector by several factors:

- Most projects are kept secret and consequently firms are reluctant to patent them early. Moreover only the product's key features are patented to minimize the amount of knowledge and research made public.
- These chemical projects initially require limited capital expenditures and a large part of the knowledge is relating to the 'art' of the chemist.

Shareholders conscious of these difficulties have aligned key employees' interests with their owns': Nikopol's founders granted free shares to the most important researchers. Therefore, shareholders and key employees are the same people in Nikopol. Patents have also been filed in the

name of persons that are obliged to do so in their employment contracts. Consequently, with these capital and legal links, Nikopol's founders attempted to ensure that the property of any growth opportunity would remain within the firm.

5.2.2 ... And so does history!

Besides this corporate governance questions, financial investors were also concerned by the ability of others (competitors, suppliers, and even Nikopol's own employees) to launch competing product and hence destroy most of Nikopol's value. Investors' underlying question was to understand what factors justified to attribute the value of these options within Nikopol's boundaries: who really owned these growth opportunities?

A first easy answer was that some of Nikopol's growth options are linked to patents, legally protected in various markets, in various countries. However this is only a partial answer since most projects are not based on patented products (avoiding patents is a way in this industry to preserve secrecy on the research strategy).

In fact Nikopol 'owned' growth options to develop a new promising chemical formula because this project depends partly on the firm's assets (tangible and intangible), but also on organizational factors (skills, knowledge, know-how, etc.) and on its stakeholders (employees, suppliers, customers). Therefore the value created by the growth option is not necessarily related to any existing contracts or assets. However, there are many path-dependencies to explain why this growth option may lie within the firm's boundaries:

- Because its founders have already been successful in the R&D business, it has been decided to create Nikopol. This earlier success has facilitated the access to funds and expertise (researchers and industry experts).

- Because Nikopol's founders already had the experience of a company's creation, they have also decided to gather the knowledge of market and industry experts. They knew, from experience, that marketing experience would be vital in their project, and that research skills were not enough in this project.

It seems that these options are within the firm's boundaries, because the firm continuously gathered assets (tangibles and intangibles) essential to the creation and exercise of the options and hence it would be extremely costly for a stakeholder (e.g. a researcher) to gather an equivalent set of assets to compete with the firm without following an equivalent long-lasting process. The value of the option within the firm seems to be higher because of these path-dependencies and the costs they imply.

All these difficulties (governance and ownership questions) have significantly influenced investors during their valuation process. These difficulties have not been solved with our real option valuation. However the real option process was key to answer some of their questions:

- Where does Nikopol's value come from?
- What are the main factors (i.e. uncertainties, people, external risks, etc.) that could affect the value?
- What are the main elements in managers' hands to protect that value?

6 Conclusion

Real option models are based on a solid theoretical background from the financial theory. At the same time, these models have been welcomed by practitioners and academics alike as a better way to model flexibility and uncertainty. However only a limited number of empirical tests of these models were conducted in the recent past.

The analysis of a sample of these studies reveals several reasons to explain this lack of empirical studies. First the difficulty to gather the massive quantity of data required to conduct such studies. This paper has highlighted a second reason intrinsic to real options. Since real options are not formally contracted, researchers have to 'design' the option. Hence, there is some subjectivity

involved in the research process. To limit this difficulty, research has been limited to commodity-like and simple assets where the real option design is obvious.

This paper has shown that case study research can be a fruitful research method for the empirical testing of option theory by providing evidence of the existence of real options (at least in managers' minds, who behave consistently with their existence) but also more importantly to progress on our comprehension of real options. This axis of research should provide a better understanding of the value of the firm and of the design of complex real options. However the scope of this research method is limited since it can only study the evidence of the consistency of management behavior with the theory, but not the validity of the models themselves (i.e. their ability to value real options).

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Figure 1: Decision tree

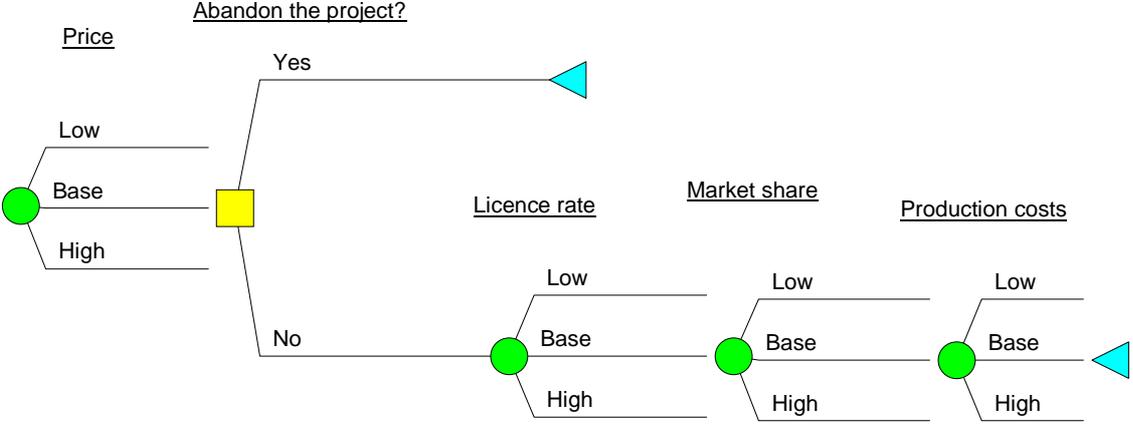


Figure 2: Tornado diagram of the value

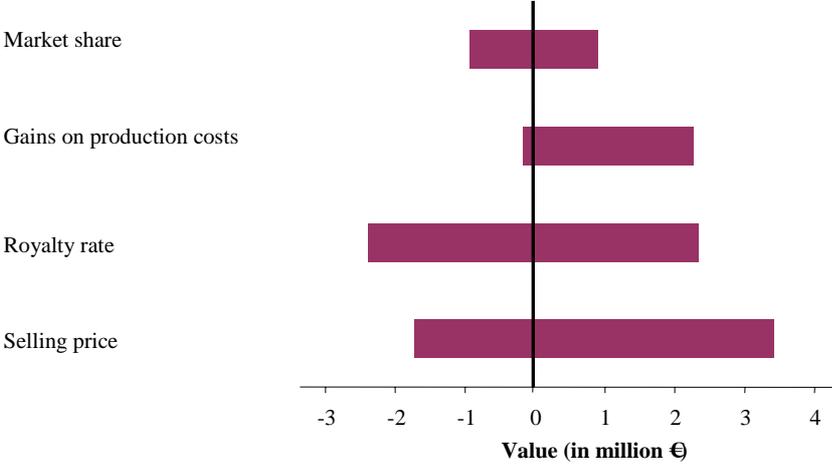
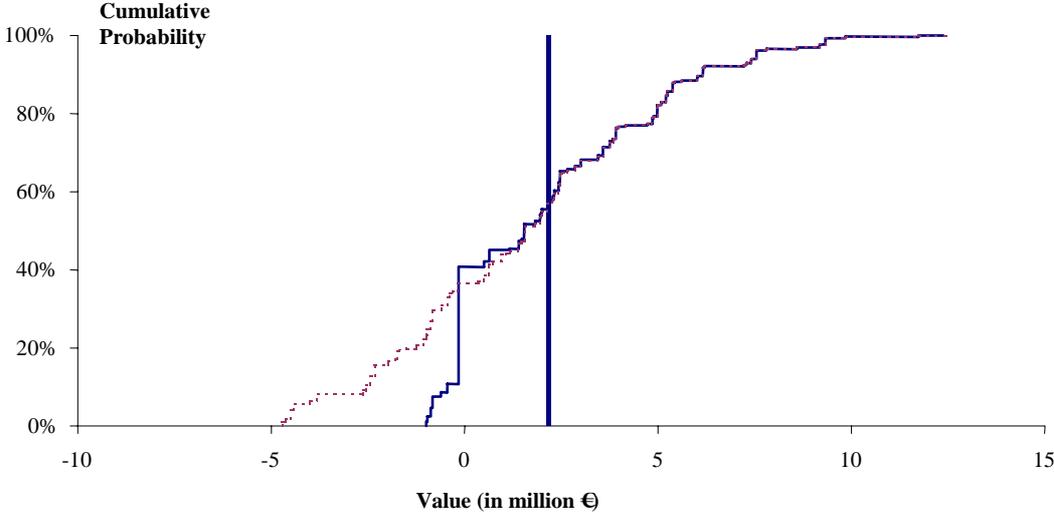


Figure 3: Risk profile of the value



ⁱ Hence the most common corporate finance handbooks dedicate a complete chapter to real options (e.g., Brealey and Myers [2000]).

ⁱⁱ Titles of these articles are unambiguous: Luehrman [1998] « Investment opportunities as real options: getting started with numbers », Mauboussin [1999] « Get real – using real options in security analysis », etc.

ⁱⁱⁱ According to Graham and Harvey [2001], 26.9% of the interviewees in their sample (US companies) use always or almost always real options in their analysis. For Geddes [1999], only 2% of their interviewees (UK and Irish companies) use usually or almost always real options.

^{iv} Quigg [1993] with a study in the real estate sector is an exception.

^v Just like the expected volatility of the return of a stock for a traditional call option on financial markets.

^{vi} Quoted by Charreaux [1998].

^{vii} Names and various elements of the context have been changed to preserve confidentiality of the information provided to us.

^{viii} Liquidation costs are considered as nil.