When Financial Derivatives can be Applied to the Real Economy – the Case of Exotic Options in Corporate Finance

JIAN WU*
Full Professor of Finance
Neoma Business School, France

I. Introduction

Over the last few decades, financial markets have made unprecedented development. Transactions are becoming faster and safer thanks to the progress made in information and communication technology. At the same time, with the help of mathematical models, a large number of financial products have been invented to meet investors' specified needs in their investment and risk management process. Such progress helps financial markets better fulfill their economic function which consists in capital and risk reallocation.

The only possible downside of this amazing development is that financial markets and their instruments are becoming more and more complicated. As a result, they turn out to be little accessible and hardly comprehensible by most investors. For example, exotic options are tailor-made to satisfy investors' specified requirements in their currency and interest-rate risk management. As they respond better to users' expectations in terms of market anticipation, exotic options are considered as more effective than traditional options in terms of risk reallocation. However, most research conducted on the topic is published in specialized academic reviews while focusing on mathematical modeling and/or statistic tests without always providing understandable explanations and/or concrete applications in a real economy context. As a result, after their impressive development over 30 years, exotic options still remain little known to many investors.

* Address: Neoma Business School – Rouen Campus
1 rue du Maréchal Juin – BP 215
76825 Mont-Saint-Aignan Cedex, France.
Email: jian.wu@neoma-bs.fr
Tel: + 33 (0)2 32 82 57 72.

The author would like to thank an anonymous referee of Bankers, Markets & Investors for his precious comments which have helped significantly improve the paper. She would also like to thank her colleague, Catherine Derrien-Churchill, for her proofreading which has made the article more pleasant to read. The usual disclaimers apply.

Misunderstanding may lead to misuse of financial products, which may induce mistaken investment decisions and inappropriate risk-taking, while proper understanding can avoid a large part of the problem. Let's take the example of structured products – a family of innovative instruments resulting from financial engineering. Marketed through mutual funds and life-insurance funds, distributed by banking networks, structured products are usually composed of two or more components. Some of these components are traditional financial assets such as bonds, stocks and equity indexes, while at least one of them is a derivative product (see Das (2000)). Structured products were introduced to investors to give them access to non-standard financial instruments by providing them with "an alternative to standard direct portfolio allocation" (see Bertrand and Prigent (2015a)). Their economic added-value involves basically offering "structures with special risk/return profiles that may not be otherwise attainable on the capital market without significant transaction costs being incurred – at least for private investors" (see Stoimenov and Wilkens (2005), Bertrand and Prigent (2015b)). In this sense, structured products contribute to completing financial markets and making the economy more efficient.

The most typical structured products are "capital-guaranteed funds" and "capital-protected funds". Capital-guaranteed funds provide investors with a "guarantee of 100% of their capital", while capital-protected funds offer them a "protection of capital at a certain level (for example 80% or 90%)". Both of them allow investors to take advantage of a possible market increase through the benchmark index while protecting them against a market decline at a certain level. It is not always easy for investors, in particular for non-sophisticated ones, to well understand the mechanism of these funds so as to distinguish between them. For example, in a capital-protected fund where the capital gain or loss is linked to an equity index, some investors may believe that their capital will remain intact in any situation while in reality they may lose part of their capital in the case of a market decline.

According to Célérier and Vallée (2013), product complexity has been constantly increasing due to competition between financial service providers, and this even after the 2008 financial crisis. This complexity is still more significant in the products distributed by networks whose customers are the least sophisticated, which is for example the case of savings banks. In this respect, there is a clear gap between supply-side complexity and demand-side sophistication, which inevitably leads to a high level of information asymmetry between the product structurer (who is usually the final provider or hedger of the derivative component, which is the case of investment banks such as JP Morgan and Goldman Sachs), the product distributor (who acts as an intermediary, which is the case of retail banks such as Caisse d'Epargne and Banque Postale), and the final consumer (i.e., mass-market retail investors).

In a transaction, a situation of asymmetric information could be harmful because one party can take advantage of the other party's lack of knowledge to make the deal in his or her favor. In the case of structured products, the only party who is able to have a perfect mastery of the situation is the product structurer, while the other two parties (in particular the final consumer who subscribes to a product just because he or she trusts the product distributer) have limited ability to well understand the mechanism and/or the risk of the product. To reduce information asymmetry, we need to reduce the gap between supply-side complexity and demand-side sophistication. This means that we need to reduce product complexity from the supply side on the one hand and increase investors' sophistication from the demand side on the other hand.

To reduce product complexity, the aspect of investor protection needs to be reinforced through market discipline (including regulation and supervision by financial authorities as well as the establishment of standards and codes of good conduct for financial service providers). To raise investors' financial literacy level, the first thing to be done is to give investors an appropriate insight of the existing products. For this, Bertrand and Prigent (2015b) analyze the main characteristics (including issuer, financial mechanism, maturity, and type of underlying-assets) of the structured products sold on the French market providing a guarantee for the whole part of investment capital. They also propose a typology which classifies these guaranteed funds into 11 groups while examining the issue of fair pricing relative to the Black-Scholes model.

From this study, two observations can be made. First, the mechanism of structured products is very complex. Second, most of the examined guaranteed funds reveal the characteristics of exotic options. More precisely, among the eleven groups of products, at least seven have a financial mechanism belonging to exotic options. Some of them have only one "exotic feature", which is for example the case of "fund with potential redemption before maturity", "Asian type", "fund based on average of past performances", "lookback type", "truncated OBRI", and "binary option type", while others have two or more "exotic features", which is the case of "truncated OBPI (average)" which combines the properties of binary options and Asian options. As a result, if investors want to understand the mechanism of structured products, they need to understand beforehand the mechanism of exotic options.

In this respect, Wu *et al.* (2011) propose a classification methodology which structures exotic options according to whether or not the five conditions respected by traditional options are met. Such a structure would help investors better discern the difference between traditional options and exotic ones.

On this basis, to help non-sophisticated investors improve their literacy in exotic options, a good way is to show how these products work in a context where "real economy" makes sense. Such an approach has the advantage of focusing on the economic rationale rather than on quantitative skills. This concern is the very purpose of the present paper. In fact, as far as we know, applications of exotic options in corporate finance have not yet been examined in a systematic way even though the topic of exotic options has been extensively analyzed in the field of financial markets. Our work aims to contribute to filling this gap by providing a comprehensive synthesis of this topic.

Corporate finance deals with financial decisions made by corporate managers. These decisions can be grouped into four main categories, namely long-term investments, long-term financing, short-term cash management and strategic management. Option applications in short-term cash management involve essentially operations in financial markets. This subject has already been largely dealt with in the literature, which is devoted to risk management. For this reason, in the present article, we choose to focus exclusively on applications of exotic options in three other categories from a "corporate" point of view.

Even though options have been developed essentially in the field of financial markets, the seminal work which triggered this impressive development was made in the field of corporate finance, more precisely in capital structure analysis based on the option approach (see Black and Scholes (1973), Merton (1973)). In fact, when a firm is financed with equity and a single zero-coupon bond, shareholders' wealth can be analyzed as a European call option with the value of the firm as underlying-asset price, the face-value of the bond as strike-price, and the repayment date of the bond as maturity date. Within this framework, once the bond is no longer a simple zero-coupon, shareholders' wealth is no longer a traditional option, but an exotic one. Given the importance of the option approach in equity valuation, we think that it is important to add a fourth part to our analysis in which will be developed the most common applications of exotic options in capital structure analysis.

The rest of the paper is organized as follows. Section 2 presents briefly the main characteristics of exotic options and their classification. Section 3 illustrates how exotic options can be used in corporate finance. Section 4 summarizes the main results obtained in this article and presents some concluding remarks.

II. CHARACTERISTICS OF EXOTIC OPTIONS

The original purpose of financial markets was "capital reallocation" which involves transferring capital from lenders to borrowers. With the development of derivative markets since the 1970s, this purpose has been extended to "risk reallocation" which involves transferring risk from "risk givers" to "risk takers". Since then, derivative markets have become an integral part of financial markets.

In financial derivatives, options are distinguished from definitive or unconditional contracts such as forwards, futures, and swaps due to their asymmetry in terms of gain/loss between option-buyer and option-writer. Options can be classified in different ways. For example, according to the right to buy or sell, call options are distinguished from put options. According to the period during which options can be exercised, European options are distinguished from Bermuda and American options. Depending on the organization of the market on which options are traded, exchange-traded options are distinguished from over-the-counter (OTC) options. According to the nature of the underlying-asset, stock options are distinguished from stock-index options, fixed-income instrument options, currency options, credit options, commodity options, and energy options. Finally, according to the mechanism of the option contract, exotic options are distinguished from traditional or plain-vanilla options.

Relative to traditional options, exotic options are characterized by their ability to be tailor-made to satisfy investors' specific needs. The first exotic options appeared in Tokyo in the 1980s and were named "Asian options". In 1991, Mark Rubinstein published a working paper entitled "Exotic options" by assembling his researches related to the topic (see Rubinstein (1991a)). Since then, the term "exotic option" has become popular, and all options, which are somewhat different from traditional ones are considered as "exotic".

On derivative markets, most exotic options are traded on OTC markets with the exception of some rare ones listed in Exchanges (such as the binary options on the equity index S&P 500 and the binary options on the implicit volatility index VIX which are both listed in the Chicago Board of Option Exchange). The attributes of exotic options are also commonly integrated into other financial contracts (including real-estate contracts, corporate financing contracts (as shown in §3.2), incentive remuneration plans (as shown in §3.4), and structured funds provided by asset management companies). Even without being a legally binding contract, the mechanism of exotic options is also embedded in the process of corporate financial management (as in investment decision-making (see §3.1) and in capital structure analysis (see §3.3)).

To define and classify exotic options, we have adopted the methodology proposed by Wu *et al.* (2011). According to this method, an exotic option is an option for which at least one of the five "traditional" conditions met by plain-vanilla options is not met. These five traditional conditions are as follows: 1) the activation of the contract is unconditional; 2) the maturity date cannot be changed; 3) the option premium payment is unconditional and definitive; 4) all variables of the option contract (i.e., the underlying-asset price, the strike-price, and the option price) are denominated in the same currency; 5) the option-payoff is limited to the "traditional form" which is the positive or negative part of the difference between the spot price of the underlying-asset and the pre-fixed strike-price.

As soon as one of these conditions is not met, the option becomes exotic. For example, for barrier options, the condition on the unconditional activation is not met (Rubinstein and Reiner (1991a)); for extendible options, the condition on the fixed maturity date is not met (cf. Longstaff (1990)); for money-back options, the condition on the non-modifiability of the premium is not met (cf. Gastineau (1994), Kat (1994)); for quanto options, the condition on the uniqueness of the currency is not met (cf. Reiner (1992), Dravid *et al.* (1993)); for lookback options, the condition on the traditional form of the payoff is not met (cf. Goldman *et al.* (1979)). This classification methodology helps us get an overview on exotic options to better understand and analyze them.

III. Applications of exotic options in corporate finance

Even though options have been widely examined in investment decision-making through real options, applications of exotic options have not been studied in a systematic way in the field of corporate finance. In §3.1, we illustrate some examples of exotic options embedded in the management process of an investment project. In §3.2, we analyze some exotic instruments used in corporate financing operations. In §3.3, we study some exotic features presented in equity valuation based on the option approach. In §3.4, we show how exotic options can be integrated into executive incentive compensation plans to make them more effective.

III.1. LONG-TERM INVESTMENT DECISIONS

In corporate long-term investments, decision-making is essentially based on the net present value (NPV), namely the difference between the project's present value (PV) (i.e., the sum of the present values of all the incoming cash flows) and the investment cost (i.e., the sum of the present values of all the outgoing cash flows). According to the traditional corporate finance theory, an investment project deserves to be accepted if its NPV is positive, whereas otherwise it should be rejected. This approach is criticized for being rigid due to the fact that it does not take into account the possible business flexibilities, which may be embedded in the production process.

These flexibilities give managers different options in their decision-making. They include the option of waiting before investing (McDonald and Siegel (1986), Pindyck (1988), Dixit and Pyndick (1994)), the option of undertaking or quitting a project (Dixit (1989), Décamps *et al.* (2006)), the option of increasing or decreasing the investment capacity (Pindyck (1988), Kandel and Person (2002)), the option of shutting down an investment process (McDonald and Siegel (1985), Létifi and Prigent (2014)), the option of "reversing" the investment process with a cost (Abel and Eberly (1994, 1996), Laughton and Jacoby (1993)), and the option of investing in a sequential way instead of at one time (Bar-Ilan and Strange (1998), Majd and Pindyck (1987)). All these business flexibilities can be analyzed as options, and their value should be added to the traditional NPV to get the adjusted NPV which better reflects the value of an investment project.

Such options, known as "real options", are somewhat different from options exchanged in financial markets. Unlike "financial options", real options do not have their own legal existence. They usually pertain to some "tangible" assets (such as capital equipment or investment projects). They are only financial properties which are embedded in these "real" assets. As their mechanism is similar to that of an option, they can be analyzed as option contracts. Over the last two decades, a lot of research has been dedicated to real options (for more references, see Brennan & Schwartz (1985), Dixit (1989), Pindyck (1991), Trigeorgis (1996), Tserlukevich (2008) among others). In practice, the real option approach is also used by a number of companies including Merck in the pharmaceutical sector, HP in the area of information technology and Boeing in the aircraft industry. In many situations, the mechanism of real options is no longer in line with that of traditional options and presents exotic features. The following examples help shed some light on this issue.

Barrier options embedded in R&D projects

The valuation of a research and development (R&D) project is a delicate issue. In fact, an R&D project usually requires outgoing cash flows without bringing direct incoming cash flows. As a result, its traditional NPV is generally negative, which means that it does not deserve to be accepted. However, an R&D project can provide investment opportunities with a positive NPV if the expected outcomes are achieved. The values of these possible investment opportunities should be added to the traditional NPV of the R&D project, which may make its NPV positive and so justify the acceptance of the investment.

Such investment opportunities can be analyzed as call options with the PV of the incoming cash flows as underlying-asset price, the PV of the outgoing cash flows as strike-price, and the deadline of the investment as maturity date. As the activation of these options is conditioned by the success of the R&D project, the first of the five traditional conditions is not met. The option is no longer a traditional option, but an exotic one known as "barrier option" (see Rubinstein and Reiner (1991a)) in the family of "contingent activation options". As the option activation is conditioned by a random factor which is not the same as the underlying-asset price, the option is called an "external barrier option" (see Heynen and Kat (1994)). The payoff of such an option can be written as: $max\{S(T)-K,0\}1_{if\ R\&D\ succeeds}$, where $S(T)$ is the PV of the incoming cash flows, K is the PV of the outgoing cash flows, and $1_{if\ R\&D\ succeeds}$ is the indicator function for the triggering of the option activation.

Growth options, contraction options, shutdown options

During an investment process, corporate managers are not just subjected to a given situation. In many cases, they can react to the ongoing event by taking actions which come to change the course and/or the outcome of the process. In fact, throughout its lifetime, an investment presents a certain number of flexibilities which give managers some leeway in managing the project. The most typical examples of these flexibilities are the following: undertaking options (to decide whether or not undertake a project), waiting options (to decide to undertake the project immediately or later), growth options (to decide whether or not to increase the investment), contraction options (to decide whether or not to reduce the investment), shutdown options (to decide whether or not to stop the investment temporarily or permanently), abandonment options (to decide whether or not to abandon the project definitively), and switch options (to decide how to switch between maintaining or temporarily interrupting the investment thanks to a flexible manufacturing system).

Typically, most of these options can be analyzed as traditional options[1]: undertaking options and growth options can be considered as call options, contraction options and shutdown options as put options, and switch options as a certain combination of call options and put options. What interests us here is the exotic feature which may be embedded in these options. For example, growth or shutdown options make sense only when the demand for the output produced by the investment project becomes significantly high or low by crossing a certain threshold (see McDonald and Siegel (1985), Letifi and Prigent (2014)). In this case, growth and shutdown options turn into barrier options whose activation is conditioned by a random event. As this random factor is not the same as the underlying-asset price, the option is an "external barrier option" (see Heynen and Kat (1994)).

The payoff of the growth option can be written as: $max\{S(T)-K,0\}1_{if\ output\ demand\ exceeds\ a\ certain\ high}$, where $S(T)$ is PV of the additional incoming cash flows brought by the incremental investment, K is the PV of the additional outgoing cash flows resulting from the incremental investment, and 1_{if} is the indicator function for the triggering of the option activation. The payoff of the shutdown option is similar to that of the growth option except that it is a put option, where the underlying-asset price is the PV of the loss in incoming cash flows because of the shutting-down, the strike-price is the PV of the savings made by shutting down the investment (including for example the sale of production equipment and the savings in the payroll of employees who are fired), and the option is activated once the output demand reaches a certain low.

Input-mix options embedded in the production process

In a production process, some management flexibilities, known as "production options", are available to managers for their decision-making. One of the best known is the "input-mix option" which gives them the possibility to choose, among acceptable alternatives, the cheapest input to produce the same output. Such an option is particularly valuable in the context where commodity and energy prices are becoming more and more volatile[2]. For example, to produce electricity, a utility company can choose different energy sources such as fuel oil, natural gas, or coal. If the price of fuel oil and the price of natural gas both increase while the price of coal decreases[3], it could be interesting for the firm to switch its input from fuel oil or natural gas to coal by taking necessary measures to limit pollution. Similar examples include feeding poultry with rice or corn, heating a building with electricity or gas, producing a cartoon film with computer software or human artists.

When the cost of production is negligible relative to the input and output prices, an input-mix option can be analyzed as a put option where the output price represents the strike-price and the minimum of the input prices represents the underlying-asset price. As two or more random factors are involved in the mechanism, the fifth traditional condition is not met. The option is no longer a traditional option, but an exotic one. It is known as "option on the minimum of two or more assets" (see Stulz (1982), Johnson (1987)) in the family of "non-traditional payoff options". The payoff of such an option can be written as: $max\{K - \min\{S_1(T), S_2(T)\},0\}$, where $S_1(T)$ and $S_2(T)$ are the spot prices of the two inputs, K is the output price, and T the length of the production period.

Output-mix options embedded in the production process

Similar to an "input-mix option", an "output-mix option" gives managers the possibility to choose, among acceptable alternatives, the output whose price is the highest from the same input (see He and Pindyck (1992)). Such an option is particularly valuable when output demand changes quickly. For example, a manufacturer may value the possibility to cease to produce a style of toy, which has become old-fashioned (ex. "Toy Story" or "Kung Fu Panda") so as to shift towards a more fashionable one (such as "Star Wars"). Similar examples include constructing residential or office buildings with the same budget, cultivating potatoes or sweet potatoes in the same fields, producing cheese or yoghurt from the same milk, producing petrol or gas from the same crude oil, and offering a program of "initial education" or "executive education" with the same academic staff.

When the cost of production is negligible relative to the input and output prices, the output-mix option can be analyzed as a call option where the maximum of the output prices represents the underlying-asset price and the input price represents the strike-price. As for an input-mix option, the fifth traditional condition is not met because two or more random factors are involved. The option is no longer a traditional option, but an exotic one known as "option on the maximum of two or more assets" (see Stulz (1982), Johnson (1987)) in the family of "non-traditional payoff options". The payoff of the option can be written as: $max\{\max\{S_1(T), S_2(T)\} - K,0\}$, where $S_1(T)$ and $S_2(T)$ are the spot prices of the two outputs, K is the input price, and T the length of the production period.

Spread options embedded in the production process

The prices of inputs and outputs of a company are usually correlated. Let's take the example of a company whose main activity is the transformation of a raw material (ex. crude oil) into a final product (ex. gasoline). Both the price of the input and the price of the output fluctuate on the market[4]. Due to these fluctuations, the company would value the possibility to decide whether or not to preserve the production activity depending on the market conditions. More precisely, if the spread between the output and the input exceeds the production cost, it is profitable for the firm to turn on the production process; otherwise, it's better to suspend the production activity momentarily.

Such flexibility can be analyzed as a call option with the spread between the output and the input as underlying-asset price and the production cost as strike-price. As two underlying-assets are involved, the fifth traditional condition is not met. The option is no longer a traditional option, but an exotic one known as "spread option" or "option on spread" (cf. Shimko (1994)) in the family of "non-traditional payoff options". The payoff of the option can be written as: $max\{[S_1(T) - S_2(T)] - K,0\}$, where $S_1(T)$ and $S_2(T)$ represent respectively the spot price of the output and that of the input, K is the production cost, and T the length of the production period.

Product options embedded in the production process

In a production process, sometimes managers can not only decide to "produce or not", but they can also decide "how much to produce" by adapting their production quantity to the market condition. These managerial flexibilities are known as "intensity options", "operating scale options", or "production options". For example, in the event of a decrease in the output price, the turnover of the company (i.e., the multiplication of the production quantity and the output price) may be reduced. If the firm wants to preserve its turnover, it needs to increase the production quantity while maintaining its input cost (i.e., the multiplication of the production quantity and the input price) at the same level thanks to the parallel decrease in the input price.

When the cost of production is negligible relative to the input and output prices, the management flexibility can be analyzed as a call option where the turnover represents the underlying-asset price and the input cost which remains at the same level represents the strike-price. As the turnover depends on two random variables, namely the production quantity and the output price, the fifth traditional condition is not met, and the option is an exotic one known as "product option" (cf. Nelken (1996)) in the family of "non-traditional payoff options". The option payoff can be written as: $max\{S_1(T) \times S_2(T) - K,0\}$, where $S_1(T)$ is the price of the firm's product, $S_2(T)$ is the production quantity over the period, K is the input cost, and T the length of the production period.

III.2. LONG-TERM FINANCING DECISIONS

In corporate long-term financing, the first question to be asked is: should the firm be financed with debt or equity? According to the "trade-off theory", debt has both advantages and disadvantages due to its tax deductibility and the bankruptcy risk it may induce; thus, the capital structure is optimal when the two opposing effects of debt are counterbalanced (see Modigliani & Miller (1958, 1963)). This vision is not shared by the "pecking-order theory" according to which the optimal capital structure does not make sense as firms choose their funding instruments in accordance with a certain "preference order". More precisely, internal funds are preferred over external funds due to their simplicity and low cost, while debts are preferred over equity in external funds due to the existence of information asymmetry between firm managers and market investors (see Myers & Majluf (1984)).

Once the capital structure has been chosen, the next question to be asked is: how to minimize the cost of funding, or in other words, how to raise more funds by issuing debts or equity? In response to this, option clauses are usually added to bonds and stocks. Some of these option clauses go outside the traditional framework and lead to exotic features.

Exchange options embedded in convertible bonds

The issuance of "convertible bonds" is a common practice in corporate financing. A convertible bond gives its holder the right to convert the bond into a certain number of stocks in the firm. Compared to a classical bond, it enables firms to reduce their cost of borrowing thanks to the conversion clause granted to debtholders.

The conversion clause can be analyzed as a call option with the stock of the firm as underlying-asset and the price of the traditional bond as strike-price. As the price of the bond varies with the level of interest-rates in the market, the strike-price of the option is not fixed at a constant level, as is the case of traditional options. As a result, the option is no longer a traditional one, but an exotic one known as "exchange option" (see Margrabe (1978)) in the family of "non-traditional payoff options". The payoff of the option can be written as: $max\{S_1(T) - S_2(T), 0\}$, where $max\{a, b\}$ is the maximum of a and b, T is the maturity of the bond, $S_1(T)$ is the stock price at time T and $S_2(T)$ the price of the traditional bond at time T.

Binary options embedded in window bonds

"Window bonds" have been designed to give firms and bondholders better flexibility in their risk management. A window bond can be prepaid at some specified dates (known as "windows") at a specified price (known as "prepayment price"). Both the firm and the bondholder can request such an early redemption by accepting to pay a penalty (called "early repayment penalty"). A clear distinction must be made between three cases. In the first one, interest-rates increase so sharply that, even after the penalty payment, it is more interesting for the bondholder to be prepaid so as to reinvest the capital at a higher coupon. In the second case, interest-rates decrease so quickly that, even after the penalty payment, it is more interesting for the firm to prepay the debt so as to issue new bonds at a lower cost. In the third case, interest-rates do not change enough to make the early redemption interesting for either of the two counterparties.

A "window bond" can be analyzed as a portfolio of "binary options" characterized by the "binary" feature of their payoffs (see Rubinstein and Reiner (1991b)). As their payoffs do not have the traditional form, binary options are actually exotic options in the family of "non-traditional payoff options". The payoff of a window bond at the date T can be written as follows: $(F-\alpha)1_{S(T) \leqslant F-\infty} + (F+\beta)1_{S(T) \geqslant F+\beta} + S(T)1_{F-\infty \leqslant S(T) \leqslant F+\beta}$, where S(T) represents the market price of the bond, F is the face-value of the bond, α is the penalty paid by the bondholder in the event of a request for early redemption, β is the penalty paid by the firm in the event of a request for early redemption. The first component represents what the bondholder receives in the event of early repayment requested by himself or herself, the second component represents what the bondholder receives in the event of early repayment requested by the firm, while the third component represents the market price of the bond when no early repayment is made. From this formula, we can see that the bond can be considered as a portfolio of "binary options", or more precisely a combination of "Cash-or-nothing" and "asset-or-nothing" options.

Extendible options embedded in corporate warrants

Warrants are usually integrated into stocks and bonds to make the issuance more attractive (see Smith (1977)). By paying a premium which is relatively low, warrant-holders can take advantage of a possible increase in the stock price of the firm. To protect investors against a decrease in the stock market, firms sometimes add an "extension clause" to a traditional warrant contract. For example, warrants issued in 1991 by two French companies, Métaleurope and Valéo, could be extended for two additional years if the stock index CAC 40 decreases more than 15% over the last month before the maturity date.

As the maturity date can be changed, an extendible warrant is no longer a traditional option, but an exotic one known as "extendible option" (see Longstaff (1990)). The option payoff can be written as: $max\{S(T) - K, 0\}1_{S(T)>K} + Call\{S(T), K, T_e - T\}$, where T is the initial maturity date, T_e the extended maturity date, $S(T)$ the stock price of the firm at time T, K the strike-price, and $Call\{S(T), K, T_e - T\}$ the value of a traditional European call option with $S(T)$ as underlying-asset price, K as strike-price, and $(T_e - T)$ as maturity.

Money-back options embedded in corporate warrants

By pursuing the same concern for investor-protection, some firms issue "reimbursable warrants" by integrating a "premium repayment clause" into a traditional warrant contract. For example, after the 1987 stock crash, reimbursable warrants were issued by a certain number of French companies (including BSN and Suez in 1988, Lyonnaise des Eaux, Pinault, and Saint-Louis in 1989, La Rochette in 1990). In the event of non-exercise of the warrant during the life-period of the contract, the warrant-holder can get back the premium paid to acquire the warrant contract.

As the premium payment is no longer definitive, such warrants are outside the framework of traditional options. They can be analyzed as exotic options known as "money-back options" (see Gastineau (1994), Kat (1994)) in the family of "contingent premium options". The payoff of the reimbursable warrant can be written as: $max\{S(T) - K, 0\}1_{S(T)\geq K} + Premium 1_{S(T)\leq K}$, where T is the maturity date, $S(T)$ the stock price of the firm, K the strike-price, and *Premium* the amount paid by the warrant-holder for subscription to the warrant claim.

III.3. CAPITAL STRUCTURE ANALYSIS

Once the capital structure of a firm has been chosen, a fundamental question to be asked is: how to assess the part of the firm's value, which belongs to shareholders? The traditional method of equity valuation consists of three approaches, namely the patrimony approach based on the balance sheet of the firm through the computation of its book-value, the comparison approach based on a financial ratio according to which the company is compared with another one whose equity is listed on a stock exchange, and the dynamic approach based on the discounted cash flow model. Taking this into consideration, the option theory comes to enrich the traditional method of equity valuation.

In their revolutionary work, Black and Scholes (1973) and Merton (1973) assert that the equity of a firm financed with equity and a zero-coupon bond can be analyzed as a European call option. However, in reality, the capital structure of a firm is much more complicated. In most cases, its debt does not take the form of a simple zero-coupon. As a result, the equity of the firm can no longer be analyzed as a traditional option, but as an exotic one.

Compound options when the bond is an *in-fine* bond

Let us assume that the firm is financed with equity and an "*in-fine*" bond with two last repayments: the coupon (K_c) at the last but one anniversary date (T_c) and the final repayment (K, including for example the last coupon and the principal) at the maturity date T (with $T \geqslant T_c$). We also assume that once the coupon K_c is repaid, it is immediately refinanced through the issuance of new stocks for the same amount. In this model, the wealth of all the shareholders (*i.e.*, the existing shareholders and the new ones who will subscribe the new stocks which refinance K_c) can be analyzed as a traditional call option with the firm's value as underlying-asset price, the final repayment of the bond K as strike-price, and the repayment date T as maturity date.

As regards the wealth of the existing shareholders, it is no longer a traditional option, but an exotic one known as "compound option" (or "option on option") in the family of "non-traditional payoff" options (see Geske (1977) and (1979)). A compound option is an option whose underlying-asset is already an option, called "mother option". In our example, the compound option is a "call on call" option where the mother option is the traditional call option mentioned above, and the strike-price is K_c (*i.e.*, the last but one coupon of the *in-fine* bond) and the maturity date is T_c (*i.e.*, the last but one anniversary date). Its payoff at T_c can be written as: $max\{Call(V(T_c), K, T - T_c) - K_c, 0\}$, where $V(T_c)$ is the value of the firm at time T_c, $Call(V(T_c), K, T - T_c)$ is the value of a traditional call option with $V(t)$ as underlying-asset price, K as strike-price, and $(T - T_c)$ as maturity.

Barrier options when the bond has a "security clause"

To protect their investors, some corporate bonds are issued with a certain "security clause" which gives the bondholders the right to take control of the company as soon as the value of the firm falls to a certain low (see Chesney and Gibson (1999)). Such a security clause presents a two-fold advantage: first of all, it warns creditors early enough to enable them to put into action a rescue plan for the firm; then, it makes shareholders aware of the risk that they are running. This clause is particularly valuable in a time of crisis when investors need to be reassured.

Let us suppose that the firm is financed with equity and a zero-coupon bond with a security clause, according to which shareholders' wealth will be cancelled definitively once the firm's value falls to a critical level before the maturity of the bond. In this case, the wealth of shareholders is no longer a traditional call option as in the Black and Scholes model. It actually constitutes an exotic option known as "barrier option", or more precisely a "down-and-out" call option. Its payoff at time T can be written as: $max\{V(T) - K, 0\} \times 1_{m(T) > B}$, where $V(T)$ is the value of the firm at time T, $m(T)$ is the lowest level reached by the value of the firm over the period $[0, T]$, and B is the threshold which triggers the takeover of the firm by the bondholders.

Compound options when the bond has an ordinary tranche and a subordinated one

To reassure their investors, some firms specify in their bond contracts that new ordinary bonds cannot be issued before the repayment date of current bonds; in the case where new fundraising is required, only "subordinated" bonds can be issued, which means that additional bond repayment is possible only after the repayment of the ordinary bonds. For this reason, it is sometimes possible for firms to have in their liabilities both ordinary and subordinated bonds.

Let us suppose that the firm is financed with equity, an ordinary zero-coupon bond (with K as face-value and T as maturity date) and a "subordinated zero-coupon bond" (with K_s as face-value and T_s as maturity date with $T_s \geqslant T$). We also assume that once the ordinary bond has been repaid, it is immediately refinanced through the issuance of new shares for the same amount. In this case, the wealth of all the shareholders (*i.e.*, the existing ones and the new ones who will refinance the ordinary bond) can be analyzed as a traditional call option, with the value of the firm V as underlying-asset price, the face-value of the subordinated bond K_s as strike-price, and the repayment date of the subordinated bond T_s as maturity date.

As regards the wealth of the existing shareholders, it is no longer a traditional option, but an exotic one known as "compound option" in the family of "non-traditional payoff options". It can be analyzed as a "call on call" option where the mother option is the traditional call option mentioned above, the strike-price is the face-value K of the ordinary bond, and the maturity date is the repayment date T of the ordinary bond. Its payoff at time T can be written as: $max\{Call(V(T), K_s, T_s - T) - K, 0\}$, where $V(T)$ is the value of the firm at T, $Call(V(T), K_s, T_s - T)$ is the value of a traditional call option with $V(t)$ as underlying-asset price, K_s as strike-price, and $(T_s - T)$ as maturity.

Extendible options when the bond has an extension clause

So far, measures have been taken to reduce the risk for bondholders in exchange for a lower cost. To reduce the bankruptcy risk for shareholders, firms sometimes integrate an "extension clause" into the bond contract, which gives them the right to postpone the repayment of the debt. This clause is particularly valuable for firms in distress because it provides them with extra time to find a solution to avoid bankruptcy. Extendible bonds have become a popular financing tool for leveraged-buyout operations since the end of the 1980s.

If a firm is financed with equity and a zero-coupon bond with an extension clause, the wealth of shareholders is no longer a traditional call option, but an exotic one known as "extendible option" in the family of "contingent maturity options" (see Longstaff (1990)). Its payoff can be written as: $max\{V(T) - K, 0\} \times 1_{V(T) > K} + Call(V(T), K, T_e - T)1_{V(T) \leq K}$, where T is the initial maturity date of the bond, K is the face-value of the bond, $V(T)$ is the value at time T of the firm, T_e is the extended maturity date, and $Call(V(T), K, T_e - T)$ is the value of a traditional call option with $V(t)$ as underlying-asset price, K as strike-price, and $(T_e - T)$ as maturity.

III.4. EXECUTIVE INCENTIVE COMPENSATIONS

Corporate strategic management involves formulating the objectives of a firm whilst implementing appropriate strategies to reach them. To ensure the success of these actions, the role of corporate governance is decisive. In corporate governance, the agency problem between shareholders and managers is at the heart of the matter. In fact, in the event of separation between ownership and management, shareholders mandate managers to run the firm on their behalf. As the interests of the two parties are not always the same, managers may place their own interests before those of shareholders, which leads to agency costs (see Jensen and Meckling (1976), Shavell (1979), Smith and Stulz (1985)).

To monitor managers' action, a certain number of devices are available, including a board of directors, shareholders' meetings, financial disclosure and audit, executive incentive remuneration, market for corporate control. Among these devices, executive incentive compensations involve reducing the interest divergence at its source by aligning the interests of managers with those of shareholders (see Jensen and Murphy (1990), Schmidt and Flowler (1990)). The long-term incentive compensations the most commonly used are employee stock options (ESO) and restrictive stocks.

ESO have met with great success in the United-States and Europe over the two last decades. However, they suffer from some weaknesses such as the lack of flexibility and the lack of incentive effect (see Johnson and Tian (2000), Wu and Yu (2003)). Facing these problems, firms tend to review the traditional ESO plan by changing some terms of the contract and/or adding some additional clauses. Most of these "adjusted" ESO plans have the mechanism of an exotic option instead of that of a traditional one.

Barrier options embedded in contingent activation ESO

When executive stock options are granted, the strike-price is usually set to the level of the stock price at the issuance date. With an average annual return of 7% in stock markets (see Siegel (2014)) and an average life-period of 7 years for ESO (see Brenner *et al.* (2000)), option-holders are almost sure to be able to get significant remuneration whatever their performance. To make ESO more incentive, some firms integrate additional conditions into the option contract. For example, options issued by Alstom in 2000 can be activated only when the operating margin of the company reaches 5.5% in one year, or if it reaches 6% in two years. Similarly, after its merger in 2000, the first ESO plan issued by BNP Paribas is activated on condition that the stock price of the bank progresses over two years. In these examples, the option activation is no longer automatic, but is conditioned by a random factor. As a result, such options are no longer traditional options, but exotic ones known as "barrier options". Their payoff can be written as: $max\{S(T) - K, 0\}1_{Activation\ condition}$.

Barrier options embedded in re-priceable ESO

ESO were originally used by start-up companies to attract managerial and technical talents. As young firms cannot afford to pay their managers salaries which are comparable to those in international groups, stock options are granted to executives for the growth potential of the firm. If the firm grows as planned, the stock price will rise and executives will get a capital gain through the option exercise. However, ESO may lose their incentive effect if the stock market enters into a bearish cycle in a time of crisis. For example, from the end of 2007 to the end of 2012, the Dow Jones Industrial Average decreased from 13264 to 13096 points. This means that most options issued in 2007 lost their incentive effect over a period of five years. To deal with the problem, one solution is to add a "re-pricing clause" with which the strike-price of the option can be "reset" at a lower level in case of market decline (see Brenner *et al.* (2000), Chance *et al.* (2000)).

The re-pricing clause is activated when the stock price falls to a certain low, denoted as B (with $B < K$, where K is the initial strike-price of the option). Once re-priced, with a new strike-price, denoted as K^*, which is lower (with $K^* < K$), the "re-priced" option becomes in-the-money again and regains its incentive effect. A re-priceable option can be analyzed as the sum of two barrier options: the first one with a higher strike-price is deactivated when the barrier is crossed by the stock price, while the second one with a lower strike-price is activated when such an event occurs. Its payoff at the maturity date T can be written as: $max\{S(T) - K, 0\}1_{m(T) > B} + max\{S(T) - K^*, 0\}1_{m(T) < B}$. The first component is the payoff of a down-and-out call option with S as underlying-asset price, K as strike-price, and B as barrier. The second component is the payoff of a down-and-in call option with S as underlying-asset price, K^* as strike-price, and B as barrier.

Forward-starting options embedded in Stock Appreciation Rights (SAR)

The practice of re-priceable options has been criticized by academics and practitioners, as the "re-pricing" clause allows executives to realize capital gain while shareholders are losing money. Therefore, instead of an adjustment of the strike-price at one go, some companies choose to opt for a periodic revision of the strike-price. In fact, option-holders are paid over a period (for example of one year) only when the stock price progresses. This system is similar to that of the "Stock Appreciation Rights" (SARs[5]) in the USA (see Scholes *et al.* (2014)). Let's take the example of a seven-year-maturity option. Such an option is made up of seven one-year-maturity "sub-options" whose life-periods $[T_{i-1}, T_i]$ follow one after the other (with $i \in \{1, 2, ..., 7\}$, $T_0 = 0$, $T_7 = 7$ years). For each sub-option, the strike-price is set at the level of the stock price at the beginning of the life-period; at the end of the life-period, the executive receives the stock price change over the period if the stock price increases and nothing otherwise. The payoff of the sub-option i at the maturity T_i can be written as: $max\{S(T_i) - S(T_{i-1}), 0\}$, where $S(t)$ is the stock price of the firm at time t, $T_0 = 0$, $T_n = T$ and $T_{i-1} = T_i - 1$. For each sub-option i with $i \geq 2$, the strike-price is set at $S(T_{i-1})$ which is an unknown variable before time T_{i-1}. At the issuance date of the option at time 0, such an option is not a traditional option, but an exotic one known as "forward-starting option" (see Rubinstein (1991b)) in the family of "non-traditional payoff options".

Exchange options embedded in relative performance-based executive compensations

So far, all the options examined in incentive remunerations have been based on "absolute performance" in the sense that the stock price of the firm is compared with itself at two different dates. However, as modern portfolio theory tells us, the risk of a stock is due to two factors – the systematic risk related to the general stock market and the specific risk which is proper to the firm. It is logical that executives should be paid only for the part of return arising from the specific risk, but not for the part related to the general market.

The idea is to pay executives according to the "relative performance" of the stock price of the firm in comparison with a benchmark which could be an equity index or the stock price of a competitor (see Ubelhart (1981), Akhigbe *et al.* (1996), Johnson and Tian (2000), Wu and Yu (2003)). As two random variables are involved in the pay, the amount of the remuneration can no longer be analyzed as a traditional option, but an exotic one known as "exchange option" (see Margrabe (1978)) in the family of "non-traditional payoff options". The payoff of the option can be written as:

$$max\left\{\frac{S_2(T)}{S_2(0)} - \frac{S_1(T)}{S_1(0)},\ 0\right\}$$

, where T is the maturity of the option, $S_2(t)$ and $S_1(t)$ are the stock price of the firm and the level of the benchmark at time t, respectively.

IV. CONCLUSION

Over the last decades, financial markets have demonstrated unprecedented development thanks to the progress made in information and communication technology as well as financial engineering. The only possible drawback in this development is that it makes financial instruments more and more complicated. Such increasing complexity makes financial products more and more difficult to understand. Misunderstanding may lead to misuse by investors, which may induce mistaken investment decisions and/or inappropriate risk-taking, while proper understanding of these instruments can avoid a large part of the problem. Exotic options are derivatives which are known for their flexibility and accuracy. Due to their complexity, they still remain little accessible to most investors in spite of their economic added-value. To help investors better understand these products, two things seem to be necessary. First, we need to provide investors with a classification methodology which gives them an overview of the existing products (see Wu *et al.* (2011)). Second, we need to show investors how these products work in a "real economy" context by putting emphasis on the economic rationale rather than on quantitative skills.

In this paper, we strive to show how exotic options can be used in corporate finance, namely in long-term investment decisions, long-term financing decisions, capital structure analysis, and executive incentive compensations (for a summary, see Table 1). For each of these topics, we have illustrated the most common applications of exotic options by specifying the type of the embedded option. Our work could be useful from several perspectives. First, it provides a relatively comprehensive synthesis on the applications of exotic options in corporate finance. Then, it is relatively accessible for investors who are not specialized in finance as its emphasis is put on the economic rationale rather than on mathematical skills. Finally, it shows corporate managers how to benefit from the technical advances made in financial markets by applying these techniques in the context of corporate finance.

---

1 Waiting options are somewhat special. In fact, a waiting option can be viewed as the additional right given by an American call option with the deadline of the decision as maturity date relative to a European option which reaches its maturity date today. Its value should be the same as the "time value" of the American option.

2 From 1988 to 2012, the annual volatility of the return of crude oil price and that of the gasoline price were 37.5% and 42.8%, respectively, which are both higher than an average level of 30% in terms of VIX in equity markets.

3 In 2012, the price of the futures contract on oil listed at NYSE varied from USD 77.28 to USD 110.55 per barrel, while the price on natural gas ranged from USD 1.90 to USD 3.93 per million BTU. As regard to Australia Coal Price, it passed from USD/MT 113.78 in November 2011 to USD/MT 83.06 in November 2012 (with a decrease of 27% over one year).

4 From 2001 to 2012, the crude oil price passed from USD 22.58 to USD 110.80 per barrel, while the gasoline price passed from USD 0.764 to USD 2.835 per Gallon.

5 Like ESO, SARs are based on the stock price of the firm. Unlike ESO, their beneficiaries do not have to pay the strike-price, because they just receive, in cash or stock, the amount of the stock price increase over the period.

Table 1. Summary of the main applications of exotic options in corporate finance

Scope	Application examples	Corresponding option (*)	Payoff	Characteristics
1. Long-term investment decisions	Options R&D project	External barrier options (Heyen and Kat (1994))	$max\{S(T)-K, 0\}\ 1_{if\ R\&D\ succeeds}$	Assessing opportunities provided by R&D projects
	Growth, contract, and shutdown options	External barrier options (Heyen and Kat (1994))	$max\{S(T)-K, 0\}$ or $max\{K-S(T), 0\}\ 1_{output\ demande\ exceeds\ a\ level}$	Assessing flexibility in an investment process
	Input-mix options	Options on the minimum of two assets (Stulz (1982), Johnson (1987))	$max\{K-\min\{S_1(T), S_2(T)\}, 0\}$	Assessing flexibility in input choice
	Output-mix options	Options on the maximum of two assets(Stulz (1982), Johnson (1987))	$max\{max\{S_1(T), S_2(T)\}-K, 0\}$	Assessing flexibility in output choice
	Spread options	Spread options (Shimko (1994))	$max\{[S_1(T)-S_2(T)]-K, 0\}$	Assessing flexibility in production process
	Intensity options	Product options (Nelken (1996))	$max\{S_1(T)\times S_2(T)]-K, 0\}$	Assessing flexibility in production quantity
2. Long-term financing decisions	Equity/In-fine bonds	Compound options (Geske (1977), (1979))	$max\{Call(S(T_c), K, T-T_c)-K_c, 0\}$	Shareholders' wealth analyzed as a call on call option
	Equity/Bonds with a security clause	External barrier options (Chesney & Gibson (1999))	$max\{S(T)-K, 0\}\times 1_{m(T)>B}$	Shareholders' wealth analyzed as an external barrier option
	Equity/Zero-coupon bonds/ Subordinated zero-coupon bonds	Compound options	$max\{Call(S(T), K_s, T_s-T)-K, 0\}$	Shareholders' wealth analyzed as a call on call option
	Equity/Zero-coupon bonds with extension clause	Extendible options (Longstaff (1990))	$max\{S(T)-K, 0\}\times 1_{S(T)>K}+Call(S(T), K, T_s-T)1_{S(T)\leq K}$	Shareholders' wealth analyzed as an extendible call option
3. Capital structure analysis	Convertible bonds	Exchange options (Margrabe (1978), Johnson & Tian (2000))	$max\{S_1(T)-S_2(T)), 0\}$	Reducing borrowing cost
	Window bonds	Binary options (Rubinstein & Reiner (1991b))	$(F-\alpha)1_{S(T)\leq F-\alpha}+(F+\beta)1_{S(T)\geq F+\beta}+S(T)1_{F-\alpha\leq S(T)\leq F+\beta}$	Providing flexibility in interest-rate risk management for the firm and the bondholder
	Extendible warrants	Extendible options	$max\{S(T)-K, 0\}1_{S(T)>K}+Call\{S(T), K, T^{*}-T\}$	Providing additional chance for option exercise for the investor and higher premium for the firm
	Money-back warrants	Money-back options (Gastineau (1994), Kat (1994))	$max\{S(T)-K, 0\}1_{S(T)>K}+Premium1_{S(T)\leq K}$	Providing more insurance for the investor
4. Executive incentive compensations	Contingent-activation employee stock options (ESOs)	Barrier options	$max\{S(T)-K, 0\}\times 1_{if\ condition\ met}$	Making ESOs more incentive
	Re-priceable ESOs	Barrier options	$max\{S(T)-K, 0\}1_{m(T)>B}+max\{S(T)-K^{*}, 0\}1_{m(T)<B}$	Keeping ESOs incentive in a bearish market
	Pay based on Stock Appreciation Rights	Forward-starting options (Rubinstein (1991b))	$\sum_{i=1}^{N} max\{S(T_i)-S(T_{i-1}), 0\}$	Keeping ESOs incentive in the long-run
	Pay based on relative performance	Exchange options	$max\left\{\frac{S_2(T)}{S_2(0)}-\frac{S_1(T)}{S_1(0)}, 0\right\}$	Paying executives for the part they deserve

(*) For the definition of each of these options, see Appendix. It is noteworthy that, for simplification purpose, the option examples summarized in this table are all supposed to be European style in the sense that they can only be exercised at the maturity date, while in reality many options in corporate finance are path-dependent such as American or barrier options.

References

- ABEL A.B. AND EBERLY J.C. (1994), A Unified Model of Investment under Uncertainty, *American Economic Review*, 84, 1369-1384.
- ABEL A.B. AND EBERLY J.C. (1996), Optimal Investment with Costly Reversibility, *Review of Economic Studies*, 63, 581-593.
- AKHIGBE A., MADURA J. AND TUCKER A. (1996), Market-controlled Options: A New Approach to Executive Compensation, *Journal of Applied Corporate Finance*, 9, 93-97.
- BAR-ILAN A. AND STRANGE W.C. (1998), A Model of Sequential Investment, *Journal of Economic Dynamics and Control*, 22, 437-463.
- BERTRAND P. AND PRIGENT J.-L. (2015a), On Path-dependent Structured Funds: Complexity does not Always Pay (Asian versus Average Performance Funds), *Finance*, Vol. 37, N°1, 67-105.
- BERTRAND P. AND PRIGENT J.-L. (2015b), French Retail Financial Structured Products : A typology and Assessment of their Fair Pricing, *Bankers, Markets and Investors*, 135, 5-19.
- BLACK F. AND SCHOLES M. (1973), The Pricing of Options and Corporate Liabilities, *Journal of Political Economy*, 637-654.
- BRENNAN M. J. AND SCHWARTZ, E. (1985), Evaluating Natural Resource Investments, *Journal of Business*, 58, 135-157.
- BRENNER M., SUNDARAM R.K. AND YERMACK D. (2000), Altering the Terms of Executive Stock Options, *Journal of Financial Economics*, 57, 103-128.
- CÉLÉRIER C. AND VALLÉE B. (2013), What Drives Financial Complexity? A Look into the Retail Market for Structured Products, HEC Paris Research Paper, N° Fin-2013-1013.
- CHANCE D.M., KUMAR R. AND TODD R.B. (2000), The 'Repricing' of Executive Stock Options, *Journal of Financial Economics*, 57, 129-154.
- CHESNEY M. AND GIBSON-ASNER R. (1999), The Investment Policy and the Pricing of Equity in a Levered Firm: A Re-examination of the 'Contingent Claims' Valuation Approach, *European Journal of Finance*, Taylor and Francis Journals, vol. 5(2), pages 95-107, June.
- DAS S.R. (2000), *Structured Products and Hybrid Securities*, 2nd edition, New York, NY: John Wiley and Sons.
- DÉCAMPS J.-P., MARIOTTI T. AND VILLENEUVE S. (2006), Irreversible Investment in Alternative Projects, *Economic Theory*, 28, 425-448.
- DIXIT A. K. (1989), Entry and Exit Decisions under Uncertainty, *Journal of Political Economy*, 97, 620-638.
- DIXIT A. AND PYNDICK R.C. (1994), *Investment under Uncertainty*, Princeton University Press.
- DRAVID A., RICHARDSON M. AND SUN T.S. (1993), Pricing Foreign Index Contingent Claims: An Application to Nikkei Index Warrants, *Journal of Derivatives*, 1, 33-51.
- GASTINEAU G.L. (1994), An Introduction to Special-purpose Derivatives: Roll-up Puts, Roll- down Calls, and Contingent Premium Options, *The Journal of Derivatives*, 1, 40-43.
- GESKE R. (1977), The Valuation of Corporate Liabilities as Compound Options, *Journal of Financial Economics*, 12, 541-552.
- GESKE R. (1979), The Valuation of Compound Options, *Journal of Financial Economics*, 7, 63-81.
- GOLDMAN M.B., SOSIN H.B AND GATTO M.A. (1979), Path Dependent Options: 'Buy at the Low, Sell at the High, *The Journal of Finance*, 34, 1111-1127.
- HE H. AND PINDYCK R. (1992), Investments in Flexible Production Capacity, *Journal of Economic Dynamics and Control*, 16, 575-599.
- HEYNEN R. AND KAT, H. (1994), Crossing Barriers, *Risk*, 7, 46-51.
- JENSEN M.C. AND MECKLING W. (1976), Theory of the Firm: Managerial Behavior, Agency Costs, and Capital Structure, *Journal of Financial Economics*, 3, 305-360.
- JENSEN M.C. AND MURPHY K.J. (1990), Performance Pay and Top-management Incentives, *Journal of Political Economy*, 98, n°2, 225-264.
- JOHNSON H. (1987), Options on the Maximum or the Minimum of Several Assets, *Journal of Financial and Quantitative Analysis*, 22, 278-283.
- JOHNSON S.A. AND TIAN Y.S. (2000), Indexed Executive Stock Options, *Journal of Financial Economics*, 57, 35-64.
- KANDEL E. AND PERSON N.D. (2002), Option Value, Uncertainty, and the Investment Decision, *Journal of Financial and Quantitative Analysis*, 37, 341-374.
- KAT H. (1994), Contingent Premium Options, *The Journal of Derivatives*, 1, 44-54.
- LAUGHTON D.G. AND JACOBY H.D. (1993), Reversion, Timing Options, and Long-term Decision-making, *Financial Management*, 22, 225-240.
- LÉTIFI N. AND PRIGENT J.-L. (2014), On the Optimality of Funding and Hiring/Firing According to Stochastic Demand: The Role of Growth and Shutdown Options, *Economic Modelling*, 40, 410-422.
- LONGSTAFF F.A. (1990), Pricing Options with Extendible Maturities: Analysis and Applications, *The Journal of Finance*, 3, 935-957.
- MAJD S. AND PINDYCK R. (1987), Time to Build, Option Value and Investment Decisions, *Journal of Financial Economics*, 18, 7-27.
- MCDONALD R. AND SIEGEL D. (1985), Investment and the Valuation of Firms when There is an Option to Shut Down, *International Economic Review*, 26, 331-349.
- MCDONALD R. AND SIEGEL D. (1986), The Value of Waiting to Invest, *Quarterly Journal of Economics*, 101, 707-727.
- MARGRABE W. (1978), The Value of an Option to Exchange One Asset for Another, *The Journal of Finance*, 33, 177-186.
- MERTON R.C. (1973), Theory of Rational Option Pricing, *Bell Journal of Economics and Management Science*, 4, 141-183.
- MODIGLIANI F. AND MILLER M. (1958), The Cost of Capital, Corporation Finance and the Theory of Investment, *American Economic Review*, 48(3), 261-297.
- MODIGLIANI F. AND MILLER M. (1963), Corporate Income Taxes and the Cost of Capital: A Correction, *American Economic Review*, 53(3), 433-443.
- MYERS S.C. AND MAJLUF N.S. (1984), Corporate Financing and Investment Decisions when Firms Have Information that Investors Do not Have, *Journal of Financial Economics*, 13 (2): 187-221.

References (continued)

- NELKEN I. (1996), *The Handbook of Exotic Options: Instruments, Analysis, and Application*, McGraw-Hill.
- PINDYCK R.S. (1988), Irreversible Investment, Capacity Choice, and the Value of the Firm, *American Economic Review*, 48, 267-297.
- PINDYCK R.S. (1991), Irreversibility, Uncertainty, and Investment, *Journal of Economic Literature*, 29(3), 1110-1148.
- REINER E. (1992), Quanto Mechanics, *Risk*, 5, 59-63.
- RUBINSTEIN M. (1991a), *Exotic Options*, working paper, University of California at Berkley.
- RUBINSTEIN M. (1991b), Pay Now, Choose Later, *Risk*, 4, 44-47.
- RUBINSTEIN M. AND REINER E. (1991a), Breaking Down the Barriers, *Risk*, 4, 28-35.
- RUBINSTEIN M. AND REINER E. (1991b), Unscrambling the Binary Code, *Risk*, 4, 75-83.
- SCHMIDT D.R. AND FLOWLER K.L. (1990), Post-acquisition Financial Performance and Executive Compensation, *Strategic Management Journal*, 11, 559-569.
- SCHOLES M.S., WOLFSON M.A., ERICKSON M.M., HANLON M.L., MAYDEW E.L. AND SHEVLIN T.J. (2014), *Taxes and Business Strategy*, Prentice-Hall, 5th Edition.
- SHAVELL S. (1979), Risk Sharing and Incentives in the Principal and Agent Relationship, *Bell Journal of Economics*, 10, 55-73.
- SHIMKO D.C. (1994), Options on Futures Spreads: Hedging, Speculation and Valuation, *The Journal of Future Markets*, 14, 183-213.
- SIEGEL J. (2014), *Stocks for the Long Run*, New York: McGraw-Hill, 4th Edition.
- SMITH C.W. JR. (1977), Alternative Methods for Raising Capital: Rights versus Underwritten Offerings, *Journal of Financial Economics*, 5, 273-307.
- SMITH C.W. JR. AND STULZ R.M. (1985), The Determinants of Firms' Hedging Policies, *Journal of Financial and Quantitative Analysis*, 20, 391-405.
- STOIMENOV P.A. AND WILKENS S. (2005), Are Structured Products 'Fairly Priced'? An Analysis of the German Market for Equity-linked Instruments, *Journal of Banking and Finance*, 29, 2971-2993.
- STULZ R. M. (1982), Options on the Minimum or the Maximum of Two Risky Assets: Analysis and Applications, *Journal of Financial Economics*, 10, 161-185.
- TRIGEORGIS L. (1996), *Real Options: Managerial Flexibility and Strategy in Resource Allocation*, MIT Press, Cambridge, MA.
- UBELHART M. (1981), A New Look at Executive Compensation Plans, *Cash Flow*, 2, 20-24.
- WU J. AND YU W. (2003), Indexed Executive Stock Options with a Ratchet Mechanism and Average Prices, *Finance*, 24, 85-127.
- WU J., YU W. AND NGUYEN T. (2011), A New Classification of Exotic Options, *Bankers, Markets & Investors*, May-June, n° 112, 54-62.

Appendix: Definitions of the exotic options quoted in Table 1

Barrier options are options whose activation depends on the fluctuation of a random factor.
Binary options are options whose payoff is based on the realization or not of a given random event.
Compound options are options written on the price of an option called "mother option".
Exchange options give their holders the right to exchange a first underlying-asset against a second underlying-asset.
Extendible options are options whose maturity date can be extended.
External barrier options are "barrier options" whose activation is conditioned by a random factor which is not the price of the underlying-asset. They are different from "internal barrier options" whose activation is conditioned by the underlying-asset price.
Forward-starting options are options whose strike-price is not known at the beginning. It is defined as a function of the underlying-asset price at a future date.
Money-back options are options whose premium paid by the option-holder can be reimbursed.
Options on the maximum of two assets are options written on the maximum of the prices of the two underlying-assets.
Options on the minimum of two assets are options written on the minimum of the prices of the two underlying-assets.
Product options are options written on the product of the prices of the two underlying-assets.
Spread options are options written on the spread between the prices of the two underlying-assets.