2

Portfolio Approach to Real Options

A portfolio perspective on real options makes it possible to gain insights into the interplay of real options that could not be captured in a stand–alone analysis. It is well established in financial theory that financial assets must be valued from a portfolio perspective (cf., e.g., Constantinides 1989). A review of financial portfolio theory is provided in Sec. 3.1. Similarly to financial portfolios, portfolios of real options are affected by numerous aspects, which will be developed in the following. In this chapter, the portfolio perspective will be introduced in detail, and then linked to the ensuing general model that is developed subsequently.

2.1 Motivation of the Portfolio Approach to Real Options

The motivation for considering real options jointly in a portfolio context derives from the specifics of real options. This is why this motivation is based on a focused introduction of the general concept of real options, and the definition of the resulting portfolio problem.

2.1.1 Real Options and Financial Options

The term "real options" was coined by Myers (1977) who stated that "real options [...] are opportunities to purchase real assets on possibly favorable terms" (Myers 1977, p. 163). A more precise definition is found in Sick (1995, p. 631) who defines a real option as "the flexibility a manager has for making decisions about real assets. These decisions can involve adoption, abandonment, exchange of one asset for another or modification of the operating characteristics of an existing asset". An introduction to real options can be found in Dixit and Pindyck (1994), Trigeorgis (1996), Amram and Kulatilaka (1999), Copeland and Antikarov (2001), and Smit and Trigeorgis (2004).

Recent comprehensive overviews of the growing body of real options literature are given in Lander and Pinches (1998), Baecker and Hommel (2004), and Trigeorgis (2005).

A financial option gives the holder the right but not the obligation to buy or sell a financial asset, e.g., stock traded on financial markets, under specified terms. These terms define the period of time over which the option can be exercised, in exchange of the exercise price. A call option gives the right to acquire the underlying asset, a put option gives the right to sell the underlying assets. An American option can be exercised at any time before and including the expiration date, whereas a European option can only be exercised on the expiration date (cf. Luenberger 1998, pp. 319 ff.). The value of an option stems from the riskiness of the underlying assets. As compared to a long position in the underlying asset, the option provides insurance against losses (cf. McDonald 2003, pp. 44 ff.). It enables to protect from the downside potential of the underlying asset, while benefiting from the upside potential. This asymmetry between upside and downside is visualized in Fig. 2.1. At maturity, if the value of the underlying asset is below the exercise price, the option is not exercised and yields zero payoff. Otherwise, the option is exercised, with unlimited upside potential. The dotted line represents the value of the call option before maturity, which is always higher than the value of the call option at maturity (cf. Brealey and Myers 1996, p. 569). In order to distinguish these two, the value of an option at maturity is called “intrinsic value”, whereas the difference between intrinsic value and current value is called “time value” of the option (cf. Hull 2003, p. 154).

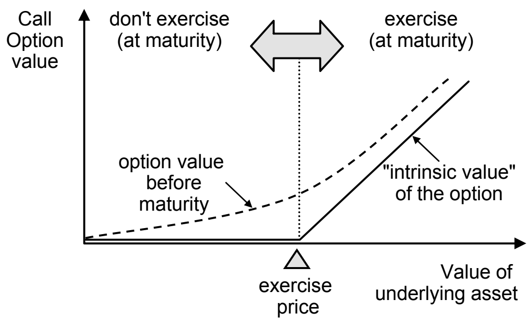

Fig. 2.1. Payoff structure of a call option

As a consequence, the modeling of the riskiness of the underlying asset is key for valuing an option on this asset. This riskiness is captured by modeling the stochastic process followed by the price of the underlying asset (cf. Hull 2003, pp. 216 ff.). Asset prices are commonly assumed to follow a random walk, i.e., price changes occur randomly (cf. Luenberger 1998, p. 308 f.). In continuous time, the random walk of a stock price is frequently modeled as a geometric Brownian motion (cf. Dixit and Pindyck 1994, p. 72), and in discrete time it is frequently modeled as a multiplicative binomial process (cf. McDonald 2003, pp. 341 ff.). Both stochastic processes obtain (the binomial process in the limit as time increments become infinitesimally small) lognormally distributed stock prices, i.e., the natural logarithm of stock price changes are normally distributed (cf. Luenberger 1998, p. 309).

Real options are similar to financial options in that they "give the holder the right, but not the obligation, to take an action in the future"(Amram and Kulatilaka 1999, p. 5). The major difference lies in the nature of the underlying assets. Real options are written on real assets which are productive capacity creating streams of income. As opposed to this, financial options are written on financial assets which are claims to the income generated by real assets. Therefore, while financial assets only define distribution rights of a given value, real assets can create economic value (Bodie et al. 1999, p. 3). The term real options stresses both the methodological analogy to financial options and the fundamental difference in the underlying assets.

Typically, the interpretation of investment decisions as real options is based on the following analogies to financial options: The current value of the stock corresponds to the (gross) present value of expected cash flows; the exercise price to the investment cost; time to expiration to the time until the opportunity disappears; stock value uncertainty to project value uncertainty; and the riskless rate is identical for both (cf. e.g. Trigeorgis 1988, p. 149). A real option that requires to pay the exercise price to receive some underlying asset corresponds to a call option, whereas a real options enabling to receive the exercise price in exchange for sacrificing some underlying asset is a put option.

Throughout this dissertation, we can use the terms value and price interchangeably, which is common in the real options literature (cf., e.g., Copeland and Antikarov 2001, p. 6). This is because in the absence of mispricing or other distortions, these two coincide.

The application of financial option pricing theory to real option valuation is subject to possible limitations of the transferability, such as incomplete markets, non–traded underlying assets, or shared options. Representing a large body of literature, a detailed discussion of these issues can be found, e.g., in Trigeorgis (1996), Smit and Trigeorgis (2004), and Smith and Nau (1995).

Different types of real options are distinguished in the literature. A detailed overview can be found in Micalizzi and Trigeorgis (1999) and Lander and Pinches (1998, p. 540, Table 2). Trigeorgis (1996, pp. 2 f., Table 1.1) distinguishes the following types of real options:

- Option to defer investment. The investment decision can be postponed, making it possible to benefit from the resolution of uncertainty during the lifetime of the option.
- Option to default during staged construction. For investment projects that take time to build, it is possible to abandon the project during construction based on the resolution of uncertainty during construction. This is desirable if the remaining investment costs are not covered by the expected future value of continuing the project as originally planned.
- Option to expand. If the underlying asset and thus the project develops more favorable than initially expected, a possible increase of capacity realizes higher value than continuing in base scale.
- Option to contract. As opposed to the option to expand, the option to contract enables to reduce the scale of operations and thus save costs if the underlying asset develops unfavorably.
- Option to shut down and restart operations. This option enables to stop operating temporarily, with the perspective of reopening in a later period. This is desirable if variable costs exceed operating revenues by more than the costs incurred for shutting down and reopening.
- Option to abandon. It is possible to scrap the project or sell it off, which is desirable if the salvage value, e.g., a resale value, is higher than the value of continuing operations.
- Option to switch use. Production input factors or the product output can be changed, e.g., as a function of prices or demand. This makes it possible to choose the strategy which generates highest profit net of switching costs.
- Growth options. An early investment opens up new investment opportunities.

Huchzermeier and Loch (2001) extend this taxonomy by the option to improve. During projects it is possible to take corrective action, such as adding resources, in order to improve the expected performance of the product. While this approach captures the fact that managers can change the performance state, it cannot cope with changes in the underlying, i.e., the option to switch underlyings.

The current dissertation takes a general view on real options by interpreting each discretionary decision right as a switch between modes, as proposed by Kulatilaka and Marcus (1988) and Kulatilaka and Trigeorgis (1994). Their concept enables interpreting real option exercise decisions as switching decisions among operating modes, which is the most general formulation of real options, having commonly analyzed real options as special cases.

2.1.2 Definition of Portfolios of Real Options

"A portfolio is a particular combination of assets in question" (Neftci 2000, p. 17). In the present discussion, the assets in question include real assets and real options written on these assets. For ease of discussion it is convenient to label sources influencing the value of the portfolio as *"portfolio aspects"*.

On the asset level, it is self–evident to assume that corporate decision makers will have a vast opportunity set, enabling them to invest in a myriad of real assets and possibly to allocate limited resources between these assets. Similarly, from a financial portfolio perspective, it is natural to consider a set of underlying assets simultaneously (see Sec. 3.1).

On the real options level, it has been shown by Trigeorgis (1993a) that options on the same underlying assets interact, requiring a simultaneous valuation of all real options written on the same underlying asset. If there are two financial options, e.g., to acquire stock of Bayer AG and BMW AG, the values of these financial options are additive because the underlying assets and the terms of the options are independent from one another. As opposed to this, consider BMW who has a European option to abandon an existing plant and the subsequent European option to expand this plant. In options terms, the European option to abandon corresponds to a European put option, while the European option to expand corresponds to a European call option. Since both affect the same underlying asset, these real options interact.

On the one hand, the value of the put is less than in isolation because it is written on the package of underlying asset and associated call option. An option is always valuable before expiration, hence the package is more valuable than the underlying asset in isolation. Since a put option value decreases with increasing value of the underlying asset, the option to abandon becomes less valuable due to the subsequent option to expand the plant. This is intuitive because exercising the put forfeits the subsequent option, such that investors may hesitate to exercise the put in order to preserve the future call option.

On the other hand, the value of the subsequent call is reduced through the existence of the prior put, because with some probability it may not be possible to exercise the call, given prior exercise of the put. This prevents the call from unfolding its full value potential and translates into a lower call option value.

Since both effects occur simultaneously, it is not possible to value put and call in isolation. The decision about exercising the first option needs to explicitly take into account the existence of the subsequent option. This relationship is structurally akin to the valuation of compound options (cf. Geske 1979). Hence, the arising effect can conveniently be labelled as compoundness. Specifically, Trigeorgis (1993a) defines interactions between real options written on the same underlying asset as "*intra–project compoundness*". Following the same logic, an analogous effect is identified for several, interdependent underlying assets which he denotes as "*inter–project compoundness*" (Trigeorgis 1996, pp. 132 f.). Both inter–project and intra–project compoundness must be considered in the context of portfolios of real options.

Further, both real options and real asset may be subject to constraints. Real assets can exhibit, for example, operating (technical or logical) or financial relationships. These can lead to mutually exclusive assets or strictly complementary assets which require one another. This affects the possibility of joint exercise of bundles of real options on different underlying assets. Likewise, the existence of constrained resources, e.g., funds available, influences the feasibility of joint option exercise.

Therefore, portfolios of real options here are defined as *combinations of multiple risky assets and multiple real options written on these assets subject to constraints.* Cases with only one underlying asset, or one real option, are special portfolio cases that reduce the scope of portfolio analysis dramatically. In order to seize all possible portfolio effects, it is important to analyze multiple underlying assets with multiple real options simultaneously. The usual "laboratory" setting for real options analysis with one underlying asset and one real option does not provide a structure capable of handling realistic decision problems. It is thus prone to ignore key portfolio effects with possibly substantial impact on (optimal) option exercise.

2.1.3 Difference Between Financial Portfolios and Portfolios of Real Options

The discussion of portfolios of real options evidently stands on a large body of literature on financial portfolios. This literature will be reviewed in detail in Chap. 3. For the motivation of the portfolio perspective chosen here, it is important to clarify the major differences between portfolios of real options and portfolios of financial options.

Financial portfolio theory dates back to Markowitz (1952) who established the concept of mean–variance analysis. At its core, it is based on the concept of diversification. Diversification is about minimizing the variance of the return of a portfolio for a given mean of the return (or maximizing the return for a given variance). This can be achieved by increasing the number of assets included in the portfolio and in the limit by holding all available assets. The only relevant risk in this perspective is the covariance risk of each asset with the (market) portfolio. In essence, this implies a passive attitude towards risk because it exclusively consists of diversifying the risk over as many assets as possible.

The portfolio approach to real options is fundamentally different from this passive perspective on risk. For portfolios of real options, the variance of returns and the resulting distributions of values of the underlying assets are considered instead of covariance with a (market) portfolio. Real options make it possible to capitalize on desirable developments of risky underlying assets while protecting from undesirable movements. For instance, a real option to expand capacity is only exercised if the value of the underlying asset is higher than the investment costs. This implies an active attitude towards risk which consists of exercising real options as a function of the resolution of uncertainty. Therefore, in portfolios of real options, the attitude towards risk is different and diversification cannot be desirable.

For financial portfolios, closely connected to the passive attitude towards risk, value additivity of the elements of the portfolio holds (cf. Brealey and Myers 1996, p. 19). Since a financial option derives its value directly from the value of the underlying financial asset, the same holds for financial options. Value additivity also holds for financial options. In contrast, a consequence of the more active real options approach is that value additivity among the elements of portfolios of real options generally breaks down (see Sec. 2.1.1). This is why it is not insightful to include financial assets and financial options in the analysis of portfolios of real options. Financial assets by definition are independent from other assets, therefore the values of the financial assets and the portfolio of real options are also independent from one another and thus do add up. Alternatively, if the portfolio of real options does have an impact on the financial asset, it can only do so by affecting the real asset underlying the financial asset. However, this is not a special case because in fact a real asset is considered, not a financial asset. Beyond this perspective, it can be insightful to consider interactions between real options and financial flexibility. This issue is discussed by Trigeorgis (1993b) where the idea is not to add an additional (financial) asset to the portfolio, but to assess the possible value of financial flexibility that can result from operating flexibility. In this context, Huchzermeier and Cohen (1996) discuss operational and financial hedging strategies. A review of this literature, citing Huchzermeier and Cohen (1996) as the key reference in the context of operational hedging, can be found in Van Mieghem (2003); Kouvelis et al. (2006). This discussion of interactions between financial and operational flexibility is beyond the scope of this dissertation.

2.2 Implications for Modeling Approach

Based on the above developed specifics of portfolios of real options, a consistent modeling approach is required. In order to derive the implication of the specifics of real options for our modeling approach, in the following we will highlight portfolio aspects, their consequences on how portfolios of real options need to be managed, and how this translates into our model.

2.2.1 Portfolio Aspects

Understanding portfolios of real options as combinations of multiple risky assets and multiple real options written on these assets subject to constraints provides a rich structure for assessing real decision problems. In this structure, the overall portfolio value is influenced by the dynamic interaction of all elements of the portfolio. This portfolio perspective on real options is a fundamental way to properly handle interdependencies between decisions over time.

A suitable perspective on portfolios of real options needs to include all relevant aspects that influence the value of such a portfolio. From the definition of portfolios of real options, it follows directly that portfolio aspects can be attributed to the real assets involved, the real options involved, or constraints. Budget constraints are of special importance because they can have a considerable limiting impact and require a detailed modeling of the investment dynamics. Moreover, the ensuing budget levels over time are state– and path–dependent. Based on these considerations, portfolio aspects can be categorized as follows (cf. Brosch 2001):

- *Interactions on the real options level*: On the real options level, intra–project compoundness and inter–project compoundness can be distinguished. While the former is due to interdependencies of several real options written on the same underlying asset, the latter is connected to interdependencies of several real options and several underlying assets. For inter–project compoundness, the correlation between the underlying assets has to be modeled explicitly.
- *Interactions on the real asset level*: On the real asset level, direct qualitative interactions and indirect qualitative interactions can be distinguished. Direct interactions are those which are inseparably connected to the underlying real assets, such as physical properties or operating synergies. Indirect interactions have their origin outside the strict asset level and are due to constraints, most prominently budget constraints. Both are qualitative in that they are not merely stochastic in nature, but result from the properties of projects or the specific background of the company (that would be different for another company).

Due to the simultaneous nature of the interactions involved, it is not possible to isolate value impacts for separate portfolio aspects. Their effects need to be assessed jointly, in order to capture their interplay. This is why they require a simultaneous modeling approach, very much like compound option pricing. Specifically, in order to handle these interactions, existing constraints can only be incorporated via a simultaneous modeling approach. Thus, the model is formulated as one stochastic optimization problem subject to constraints. Interactions are captured through the interplay of constraints as well as state– and path–dependency of investment decisions and cash flows.

2.2.2 Management of Portfolios of Real Options

Based on this broad understanding of portfolios of real options, optimal management of portfolios of real options requires capturing all relevant portfolio aspects simultaneously in order to maximize overall portfolio value. Specifically, two dimensions of managing portfolios of real options can be distinguished:

1. *Portfolio design*: creating the optimal portfolio with maximum value, supposing optimal future exercise.
2. *Portfolio execution*: exercising existing real options optimally in order to realize the full value potential of real options.

On the one hand, portfolio design analyzes which assets and which options to include in the portfolio of real options. This decision can be based on the proposed model, by choosing the portfolio which yields the highest value for the portfolio of real options. In order to assess different portfolio designs, a valuation needs to be carried out for each possible alternative. This process is depicted in Fig. 2.2. By choosing the optimal portfolio design, the decision maker in fact defines the company's strategy, because this defines the way the company is planning to create value in the future. This approach helps to quantify the impact of new investment proposals and more generally ideas form a portfolio perspective, which in options terms corresponds to assessing new real options and their interactions with the portfolio.

Apart from assessing new real options, management may be able to influence the underlying assets or the embedded real options, such as modifying the volatility involved (cf. Damisch 2002, pp. 365 ff.). The desirability of these alternatives can also be assessed as different design options. At its core, the design of a portfolio of real options is about the choice of the underlying assets to be included in the portfolio, and thus, strategic. This deserves special attention, because it will be shown that conventional wisdom may not hold true for portfolios of real options. For instance, it is not always desirable to increase volatility to enhance value (see Sec. 5). Hence the portfolio design can be supported by the proposed model.

On the other hand, portfolio execution is about optimally managing the existing design of a portfolio of real options. The value created through real options implicitly assumes that real options are exercised at the optimal

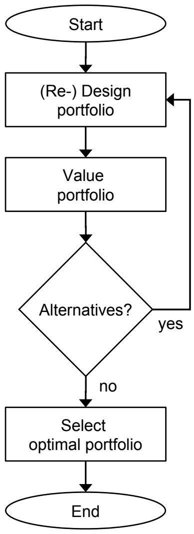

Fig. 2.2. Portfolio design process

point in time. Therefore, management needs to know when this optimal point in time is. This information is provided together with the optimal portfolio value, because the optimization result contains the optimal contingent exercise policy. Thus, the proposed model gives clear management recommendations about which options should be exercised, and when, suggesting to exercise real options as in the optimal policy.

Generally, the portfolio design defines the basis for the portfolio execution because the latter is about optimally using an existing structure which is defined in the first. At the same time, the portfolio execution can provide unanticipated new information which opens up new portfolio alternatives for the portfolio design. An example for this is research on a specific drug which, by chance, provides insights about another new drug that had not been considered before. Thus both dimensions of managing portfolios of real options are interrelated.

2.2.3 Translation into Model Features

The motivation for considering portfolios of real options has not only clarified the understanding of portfolios of real options, but at the same time has also stated the requirements for the model formulation. A suitable model formulation needs to incorporate the above introduced elements. Before the model is derived in detail in Chap. 4, an overview of the model features is given below. The model formulation will incorporate the following features:

1. Multiple correlated underlying assets.

2. Multiple real options embedded in the underlying assets.
3. State–dependent cash flows leading to path–dependencies.
4. intra–project compoundness.
5. Inter–project compoundness.
6. Direct qualitative interactions, i.e., operational (non–financial) constraints.
7. Indirect qualitative interactions, i.e., state–dependent budget constraints with carry–over of funds (including borrowing).
8. Choice of the underlyings.

These features are incorporated into the model formulation as follows:

1. General model formulation: The case of portfolios of real options is formulated as one stochastic mixed–integer program that captures path–dependent and multi–dimensional real options settings.
2. Simultaneous, i.e., forward–backward looking, approach: The backward looking element consists of choosing the optimal investment strategy which maximizes both current cash flow and expected value of future cash flows. This is a standard approach in financial option pricing (cf. Hull 2003, pp. 392 ff.). This is complemented by a forward looking element which captures the sequence of decisions up to a certain point in time that meet the budget constraints on that path. This is not typical for financial options. Both are considered simultaneously in order to capture their interdependencies.
3. Model implementation and solution: The model is solved by an algorithmic solution implementation, using the GAMS modeling platform, which can readily be applied to practical decision problems.

The proposed modeling approach provides a rigorous and flexible structure that can cope with more realistic and rich decision problems, deriving an optimal dynamic sequence of investment and disinvestment decisions from a portfolio perspective. It is very flexible in incorporating specific investment problems with different kinds of constraints and changes in the underlyings. Especially, the global dynamic budget depends on the sequence of decisions which depends on the paths taken by the joint stochastic processes of the underlying assets. This is achieved by a path–dependent, forward–backward looking approach that keeps track of past decisions and the expected future effect of current decisions. For a visualization of this approach, see Fig. 2.3. To our knowledge, the formulation of such a model for portfolios of real options has not been provided in the literature so far.

In order to account for these features, this dissertation follows a new direction for the quantitative assessment of real options. The model interprets the portfolio problem as an optimization problem with the objective of maximizing portfolio value subject to “constraints”. On the one hand, these

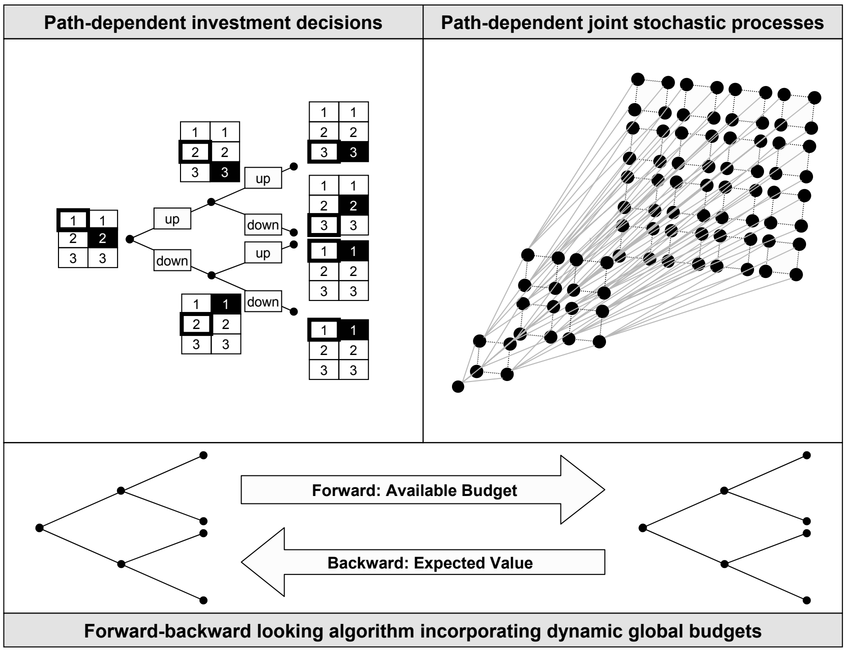

Fig. 2.3. Modeling approach

constraints model portfolio aspects which are automatically understood as constraints, such as budget constraints. On the other hand, other features are also captured by modeling these as balance equations, such as the specification of the processes of the underlying assets, the determination of available funds, or the calculation of expected values. The dynamic nature of the problem is incorporated through constraints that are either backward– or forward–looking, but either way dynamic. This makes it possible to handle simultaneous interaction effects and to define the problem in a formulation that can incorporate operating and financial constraints. Moreover, this approach makes it possible to solve the problem with commercially available solvers.

The model implementation reverts to commercially available software packages, i.e., the optimization platform GAMS© (cf. Bussieck and Meeraus 2004), together with suitable optimizers such as BARON© and Cplex©. This implementation makes it possible to benefit from advanced optimization techniques that have been tested and adapted continuously and enables to separate the problem implementation from the actual optimization algorithms. Consequently, the model becomes verifiable and portable between applications.

Based on this understanding, our approach to portfolios of real options will be positioned in the relevant literature next. This will provide the basis for our ensuing model development.

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