Valuation of IT Investments Using Real Options Theory

Real Options Theory is often applied to the valuation of IT investments in scientific literature. As a result, the application of Real Options Theory is often accompanied by the monetary valuation of real options through option pricing models. However, due to their assumptions, the application of option pricing models is subject to criticism. By means of a structured literature review, this paper reveals that critical assumptions are frequently neglected although their non-fulfillment is known. This analysis points out that the fulfillment of assumptions depends on the type of IT investment that is evaluated. Moreover, further option pricing methods can be found in scientific literature which allow for the relaxation of critical assumptions.

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The Author

Dipl.-Kfm. Christian Ullrich MBA (✉)
Department of Information Systems Engineering & Financial Management
FIM Research Center
University of Augsburg
Universitätsstraße 12
86159 Augsburg
Germany
christian.ullrich@wiwi.uni-augsburg.de

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1 Introduction

Investments in information technology (IT) often bear great uncertainty which arises, amongst others, from their complexity or from unpredictable, changing circumstances (Fichman et al. 2005, p. 74). In order to be able to adequately react to uncertain developments, companies need to possess managerial flexibility. Managerial flexibility enables companies, e.g., to pause or abandon an IT investment in case of a negative development, or to extend it in case of a positive development. But traditional investment valuation methods such as 'net present value' are incapable of accounting for managerial flexibility in the valuation. Therefore, critical scientists argue that IT investments are undervalued (Trigeorgis 1996, p. 152). Thus, scientific literature suggests the application of Real Options Theory (ROT) to the valuation of IT investments because it leads to a more precise valuation (Benaroch 2002, p. 47).

ROT is derived from the theory of financial options and assumes that managerial flexibility can be modeled as a real option. Whereas securities, e.g. stocks, serve as underlyings for financial options, real investment projects constitute the underlying in case of real options. Financial options as well as real options can both be considered options for conducting a certain action for an agreed price in a certain period of time. The option is European if the execution of the option is only possible at the maturity date. If an execution prior to the maturity date is possible, the option is American.

The idea of transferring options theory to real investments traces back to Myers (1974), whereas the application of ROT to the valuation of IT investments started in the early 1990s. The application of ROT is often accompanied by a monetary valuation of real options, for which mostly option pricing models (OPMs), known from financial theory, are used. The most popular OPMs are the "Black-Scholes Model" (BSM), developed by Black and Scholes (1973) and Merton (1973), and the "Binomial Model" (BM), developed by Cox et al. (1979). However, the application of these pricing models is subject to criticism due to the fact that essential assumptions are not fulfilled, which can lead to false valuations and, therefore, to wrong investment decisions (Zhu 1999). This issue prompted Kruschwitz (2011) to state, "that the concept of real options is a meander. The valuation formulas known from financial options must not be applied (…) [to the valuation of real investments]" (Kruschwitz 2011, p. 420).

Despite this criticism, several scientific articles can be found that apply ROT to the monetary valuation of IT investments and thus valuate real options monetarily. Therefore, the question arises to which extent the application of ROT and, accordingly, the application of OPMs is justified in the respective context. This paper addresses this question and pursues two objectives:

1. It will be revealed which scientific articles monetarily valuate IT investments with the help of ROT. Since different types of IT investments possess different characteristics which are relevant for the valuation, it will be further analyzed which types of IT investments are evaluated.
2. It will be analyzed how the identified articles address the critical assumptions. Furthermore, it will be

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discussed whether the approach pursued in an article is compatible with the characteristics of the type of IT investment valuated.

The research approach pursued in this "state-of-the-art" article is based on the five phases of review-research introduced by Fettke (2006, p. 260). It extends the five phases to an explanation of the theoretical background required for this article. After formulating the research questions in this section ("problem formulation"), the fundamentals of ROT as well as the fundamentals of OPMs are described in Sect. 2. This is followed by the selection of relevant literature ("literature search") and the classification of identified articles according to the respective type of IT investment evaluated ("literature review") in Sect. 3. After that, the different types of IT investments are analyzed with respect to the characteristics which are relevant for the valuation. Additionally, the implications of the characteristics for the assumptions of the OPMs are investigated. Based on this analysis, it is discussed how the respective authors address these assumptions in their articles and if this is legitimate with respect to the type of IT investment considered ("analysis and interpretation"). The publication of this article presents the results ("presentation").

2 Foundations of Real Options Theory

2.1 Managerial Flexibility as Real Options

Changing circumstances often influence ongoing IT projects. Therefore, companies must be able to flexibly react to new situations. However, companies *do not have to* react, but rather *can* react according to their current situation. Therefore, this possibility to react can be modeled as a real option. Trigeorgis (1996, p. 2) provides a good overview of possible types of managerial flexibility as well as corresponding types of real options (**Table 1**).

Table 1 Types of managerial flexibility/real options

Type of managerial flexibility	Type of real option
A project can be abandoned at predefined milestones if it evolves unfavorably	Option to Abandon
The scope of a project can be scaled down if it evolves unfavorably	Option to Contract
The scope of a project can be scaled up if it evolves favorably	Option to Expand
The implementation of a project can be carried out in stages	Staging Option
The start of a project can be delayed	Option to Defer
The successful implementation of a project can lead to follow-up projects	Growth Option
Depending on the course of a project, the input resources can be replaced	Option to Switch

Whereas the option to abandon and the option to contract are usually modeled as put options, the other types of real options are modeled as call options.

Besides articles that proclaim "Option Thinking" in the context of IT investments (Fichman 2004; Fichman et al. 2005), there are also empirical investigations regarding either the perception of real options (Lankton and Luft 2008; Tiwana et al. 2006) or option-based risk management (Benaroch et al. 2006; Hilhorst et al. 2008). Furthermore, several articles apply ROT to the monetary valuation of IT investments. As a result, the net present value of an investment is extended by the value of managerial flexibility, i.e., the value of the real option (Trigeorgis 1996, p. 152). OPMs are often used to determine the value of real options, which is why they will be described in the following section.

2.2 Valuation of Real Options

The BM and the BSM are the most highly-favored OPMs, which is why they are hereinafter referred to as "traditional OPMs". Traditional OPMs assume that the value of the option is known at the date of maturity and that this either equals the positive difference between the value of the underlying and strike price or zero at that time. Traditional OPMs also assume that the pay-off of the option can be replicated by a self-financing portfolio consisting of the underlying and a riskless asset (Perridon et al. 2009, p. 335). The risks of the portfolio can then be hedged by choosing the right portfolio shares and adjusting them according to the current value of the underlying, which is why this portfolio yields a risk-free rate. Since this option valuation is solely based on market instruments, the valuation is free of any preferences.

The BM assumes a binomial evolution of the value of the underlying for discrete points in time. In the resulting binomial tree, the option values of the final states are discounted to the time of acquisition and weighted with risk-neutral probabilities in order to determine the value of the option at that point in time. In contrast, the BSM is based on continuous time and assumes that the underlying evolves according to a continuous stochastic process, more precisely a geometric Brownian motion (GBM). From this, Black and Scholes (1973) derived an analytic, solvable equation which determines the value of a European option.

In order to determine the value of the option with the help of traditional OPMs, the following assumptions have to be fulfilled[1]:

(A1) There is a complete market that allows for continuous trading of both the underlying and the option.

(A2) The value of the underlying evolves according to a GBM and has a constant variance.

(A3) The strike price of the option is known and constant over the duration of the option.

(A4) The option can be exercised only at the certain maturity date (European option).

(A5) The market is perfect.[2]

Five input parameters are required to determine the value of the option.[3] **Table 2** shows the parameters and their interpretation for both financial options and real options in the context of IT investments.

[1] Here, the assumptions of the BSM are listed although only assumption (A2) differs from the assumptions of the BM. But if the time intervals of the BM are scaled down, the binomial process of the BM can be converted to the continuous process of the BSM (Trigeorgis 1996, p. 83).

[2] Assumption (A5) will not be further considered since it is not ROT-specific but rather necessary for several capital market models (as, e.g., the Capital Asset Pricing Model).

[3] For the derivation of the formulas necessary for option valuation, see standard literature such as Franke and Hax (2003) or Perridon et al. (2009).

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Table 2 Comparison of the parameters for the valuation of financial options and real options

Financial option	Real option
Stock (value of the underlying)	Present value of the cash inflows of IT investments
Strike price	Present value of cash outflows of the IT investments at the maturity date
Standard deviation of the underlying	Standard deviation of the present value of cash inflows
Time to maturity	Time until the managerial flexibility can be exercised
Risk-free interest rate	Risk-free interest rate

Table 3 Criteria for the literature selection

Criterion	Characteristic
Database	AIS Electronic Library, EBSCOhost, EmeraldInsight, IEEEXplore, ProQuest, ScienceDirect, SpringerLink
Additional conferences	Americas Conference on Information Systems (AMCIS), European Conference on Information Systems (ECIS), International Conference on Information Systems (ICIS)
Search fields	Title, abstract, keywords (if applicable)
Search strings	("real option" OR "real options") AND ("information systems" OR "information technology")

If the assumptions described above are not fulfilled, a correct option valuation conducted by means of traditional OPMs would fail. Therefore the following section analyzes how these assumptions are compatible with the characteristics of different types of IT investments and how scientific literature addresses them.

3 Identification and Classification of Literature

3.1 Identification of Relevant Literature

The selection of literature relevant for the following analysis was obtained by a systematic database search based on keywords. In addition to the scientific journals considered, IS-related conferences were also included in the selection process. **Table 3** provides an overview of the databases and search strings used for the database search.

In order to consider the most relevant IS journals, journals listed in the VHB-Ranking for Wirtschaftsinformatik (VHB Jourqual 2, rating category A or B) were also scanned for the search strings "real option" or "real options", which made the results more comprehensive. In a last step, the identification of relevant articles was concluded with a forward and backward search of the citations, as postulated by Webster and Watson (2002).

After reviewing all articles, only those which monetarily evaluate real options were considered, because only these articles must consider the assumptions of OPMs. After this search, a total of 35 articles could be identified.

3.2 Classification of Literature

The articles identified in the approach described above are similar in that they monetarily evaluate IT investments with the help of ROT. As mentioned earlier, the valuation object "IT investment" needs to be further specified for a detailed analysis of the applicability of ROT. Therefore, in a first step, these articles were analyzed with regard to the concrete IT investment (valuation object) they focus on. In a second step, the type of real option considered was analyzed. For most types of real options, the underlying of the option corresponds to the valuation object of the IT investment. The only relevant exception is the growth option, which specifies the flexibility to conduct a follow-up project (underlying of the option) after a successful implementation of a prior project (valuation object). Thus, it must be separately analyzed for growth options which type of IT investment the underlying refers to.

After the valuation objects had been specified, the articles were categorized according to the type of IT investment which results from the underlying of the real option. **Table 4** shows that 28 out of 35 articles fit into the three categories "Investments in Standard Software" (10 articles), "Investments in Individual Software" (6 articles), and "Investments in New Technologies" (13 articles, with one article fitting into two categories). Seven articles could not be assigned to one of those categories. This is due to the fact that some of these articles consider abstract IT investments and do not describe their valuation object in greater detail (Banker et al. 2010; Kumar 1996; Lee et al. 2009; Zandi and Tavana 2011). Gull (2011) determines the value of discount options which are often part of licensing agreements for commercial standard software. Heinrich et al. (2011) evaluate the option of a bank to sell software which was developed in-house as a service over the internet. Since the sale of IT services corresponds to the underlying of the option, the underlying does not refer to a classical IT investment. Herath and Herath (2008) evaluate the cash outflows of a company for IT security arrangements, which is why this article cannot be assigned to one of the identified categories.

4 Analysis of the Identified Literature

The analysis of the identified literature was carried out sequentially for each type of IT investment and structured as follows: First, the characteristics relevant for the valuation were described for each type of IT investment and compared with the assumptions of the traditional OPMs ('General Description'). Here, each assumption was discussed as to whether it hinders the use of traditional OPMs ('critical') or if it could possibly be fulfilled ('rather uncritical'). Furthermore, some characteristics of IT investments might not allow conclusions to be drawn about the fulfillment of an assumption ('no statement'). Second, it was determined how the identified articles discuss the assumptions or how they address them in their models ('Analysis of the Articles'). Three levels of consideration were distinguished:

- Discussion of the assumption, consideration in the model (+)
- Discussion of the assumption, no consideration in the model (∘)
- No discussion of the assumption, no consideration in the model (−)

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Table 4 Classification of the Identified Literature

Article	Valuation object	Type of real option	Underlying of the real option (if deviating)	Type of IT investment
Angelou and Economides (2008)	Prioritizing a portfolio of IT projects with interdependencies to follow-up projects of a water supply and sewage company	Growth Option	Extension of the existing IT infrastructure by standard functionalities	Investments in Standard Software
Balasubramanian et al. (2000)	Implementation of a document imaging software in a Canadian mortgage bank	Growth Option	Roll-out of the software in all offices	
Cao et al. (2009)	Implementation of a supply chain management system considering alternative implementation strategies	Staging Option		
Ekström and Björnsson (2005)	Purchase of an enterprise resource planning software	Growth Option	Extension of the system by additional standard functionalities	
Hilhorst et al. (2006)	Implementation strategy for the introduction of a capability management information system	Staging Option		
Maklan et al. (2005)	Purchase of a customer relationship management software	Staging Option		
Singh et al. (2004)	Leasing of a total accounting package from an application service provider	Option to Abandon		
Taudes (1998), Taudes et al. (2000)	Switch from SAP R/2 to SAP R/3	Growth Option	Implementation of web-based standard functionalities	
Wu et al. (2009)	Implementation of an enterprise resource planning software	Staging Option		
Bardhan et al. (2004)	Valuation of the IT project portfolio of an energy provider	Growth Option	Valuation of web-based follow-up projects	Investments in Individual Software
Diepold et al. (2009; 2011)	Purchase of a new backend system by a retail bank	Growth Option	Connection of the sale frontends to the backend	
Dolci et al. (2010)	Implementation of a system for managing the delivery date of products required by the market	Growth Option	Development of additional features, e.g. an e-procurement website	
Kumar (2002)	Development of a computer-aided software engineering (CASE) tool	Option to Defer		
Schwartz and Zozaya-Gorostiza (2003)	Development of individual software	Option to Defer		
Benaroch and Kauffman (1999, 2000)	Deployment of point-of-sale debit services by an electronic banking network	Option to Defer		Investments in New Technologies
Dos Santos (1991)	Implementation of a company-wide ISDN infrastructure	Growth Option	Conduct of an ISDN-based follow-up project	
Harmantzis and Tanguturi (2007)	Investment of a telecommunications service provider into the extension of either the UMTS network or the Wi-Fi network	Option to Defer&Growth Option	Integration of both technologies	
Ji (2010)	Deployment of point-of-sale debit services by an electronic banking network	Option to Defer		
Kauffman and Kumar (2008)	Investment in a network technology	Option to Defer		
Kauffman and Li (2005)	Investment in one of two competing technologies considering competition	Option to Defer		
Kim (2008)	Determination of the optimal technology migration path for a telecommunications service provider	Growth Option	Investment in a new and revolutionary technology	
Li (2009)	Investment in new technologies considering organizational learning	Option to Defer		
Miller et al. (2004)	Investment in an information super-highway infrastructure	Growth Option	Implementation of an IPv6 address system	
Panayi and Trigeorgis (1998)	Development of an information system required for extending the telecommunications network of a federal communications authority	Growth Option	Extension of the telecommunications network	
Schwartz and Zozaya-Gorostiza (2003)	Deployment of point-of-sale debit services by an electronic banking network	Option to Defer		
Tao et al. (2007)	Deployment of point-of-sale debit services by an electronic banking network	Option to Defer		

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Articles which at least discuss the assumptions (+ or ∘) were analyzed in greater detail. Finally, preliminary conclusions were drawn for each subsection.

4.1 Investments in Standard Software

4.1.1 General Description

Standard Software is a collective term for programs that "are not written for an individual customer of the software-vendor, but rather for a group of customers with similar problems" (Mertens et al. 2010, p. 18). One key feature of standard software is that it can be used shortly after being purchased and therefore the cash inflows can be realized promptly, provided that customizing is not necessary.

Assumption of the Complete Market (A1) As stated earlier, a complete market is necessary to build and – in case of a change in the value of the underlying – hedge a replicating portfolio consisting of the underlying and a riskless asset. Even though standard software is traded on a market and therefore has a price, the assumption is not fulfilled from the users' perspective. This is due to the fact that the value of the underlying corresponds to the present value of cash inflows resulting from the use of the software (and thus not to cash outflows). Cash inflows generated by the use of the software are highly specific for each company. Therefore, assumption (A1) is critical for the valuation of investments in standard software using traditional OPMs.

Assumption of the Stochastic Process and Constant Variance (A2) The GBM describes how the value of the underlying, and therefore the present value of cash inflows of the IT investment, evolves during the duration of the option. This evolution is further characterized by the fact that the value of the underlying changes only slightly in a short period of time (Franke and Hax 2003, p. 380). Therefore, volatile changes in the value of the underlying cannot be taken into account. If a growth option is considered, the duration of the option equals the runtime of the earlier base project. Therefore, the GBM describes the deviation of the underlying which occurs during the runtime of the base project. Due to this, no general statement can be derived regarding the question of whether the GBM correctly describes the evolution of the underlying in the case of investments in standard software.

Assumption of the Certain Cash Outflows (A3) Cash outflows for the purchase of standard software are mostly known or can easily be assessed (Bernroider and Koch 2000, p. 330). But standard software often does not fulfill all firm-specific requirements (Krcmar 2010), so additional, uncertain cash outflows for customizing the software can occur (Bernroider and Koch 2000, p. 330). If one puts aside these uncertain cash outflows, it can be stated that assumption (A3) is rather uncritical for the valuation of options. However, if high and uncertain cash outflows for customizing occur, the investment should rather be treated as an investment in individual software.

Assumption of the Certain Duration of the Option (A4) In case the investment in standard software is modeled as a growth option, the duration of the base project determines the duration of the option. However, since investments in standard software often also serve as base projects for real options (Taudes 1998), it can be assumed that the duration of the option can be estimated reliably if there is no effort for customizing. For other types of real options, the underlying corresponds to the investment in standard software, which means that also here assumption (A4) seems to be rather uncritical.

4.1.2 Analysis of the Articles

Assumption of the Complete Market (A1) Angelou and Economides (2008), as well as Singh et al. (2004), legitimate the application of OPMs – despite the fact that the underlying is not traded – by referring to the argumentation used by Benaroch and Kauffman (1999). These authors state that "irrespective whether a project is traded, we seek to determine what the project cash flows would be worth if they were traded" (Benaroch and Kauffman 1999, p. 77). A potential difference between the subjective estimate and the objective market value, and thus a misevaluation, will lead to an over- or undervaluation of the whole company, which will be corrected by market adjustments in the long term (e.g., in an acquisition or sale of the company) (Benaroch and Kauffman 1999). Taudes (1998) also acknowledges that there is no traded underlying in the context of IT investments. He points out that a preference-dependent valuation would be necessary. However, he also defends the application of OPMs since BSM-based models allow for a straightforward sensitivity analysis, which helps to check the robustness of the results. As he also states in his follow-up paper (Taudes et al. 2000), Taudes (1998) argues that the determination of the precise option value is of secondary importance because the value of the underlying also has to be estimated. Instead, he wants to determine a lower boundary for the value of flexibility. Ekström and Björnsson (2005) argue that the underlying itself does not necessarily need to be traded on a market if there is a traded asset that is perfectly correlated with the underlying (twin security). Because the authors put aside project-specific risks and only consider market risks, they account for assumption (A1) in case a twin security exists.

Two articles extend their OPM by a preference-dependent valuation so that assumption (A1) can be avoided: Balasubramanian et al. (2000) distinguish between project-specific risks and market risks. In addition to the valuation of market risks with a binomial tree, the authors suggest evaluating project-specific risks using a decision tree. Hilhorst et al. (2006) also consider individual preferences besides a market valuation and compute an expected option value. Wu et al. (2009) acknowledge that OPMs in general do not have the ability to correctly account for the complexity of IT investments. Therefore, in their paper the authors formulate the determination of the option value as a stochastic optimization problem. Thus, the assumptions of the OPMs become irrelevant to them.

Assumption of the Stochastic Process and Constant Variance (A2) Besides a traditional OPM, Angelou and Economides (2008) apply the "Analytical Hierarchy Process", through which the quality of different sources of uncertainty can be considered. However, assumption (A2) is not directly considered. In contrast, Taudes et al. (2000) explicitly take up this assumption and argue that empirical studies have shown that the GBM is a valid descriptor of the future development of the underlying value. Hilhorst et al. (2006) also discuss this assumption and admit that the variance does not remain constant over time. Therefore, the authors conduct sensitivity analyses for different variances at different

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Table 5 Assumptions of the OPMs – Investments in Standard Software

Investments in standard software	Critical	No statement	Rather uncritical	Rather uncritical
	A1	A2	A3	A4
Angelou and Economides (2008)	○	○	+/○	–
Balasubramanian et al. (2000)	+	–	–	–
Cao et al. (2009)	–	–	–	–
Ekström and Björnsson (2005)	○	–	–	–
Hilhorst et al. (2006)	+	○	–	–
Maklan et al. (2005)	–	–	–	–
Singh et al. (2004)	○	○	–	–
Taudes (1998)	○	–	+	+
Taudes et al. (2000)	○	○	–	–
Wu et al. (2009)	+	–	+	+

"+"= Discussion of the assumption, consideration in the model
"○" = Discussion of the assumption, no consideration in the model
"–" = No discussion of the assumption, no consideration in the model

points in time. Singh et al. (2004) argue that the value of the variance depends on the value of the underlying and decreases with the diminishing time to maturity. However, the authors act on the assumption of a constant variance due to the simpler valuation in their article.

Assumption of the Certain Cash Outflows (A3) Angelou and Economides (2008) account for assumption (A3) and initially calculate the option value considering uncertain cash outflows using a single-step binomial tree. As a result, the authors find that uncertain cash outflows increase the option value, but the authors assume certain cash outflows for further calculations.

Taudes (1998) is the only article which considers assumption (A3) in the model. The author applies, amongst others, the Margrabe (1978) model to account for uncertain cash outflows.

Assumption of the Certain Duration of the Option (A4) Taudes (1998) mentions that the possible investment can take place at different points in time, which is why the investment should rather be modeled as an American option. Thus, the author uses an OPM to evaluate American options.

Table 5 compares the articles and their handling of the four assumptions of traditional OPMs.

Interim Conclusion As a conclusion for the valuation of investments in standard software, it can be stated that assumption (A1), which is critical for the option valuation, is mostly discussed in a qualitative way. Seven of the ten identified articles use traditional OPMs without considering assumption (A1) in their models. Only Balasubramanian et al. (2000) and Hilhorst et al. (2006) construct their OPM in a way that assumption (A1) no longer prevents the option valuation, whereas Wu et al. (2009) distance themselves from OPMs. Furthermore, it can be shown that the majority of the articles do not consider assumptions (2), (3), and (4). However, due to the characteristics of investments in standard software, especially assumptions (A2) and (A3) do not necessarily hinder the application of traditional OPMs, as long as uncertain efforts for customizing, which can affect cash outflows as well as the time to maturity of the option, can be neglected.

4.2 Investments in Individual Software

4.2.1 General Description

In contrast to standard software, individual software is "individually fabricated for a special business requirement with the corresponding hardware and software environment" (Mertens et al. 2010, p. 24). Therefore, it can be described as "customized software for special applications" (Krcmar 2010, p. 167). Compared to standard software, individual software only becomes available at an uncertain future point in time due to the development time, which is why cash inflows generated by the use of individual software can also only be realized at a later and uncertain point in time (Krcmar 2010).

Assumption of the Complete Market (A1) In case of investments in individual software, the existence of a market for the underlying is implausible, which is why assumption (A1) is critical.

Assumption of the Stochastic Process and Constant Variance (A2) Similar to investments in standard software, it is not possible to make a general statement due to the fact that the development of the underlying is highly project-specific.

Assumption of the Certain Cash Outflows (A3) Cash outflows for the development of individual software are often accompanied by high uncertainties (Bernroider and Koch 2000), since cost estimates are difficult, resulting from both little experience in companies and rapidly changing circumstances (Henrich 2002). Therefore, assumption (A3) is critical for the valuation as long as in-house developments are considered. If the individual software is developed by an external service provider, it is essential to determine who bears the risks and therefore the potential additional cash outflows.

Assumption of the Certain Duration of the Option (A4) Since investments in individual software are often modeled as growth options, the duration of the option depends on the runtime of the base project. Therefore, there is no connection between the duration of the option and the time for the developing the individual software. This also holds true for deferral options. In both cases, the development of the individual software begins at the maturity date of the option. Thus, no conclusion can be drawn from the characteristics of this type of IT investment for the fulfillment of assumption (A4).

4.2.2 Analysis of the Articles

Assumption of the Complete Market (A1) Bardhan et al. (2004, p. 39) base their discussion about assumption (A1) on the ar-

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Table 6 Assumptions of the OPMs – Investments in Individual Software

Investments in individual software	Critical	No statement	Critical	No statement
	A1	A2	A3	A4
Bardhan et al. (2004)	–	–	+	–
Diepold et al. (2009)	+	–	–	–
Diepold et al. (2011)	+	–	–	–
Dolci et al. (2010)	–	–	–	–
Kumar (2002)	○	–	+	○
Schwartz and Zozaya-Gorostiza (2003)	+	–	+	○

"+" = Discussion of the assumption, consideration in the model
"○" = Discussion of the assumption, no consideration in the model
"–" = No discussion of the assumption, no consideration in the model

gument made by Benaroch (2002). According to this argument, the valuation of non-traded assets is legitimate since companies "seeking to maximize shareholders' value may use risk-free discounting to evaluate real options" (Benaroch 2002, p. 78). The application of a risk-adjusted discount rate would only lower the option value marginally. Kumar (2002) argues that the option value constitutes a good approximation for the value of flexibility, even though there is no replicating portfolio.

Diepold et al. (2009, 2011) apply a preference-dependent valuation approach in their articles. They extend the BSM by using a decision tree similar to Balasubramanian et al. (2000). Schwartz and Zozaya-Gorostiza (2003) assume that because of the missing market, the value of the cash inflows equals the expected value of a random variable which also contains a risk premium. The authors therefore do not use a traditional OPM, but rather model the option valuation as a dynamic optimization problem.

Assumption of the Stochastic Process and Constant Variance (A2) None of the identified articles dwell on this assumption.

Assumption of the Certain Cash Outflows (A3) Bardhan et al. (2004) as well as Kumar (2002) account for the uncertain costs of software development projects by applying the Margrabe model and, therefore, by modeling the cash outflows as a random variable following a stochastic process. Schwartz and Zozaya-Gorostiza (2003) also represent the uncertain cash outflows of software development projects as a stochastic process. This process accounts for a decrease of uncertainty in cash outflows over time, a decrease of the costs of necessary IT assets over time, the technical uncertainty of the implementation, and volatile cash outflows for time and material.

Assumption of the Certain Duration of the Option (A4) Kumar (2002) discusses the assumption and states that the duration of software development can be uncertain; however, he assumes the duration to be certain in his model. Schwartz and Zozaya-Gorostiza (2003) also address the fact that software development projects are characterized by uncertain durations, although they neglect this issue in their model.

Table 6 compares the identified articles and their handling of the assumptions.

Interim Conclusion The analysis of the identified literature, which valuates investments in individual software, reveals that four out of the six articles at least discuss the critical assumption (A1), whereas three of them use preference-dependent valuation approaches. However, no article discusses assumption (A2). In contrast to the investments in standard software analyzed above, it can be stated that half of the articles actively address the uncertainty of cash outflows of the investment and adequately account for this by applying a suitable valuation approach. Therefore, these articles allow for the essential characteristics of investments in individual software. Kumar (2002) as well as Schwartz and Zozaya-Gorostiza (2003) further discuss the fact that the duration of the option could be uncertain. They are the only authors in this category who model and valuate deferral options. Since the start of the investment does not depend on previous basic projects in deferral options, but rather on more favorable conditions, the discussion of an execution of the option before maturity seems appropriate.

4.3 Investments in New Technologies

4.3.1 General Description

Investments in new technologies are characterized by significant and irreversible upfront cash outflows opposed to uncertain future cash inflows (Harmantzis and Tanguturi 2007, p. 110). The determination of optimal timing constitutes an important issue for the valuation of investments in new technologies. The best moment for these investments is highly uncertain due to external influences, e.g., the behavior of competitors or technological change, which in turn also influence the cash flows of the investment (Kauffman and Li 2005, p. 15). In order to integrate the characteristics of investments in new technologies into the valuation, ROT is frequently used. As a result, the investment situation is often modeled as a deferral option (Benaroch 2002, p. 45). This represents the possibility of companies to watch for uncertain market developments and delay the investment decision. It is assumed that uncertainties decrease over time and that primarily estimated values and realized values converge. This type of managerial flexibility is often called the "wait-and-see"-strategy (Benaroch 2002, p. 45). But the delay of investment decisions also bears additional risks, e.g., the occurrence of competition or alternative technologies.

Assumption of the Complete Market (A1) The assumption of the complete market is also critical for this type of investment.

Assumption of the Stochastic Process and Constant Variance (A2) As described earlier, the GBM describes only small changes in the value of the underlying over a short period of time. But the development of new and innovative technologies is characterized by external influences which can have a significant impact on cash inflows generated by the use of the new technology. Therefore, this assumption is critical for the valuation of the option.

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Assumption of the Certain Cash Outflows (A3) The uncertain development of new technologies described above also affects corresponding cash outflows, since it cannot be foreseen how they evolve. Particularly due to the fact that this type of IT investment is often modeled as an option to defer, which means that the cash outflows will only incur at an uncertain future point of time, assumption (A3) is also critical.

Assumption of the Certain Duration of the Option (A4) As mentioned earlier, investments in new technologies are often modeled as options to defer in order to evaluate a "wait-and-see" strategy. Since the optimal timing of the investment is normally uncertain, this assumption is also critical for the valuation of the option.

4.3.2 Analysis of the Articles

Assumption of the Complete Market (A1) Dos Santos (1991, p. 79) mentions that it is nearly impossible to identify a traded twin security. Nevertheless, he applies the BSM-based Margrabe model to value the real option. Benaroch and Kauffman (1999) also discuss the assumption of the complete market and go back to the argumentation described in Sect. 4.1.2 to justify the application of OPMs.

Other authors address the critical assumption (A1) in their models: Kauffman and Li (2005), as well as Li (2009), acknowledge that the underlying itself is not traded and that there is no traded twin security. The authors reason that traditional OPMs should, therefore, not be applied. While Kauffman and Li (2005) formulate an optimization problem and derive their own analytical solution, Li (2009) determines the option value by means of a simulation. Therefore, assumption (A1) does not oppose these approaches. Kauffman and Kumar (2008), as well as Schwartz and Zozaya-Gorostiza (2003), model the underlying as a random variable that contains a risk premium. Both approaches formulate the option valuation as a dynamic optimization problem so that assumption (A1) is of no importance for the solution. Benaroch and Kauffman (2000), as well as Harmantzis and Tanguturi (2007), account for assumption (A1) in the valuation by applying a preference-dependent valuation approach. Both extend the BSM by adding the parameter "rate-of-return shortfall" due to the following reason: According to Trigeorgis (1996, p. 101ff), the return of an underlying which is either not traded or only traded in a limited amount is lower than the return of a traded asset bearing the same risk. This difference is called "rate-of-return shortfall". Trigeorgis (1996, p. 101ff) concludes that irrespective whether the underlying is traded or not, the option valuation is valid as long as project-specific risks are accounted for by adapting the growth rate of the underlying.

Assumption of the Stochastic Process and Constant Variance (A2) Benaroch and Kauffman (1999) assume a GBM in their article. However, the authors mention that there are extensions of OPMs which can account for alternative stochastic processes, and these in turn can lead to imprecise results. Kauffman and Kumar (2008) address this issue and model a jump diffusion process. Therefore, they explicitly allow for jumps in the evolution of the underlying.

Assumption of the Certain Cash Outflows (A3) Benaroch and Kauffman (1999) assume the cash outflows for the investment to be certain, but they refer to the Margrabe model for the case that cash outflows are uncertain. Ji (2010) explicitly addresses the cash outflows and assumes that the cash outflows for the investment depend on the cash outflows for organizational learning. To address assumption (A2), Dos Santos (1991) also models uncertain cash outflows by applying the Margrabe model in addition to uncertain cash inflows Kauffman and Kumar (2008), as well as Schwartz and Zozaya-Gorostiza (2003), account for the uncertainty of cash outflows by modeling it as a random variable which follows a stochastic process.

Assumption of the Certain Duration of the Option (A4) Harmantzis and Tanguturi (2007) mention assumption (A4) but state that the duration of the option is given exogenously.

Li (2009) argues that the timing of the investment in a new technology, and therefore the duration of the option, depends on the process underlying the model. He concludes that the timing of the investment depends on both organizational learning as well as a company's absorptive capacity. Therefore, the author models the duration as a random variable. Kauffman and Li (2005) also model the point in time of the investment as a random variable. The investment should be conducted as soon as the development of two competing technologies, which follows a stochastic process, exceeds a certain threshold. Benaroch and Kauffman (1999, 2000), Harmantzis and Tanguturi (2007), and Ji (2010) also take up assumption (A4) and apply Black's Approximation (Black 1975) in order to determine the optimal timing of the investment. This approach is based on the BSM and allows for an approximation of an American option by evaluating multiple European options with different durations.

Table 7 compares the identified articles and their handling of the assumptions.

Interim Conclusion The analysis of the identified literature reveals that, in contrast to the other types of IT investments, all assumptions are critical for the valuation. It should be noted that some articles refrain from applying traditional OPMs or their extensions and rather base their option valuation either on simulations or on dynamic programming. This underlines the fact that traditional OPMs are not adequate for the valuation of this type of IT investment. Several factors such as competition or technological progress influence the investment decision, which is why some articles model alternative stochastic processes. Assumption (A3) also seems to be very restrictive for this type of IT investment, thus some articles model cash outflows as random variables. Since the optimal timing of the investment can be critical for its success (Benaroch and Kauffman 1999) and therefore is important for the valuation, assumption (A4) is also very restrictive. Schwartz and Zozaya-Gorostiza (2003), as well as Kauffman and Kumar (2008), are the only articles which account for at least three out of the four assumptions.

4.4 Conclusions from the Literature Analysis

The analysis of the literature revealed that extensions of the traditional OPMs are applied in some articles in order to relax individual assumptions of the traditional OPMs (**Table 8**).

The assumption of the complete market (A1) can be addressed by distinguishing between market risks and project-specific risks. Market risks can be valuated with OPMs, however, project-specific risks need to be addressed by

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means of a preference-dependent valuation. Therefore, project-specific risks need to be assessed subjectively by the decision makers and taken into account in the valuation. This can be achieved, e.g., either with help of the integration of a decision tree or the "rate-of-return shortfall" (Trigeorgis 1996, p. 101ff).

If the evolution of the underlying is assumed to be erratic and therefore cannot be described by the GBM, then – according to Merton (1976) – a jump process can be assumed to describe the evolution of the underlying (Jump Diffusion model) However, this approach increases the complexity of the option valuation.

The application of the Margrabe (1978) model is suitable if an IT investment is characterized by uncertain cash outflows. It is based on the BSM and values an option by which one risky asset is exchanged for another. The strike price of the option is uncertain and follows a continuous stochastic process with constant variance, which is correlated with the stochastic process of the underlying. Therefore, uncertain cash outflows can be considered in the application of this model.

If the duration, and therefore the exercise date, of the option is uncertain or if the option can be executed prior to the maturity date, Black's approximation can be used to approximate the value of an American option. Therefore, e.g. in the case of deferral options, the optimal exercise time can be determined (Benaroch and Kauffman 1999, 2000).

The partial extensions identified in this literature analysis can be further combined so that several critical assumptions can be considered at the same time. When the characteristics of the real options to be valued are incompatible with the assumptions of traditional OPMs, some authors use dynamic programming approaches to model the investment decision. Therefore, traditional OPMs, or rather their partial extensions, are not used anymore, and thus corresponding assumptions do not need to be met.

Table 7 Assumptions of the OPMs – Investments in New Technologies

Investments in new technologies	Critical A1	Critical A2	Critical A3	Critical A4
Benaroch and Kauffman (1999)	∘	∘	∘	+
Benaroch and Kauffman (2000)	+	–	–	+
Dos Santos (1991)	–	–	+	–
Harmantzis and Tanguturi (2007)	+	–	–	∘
Ji (2010)	–	–	+	+
Kauffman and Kumar (2008)	+	+	+	–
Kauffman and Li (2005)	+	+	–	+
Kim (2008)	–	–	–	–
Li (2009)	+	–	–	–
Miller et al. (2004)	–	–	–	–
Panayi and Trigeorgis (1998)	–	–	–	–
Schwartz and Zozaya-Gorostiza (2003)	+	+	+	–
Tao et al. (2007)	–	–	–	–

"+" = Discussion of the assumption, consideration in the model
"∘" = Discussion of the assumption, no consideration in the model
"–" = No discussion of the assumption, no consideration in the model

Table 8 Extensions of the traditional OPMs

Assumption of OPMs	Partial extension for relaxation
(A1) Complete market	Preference-dependent valuation
(A2) GBM and constant variance	Jump diffusion model
(A3) Certain cash outflows	Margrabe model
(A4) Certain duration	Black's approximation

5 Conclusion

The objective of this paper was first to reveal which articles monetarily evaluate IT investments with ROT. These articles were analyzed in particular with regard to what types of IT investments serve as valuation objects. A second analysis dealt with the way in which the authors address critical assumptions of the OPMs and how far their approaches are compatible with the characteristics of the related type of IT investment.

The analysis of these twenty-eight articles has shown that the criticism by Kruschwitz (2011) mentioned above is valid because traditional OPMs contain assumptions which are not met in the context of IT investments. Not surprisingly, the assumption of the complete market contradicts the applicability of ROT to the highest degree. This issue is known in scientific literature and is often discussed qualitatively. Instead, however, users of ROT should address this assumption through adequate modeling which can be achieved for instance with a preference-dependent valuation. There also might be situations in which assumption (A1) is fulfilled: If a company e.g. develops software and sells it on a market, the resulting revenues determine the value of the underlying. A similar discussion can be found in the article written by Heinrich et al. (2011). This analysis reveals that the criticality of assumptions (A3) and (A4) in particular depend on the type of IT investment evaluated, which leads to the following insights:

- *Investments in standard software* are often evaluated with traditional OPMs in scientific literature. This is due to the fact that uncertainty regarding the costs is relatively low as long as costs for customizing the software can either be neglected or reliably estimated. Additionally, the utilization of standard software begins immediately so that

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Abstract

Christian Ullrich

Valuation of IT Investments Using Real Options Theory

Real Options Theory is often applied to the valuation of IT investments. The application of Real Options Theory is generally accompanied by a monetary valuation of real options through option pricing models which in turn are based on restrictive assumptions and thus subject to criticism. Therefore, this paper analyzes the application of option pricing models to the valuation of IT investments. A structured literature review reveals the types of IT investments which are valued with Real Options Theory in scientific literature. These types of IT investments are further investigated and their main characteristics are compared to the restrictive assumptions of traditional option pricing models. This analysis serves as a basis for further discussion on how the identified papers address these assumptions. The results show that a lot of papers do not account for critical assumptions, although it is known that the assumptions are not fulfilled. Moreover, the type of IT investment determines the criticality of the assumptions. Additionally, several extensions or adaptions of traditional option pricing models can be found which provide the possibility to relax critical assumptions. Researchers can profit from the results derived in this paper in two ways: First, it is demonstrated which assumptions can be critical for various types of IT investments. Second, extensions of option pricing models that relax critical assumptions are introduced.

Keywords: Real options, Black-Scholes model, Binomial model, Investment valuation, Information technology, Project valuation

cash inflows can be predicted more accurately. If assumption (A1) is considered with a preference-dependent valuation, the characteristics of this type of IT investment do not hinder the application of ROT. However, if the IT investment is characterized by high and uncertain costs for customizing, it should instead be treated as an investment in individual software.

- *Investments in individual software* are characterized by uncertain cash outflows which result from uncertain duration of development and from other project-specific risks during the development. Therefore, an OPM should be used to account for an uncertain strike price (e.g., the Margrabe model). Moreover, a differentiation between in-house development and outsourcing is needed since risks can be partially shifted in the latter case. Also here, however, a preference-dependent valuation is necessary.
- *Investments in new technologies* are particularly characterized by the uncertain future development of cash inflows as well as cash outflows and regarding the right timing of the investment. Since there is also no complete market, all assumptions of the traditional OPMs discussed in this article can be viewed as critical. Thus, it is no surprise that the majority of the identified articles fall back on simulations or dynamic programming approaches in order to evaluate real options.

As the analysis reveals, the legitimacy of the monetary valuation of real options has to be investigated for both the concrete valuation object, i.e., the type of IT investment, and the concrete OPM used for the valuation. This is due to the fact that often specific characteristics of the investments contradict the assumptions and, therefore, the applicability of OPMs. However, it needs to be pointed out that the insights generated in this article do not possess general validity for every IT investment of each particular type. These insights should be treated rather as tendencies, and they possess the status of recommendations due to the abstractive perspective taken in this article. Thus, for the valuation of a specific IT investment on the basis of ROT, its characteristics have to be compared to the assumptions of existing OPMs. Nonetheless, it should be noted that future IT investments most likely will not only be characterized by the types of IT investments considered in this article. Rather, new developments and trends in IT will influence the characteristics of IT investments and also the applicability of ROT. If one considers the increasing interconnections in IT, the consequences of corresponding risks (e.g., cyber-attacks or viruses) for the assumptions of the OPMs also need to be analyzed.

The connections demonstrated in this article therefore should provoke thoughts for further research concerning the valuation of IT investments with the help of ROT. Furthermore, they should create awareness for an active discussion and consideration of the assumptions of OPMs.

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