Towards a Well-Founded Valuation of Managerial Flexibilities in IT Investment Projects

-A Multidisciplinary Literature Review-

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Introduction

To value managerial flexibilities in uncertain Information Technology Investment Projects (ITIPs) such as investments in standard software (e.g., Angelou and Economides 2008; Taudes et al. 2000), individual software (e.g., Bardhan et al. 2004; Schwartz and Zozaya-Gorostiza 2003), or new technologies (e.g., Benaroch and Kauffman 2000; Ji 2010)[1], real option analysis (ROA) approaches are considered to be highly relevant by practitioners and researchers (cf., Benaroch et al. 2006). To value such real options most approaches featuring in the Information Systems (IS) literature use standard financial option pricing models such as the Black-Scholes model (BSM; e.g., Benaroch et al. 2006; Heinrich et al. 2011; Taudes 1998), the Binomial model (e.g., Kambil et al. 1991; Khan et al. 2013), or the Margrabe model (e.g., Bardhan et al. 2004; Dos Santos 1991). However, these approaches are currently rarely applied by companies since managers are not satisfied with the results given that investment projects are far more complex than financial options. They argue that it is not appropriate to try to make an ITIP fit into a financial option pricing approach which considerably reduces its complexity (cf., Copeland and Tufano 2004; Van Putten and Macmillan 2004). Thus, researchers should not only focus on gaining further insights into “option thinking” (Taudes et al. 2000) but rather develop approaches which enable the valuing of real options in ITIPs as accurately as possible (cf., Tallon et al. 2002).

In response to this call, the main goal of this paper is to review the existing ROA literature from IS, Finance, and Economics[2] to lay the basis for the development and prototypical implementation of a well-founded ROA approach, which paves the way for an accurate valuation of managerial flexibilities in ITIPs. Consequently, in this paper, we first answer the following research questions:

> *(RQ1) How do the assumptions of standard financial option pricing models need to be adapted for a better representation of the characteristics of ITIPs?*
>
> *(RQ2) Do ROA approaches exist that adequately represent the characteristics of ITIPs with their underlying assumptions?*

Based on a multidisciplinary literature review, we argue for a relaxation of the BSM[3] assumptions to better represent the characteristics of ITIPs. Additionally, we validated these relaxed assumptions based on interviews with IT executives from industry. Moreover, we discuss existing real option approaches from the fields of IS, Finance, and Economics that are based on at least one modified assumption (i.e., an assumption that is different to the related BSM assumption) and examine if these modified assumptions

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[1] Classification of ITIPs given by Ullrich (2013).

[2] We included the latter two disciplines to our review as both offer focused methodological discussions on extensions in their ROA approaches and do not only apply existing models.

[3] The analyses are based on the BSM assumptions as it is most commonly used in the IS literature (e.g., Benaroch and Kauffman 1999; Benaroch et al. 2006; Heinrich et al. 2011; Su et al. 2009; Taudes 1998; Taudes et al. 2000). The Binomial model as well as the Margrabe model are generally based on the same assumptions: The Binomial Model is the discrete counterpart of the BSM (cf., Cox et al., 1979) and the Margrabe model relaxes one assumption and allows for uncertain discounted cash outflows following a Geometric Brownian Motion (cf., Margrabe 1978).

comply with our relaxed assumptions.[4] The findings are: (I) by relaxing the assumptions, the option value and project selection decisions are liable to change; (II) several approaches from the Finance and Economics literature better comply with our relaxed assumptions compared to existing approaches in the IS literature; (III) no existing real option approach complies with all our relaxed assumptions. Nevertheless, adapting and enhancing approaches of other disciplines could be a push towards a well-founded valuation of managerial flexibilities in uncertain ITIPs that is requested by several researchers (e.g., Benaroch et al. 2006; Diepold et al. 2011).

Multidisciplinary Literature Review

We conducted a literature review in the fields of IS, Finance, and Economics according to the guidelines of Webster and Watson (2002). We included IS journals from the basket of 8 of the AIS[5], Finance and Economics journals that are ranked B or higher according to the German Academic Association for Business Research[6], as well as all relevant Finance and Economics journals from the Financial Times Ranking[7]. After eliminating duplicates, we conducted a keyword search within the resulting journals for "Real Option" by its own and in combination with the terms "Assumption", "Black-Scholes", "Brownian Motion", "Stochastic Process", "Complete Market", "Valuation", "Option Runtime" and the corresponding plural forms.[8] Afterwards, we reviewed the references contained in the first identified articles to determine contributions on which their work is built. Finally, we used the Google Scholar service to identify contributions citing the previously found articles. We then conducted a title analysis where we identified 183 articles for further consideration. From this set of articles we extracted two intersecting subsets based on abstract analyses: (I) We extracted articles from the IS, Finance, and Economics literature that criticize the assumptions of financial option pricing models and especially those of the BSM. Based on the resulting 25 articles we answer RQ1 (subsection "Discussion of the Assumptions"). (II) We extracted all articles from the IS, Finance, and Economics literature where ROA approaches are presented that are based on at least one modification of the BSM assumptions. Based on the resulting 42 articles (cf., Table 2) we answer RQ2 (subsection "Status Quo in the Literature").

Discussion of the Assumptions

Several authors suggest ROA for the valuation of ITIPs (e.g., Benaroch et al. 2010; Benaroch et al. 2006; Heinrich et al. 2011; Taudes 1998). Specifically the BSM is widely used (e.g., Benaroch and Kauffman 1999; Benaroch et al. 2006; Heinrich et al. 2011; Su et al. 2009; Taudes 1998) to value real options embedded in ITIPs. Subsequently, we explicate how the BSM assumptions relate to ITIPs and suggest relaxed assumptions that better represent the characteristics of ITIPs.

Core Assumptions of the Black-Scholes Model

In the IS literature, the core assumptions of the BSM are (implicitly) transferred to the valuation of real options in ITIPs (cf., Benaroch and Kauffman 1999; Heinrich et al. 2011; Taudes et al. 2000) as follows:

- Assumption (A1): Discounted cash-inflows (dcif) of ITIPs are uncertain and follow a Geometric Brownian Motion (GBM)[9].
- Assumption (A2): Discounted cash-outflows (dcof) of ITIPs are certain and known.
- Assumption (A3): A complete market exists (ITIPs are perfectly divisible and traded continuously).
- Assumption (A4): The option runtime is certain and known.

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[4] Consequently, these modifications of the BSM assumptions (i.e., a modified assumptions) can be instantiations of our relaxed assumptions.

[5] http://aisnet.org/?JournalRankings.

[6] http://vhbonline.org/service/jourqual/vhb-jourqual-21-2011/alphabetische-uebersicht-jq-21/.

[7] http://www.ft.com/cms/s/2/3405a512-5cbb-11e1-8f1f-00144feabdc0.html.

[8] These keywords are chosen for the following reasons: (I) our focus lies on a review of approaches that value real options on ITIPs; (II) we aim at matching the characteristics of ITIPs with the BSM; (III) they are motivated by the BSM assumptions (cf., subsection "Core Assumptions of the Black-Scholes Model").

[9] GBM is a stochastic process where the value of the underlying asset follows a generalized Wiener process (cf., Hull 2009, p. 782) with an expected rate of return (drift rate) and volatility (variance rate) per unit of time (cf., Hull 2009, pp. 263).

In the next four subsections we discuss the compatibility of the four core assumptions taking into account the actual characteristics of ITIPs.

Discounted Cash-Inflows of IT Investment Projects

In several articles of the IS field, dcif of ITIPs are modelled to follow GBM (e.g., Benaroch et al. 2006; Heinrich et al. 2011; Su et al. 2009; Taudes 1998). The probability distribution of GBM at any one point in time is lognormal with linearly increasing mean and variance in time (cf., Hull 2009, p. 278). This implies that GBM is unbounded above (Metcalf and Hassett 1995) and its mean and variance go to infinity as time goes by (Brandimarte 2006, p. 101). While this seems to be an appropriate assumption to make in the speculative setting of a stock market (Ewald and Yang 2008) this rarely applies to ITIPs. Software or technology investment projects are usually subject to life cycles (Bollen 1999; Mahajan et al. 1990) implying that the mean of dcif will only increase up to a certain point in time and decrease afterwards. Moreover, dcif of ITIPs often result from cost savings that are always bounded. This contradicts a linear increase of mean and variance. Consequently, an empirical validation of GBM as a descriptor of the future evolution of ITIPs' dcif is required (cf., Taudes 1998; Taudes et al. 2000). And the properties of the underlying process have to be considered carefully and separately for each type of ITIP. Hence, assumption (A1) is relaxed as follows:

> *Assumption (A1'): Dcif of ITIPs follow an arbitrary non-negative stochastic process*[10] *depending on the characteristics of the underlying ITIP.*

Leaving GBM unaltered to represent the evolution of dcif over time may lead to an overvaluation of the real option, because of its linearly increasing mean and variance. Thus, the probability of an overvaluation increases with the runtime of a real option. This could imply a non-profitable project selection decision.

Discounted Cash-Outflows of IT Investment Projects

As dcof of ITIPs are usually subject to different risk factors (e.g., unforeseen changing requirements or labor costs), assumption (A2) is also criticized by several authors (e.g., Angelou and Economides 2008; Bardhan et al. 2004; Benaroch and Kauffman 1999; Kaufmann and Kumar 2008; Ji 2010; Schwartz and Zozaya-Gorostiza 2003), who make the case for uncertain dcof. Accordingly, several authors suggest that dcof follow GBM similarly to dcif and then apply the Margrabe Model (e.g., Bardhan et al. 2004; Dos Santos 1991; Kumar 1996; Kumar 2002; Taudes 1998). However, GBM does not seem to be plausible for all types of ITIPs especially if dcof mainly result from the following two sources: cash-outflows for IT infrastructure (e.g., hardware costs) and labor costs (e.g., software developers). Costs of obtaining hardware infrastructure usually decrease over time and changes in labor costs usually occur as a result of specific events such as changes in labor agreements or staffing. In this case dcof do not seem to linearly increase over time.

Considering dcof to be uncertain raises the question of whether and how dcif and dcof are correlated with each other. Consequently, decision makers have to be aware of the possibility that the value of a real option may be affected if dcif and dcof of the underlying ITIP are correlated (cf., Dos Santos 1991; Taudes 1998). Accordingly, assumption (A2) is relaxed as follows:

> *Assumption (A2'): Dcof of ITIPs follow an arbitrary non-negative stochastic process*[11] *(that might be correlated with dcif) depending on the characteristics of the underlying ITIP.*

Assuming dcof to be uncertain leads to a higher option value compared to the BSM as the additional risk increases the option value. The higher option value resulting from uncertain dcof is further increased by a negative correlation since the probability of a high difference between dcif and dcof will be higher and vice versa for a positive correlation (cf., Dos Santos 1991; Taudes 1998). Hence, in fact profitable ITIPs that are not selected based on the BSM may be selected.

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[10] A stochastic process is reasonable since mean and variance of ITIPs usually vary over time. Assuming merely an arbitrary distribution would imply that mean and variance remain constant throughout an investment project's runtime, which is hardly justifiable.

[11] A stochastic process instead of a probability distribution is reasonable for the same reason as for dcif (time dependency of mean and variance).

Completeness of the Market for IT Investment Projects

A complete market implies that the underlying ITIP is continuously traded in any amount and thus, a perfect hedge can be built to eliminate its risk. Through the elimination of the risk, the resulting option value is deterministic and independent of the decision maker's risk preference.

Continuously traded ITIPs are rare (e.g., Diepold et al. 2011; Kambil et al. 1991; Schwartz and Zozaya-Gorostiza 2003). Many authors pick up on this criticism and argue that it is sufficient to identify a "twin security" (Sick and Gamba 2010; Smith and Nau 1995; Taudes et al. 2000) that perfectly correlates with the underlying ITIP. However, as the majority of ITIPs' risk factors are unique, a perfect hedge of an ITIPs' risk by a twin security is unrealistic (Benaroch and Kauffman 2000) and the identification of a twin security that correlates highly but not perfectly is insufficient for obtaining an accurate option value (Hubalek and Schachermayer 2001).

Hence, without the possibility of perfectly hedging the risk of ITIPs, the resulting option value is uncertain and a decision maker has to consider her individual risk preference (cf., Diepold et al. 2011). Accordingly, assumption (A3) is relaxed as follows:

> *Assumption (A3'): An incomplete market exists where the risk of ITIPs is either unhedgeable or can only be partially hedged.*

Taking into account an incomplete market and adjusting for unhedgeable risks (for dcif and dcof), every risk-averse decision maker will perceive a lower, and a risk-seeking decision maker a higher option value compared with the complete market assumption.

Option Runtime of IT Investment Projects

A very common real option in the context of ITIPs is the strategic growth option (e.g., Benaroch et al. 2006; Diepold et al. 2011; Dos Santos 1991; Heinrich et al. 2011; Taudes 1998; Taudes et al. 2000). An example of a strategic growth option is an infrastructure investment that spawns the option for further follow-up investment projects. In this case, the option runtime equals the runtime of the infrastructure investment project. Within this investment project unforeseeable events such as staffing problems or collaboration problems might come up and influence the runtime. Consequently, it is difficult to assume the option runtime to be certain and known for all kinds of real options in ITIPs. Consequently, assumption (A4) is relaxed as follows:

> *Assumption (A4'): The option runtime is uncertain and represented by a non-negative random variable depending on the characteristics of the underlying ITIP.*

Taking into account an uncertain option runtime, the decision maker has to consider additional (usually unhedgeable) risks according to her risk preference when determining the option value and making a project selection decision. Consequently, every risk-averse decision maker will perceive a lower, and a risk-seeking decision maker a higher option value compared with the BSM's assumption of a certain option runtime.

The relaxed assumptions and their potential implications for a risk averse decision maker are summarized in Table 1.

Assumption	BSM	Relaxed	Possible Implications
(A1)/*(A1')*	Dcif are uncertain and follow GBM.	Dcif follow an arbitrary non-negative stochastic process.	Extremely high values can be avoided. Lower option value. → Non-profitable ITIPs that would be selected based on the BSM may be avoided.
(A2)/*(A2')*	Dcof are certain and known.	Dcof follow an arbitrary non-negative stochastic process (possibly correlated with dcif).	Additional risk associated with dcof can be considered. Higher option value (further increased by negative correlations and decreased by positive correlations). → In fact profitable ITIPs that would not be selected based on the BSM may be selected.
(A3)/*(A3')*	A complete market exists.	An incomplete market exists where the risk of ITIPs is either unhedgeable or can only be partially hedged.	Unhedgeable risks of dcif and dcof can be considered. Uncertain option value. Uncertainty has to be considered according to the decision maker's risk preference. → Risk-averse decision maker may avoid the selection of non-profitable ITIPS.
(A4)/*(A4')*	Option runtime is certain and known.	Option runtime is uncertain and represented by a non-negative random variable.	Risks associated with uncertain option runtime can be considered. Increase of option value's uncertainty, which has to be considered according to the decision maker's risk preference. → Risk-averse decision maker may avoid the selection of non-profitable ITIPs.

Table 1. Modifications of the BSM assumptions and their potential implications

To validate the relaxed assumptions, we conducted five semi-structured telephone interviews. The interviewees work in different ITIPs, functions, and companies. Each of the interviews took about an hour. We structured the interview questions according to the four topics given by the relaxed assumptions: 1) Dcif, 2) Dcof, 3) Market Completeness, and 4) Option Runtime. All interviews were audio-taped, transcribed, notes were taken during the interviews, and written summaries were produced immediately after the interviews were finished. Subsequently, we performed a qualitative content analysis (cf., Patton 2002) on the interview transcripts and summaries, resulting in insights from practice concerning the relaxed assumptions for ITIPs. The results of the interviews strongly support the relaxed assumptions.[12]

Status Quo in the Literature

In this section, we first discuss ROA approaches from IS and second from Finance and Economics literature in respect to their compliance with our relaxed assumptions *(A1')-(A4')*. We included ROA approaches from Finance and Economics literature as both of these disciplines offer focused methodological discussions on extensions in their ROA approaches.

IS Literature

(A1'): In the IS literature, dcif are usually assumed to follow GBM. To mention a few papers, for instance, Benaroch and Kauffman (1999; 2000) examine the case of Yankee 24 and value a deferral option to provide a POS debit card network to other companies, applying the BSM. Similarly, Heinrich et al. (2011) value the option to sell an internally developed web service after its development, using the BSM. Benaroch et al. (2006) value a nested option using an extension of the BSM, but also assume dcif to follow GBM. To the best of our knowledge, there is no ROA approach in the IS literature that modifies assumption (A1) in terms of using a stochastic process other than GBM. However, in some articles jumps are added to GBM (e.g., Kauffman and Kumar 2008; Schwartz and Zozaya-Gorostiza 2003).

[12] Due to space restrictions, the detailed results of the interviews were not included in the paper but can be provided on request from the authors.

(A2'): A modification of assumption (A2) is first mentioned by Dos Santos (1991) who values an Integrated Services Digital Network project with uncertain dcof that follow GBM using the Margrabe Model[13]. Kumar (1996) reveals the difference in the value of a real option using either BSM (certain dcof) or the Margrabe Model (uncertain dcof). Taudes (1998) values a growth option on an ITIP where a company decides whether to migrate to the client/server version of SAP R/3 and subsequently adopt new software technologies such as electronic data interchange (EDI), workflow management, or document retrieval and archiving. He values this ITIP using the BSM as well as the Margrabe Model. Kumar (2002) shows how to manage different kinds of risks of uncertain ITIPs using the Margrabe Model to value several types of options assuming dcof to follow GBM. Bardhan et al. (2004) use the Margrabe Model to value an option portfolio of 31 e-business projects of a U.S.-based energy utility firm, again assuming dcof to follow GBM. Angelou and Economides (2008) use the BM to value an option portfolio of ITIPs of a Water Supply and Sewerage Company, which includes IT infrastructure projects and an information portal for customer support, and assume uncertain dcof. Kauffman and Kumar (2008) value a growth option on the development of a network technology with uncertain dcof following GBM. Finally, Wu et al. (2009) value a multistage option on an ERP project considering uncertain dcof. Thus, the IS literature already acknowledges that dcof are uncertain and modify assumption (A2). Nevertheless, all these authors assume dcof to follow GBM and some of them add jumps (cf., Schwartz and Zozaya-Gorostiza 2003) that result from events such as security threats, deadlines, and software glitches and reveal their effect on the project value (Kumar 2004). The herein discussed approaches comply with our relaxed assumption *(A2')*. However, no approach exists that uses a stochastic process other than GBM to model dcof, which seems to be questionable at least in the case of the discussed ITIPs.

(A3'): Modifications of assumption (A3) are made in the IS literature. Balasubramanian et al. (2000) use the BM and acknowledge the difference between hedgeable market risks and unhedgeable project risks in their approach to valuing an IT infrastructure project. Hilhorst et al. (2006) also use the BM to value a multistage IT infrastructure implementation project and consider the risk preference of a decision maker to value unhedgeable risks. Diepold et al. (2011) value a growth option embedded in a project for a new backend system for a retail bank. They split the risk of dcif into hedgeable and unhedgeable parts and enhance the BSM with a decision analysis. Hence, the IS literature is aware of the difficulty to hedge all risks stemming from ITIPs and thus, consider unhedgeable risks according to the decision maker's risk preference. These approaches comply with our relaxed assumption *(A3')*.

(A4'): To the best of our knowledge, there is no ROA approach in the IS literature that complies with our relaxed assumption *(A4')*.

Concluding this subsection, many IS researchers have acknowledged the fact that standard assumptions of the BSM do not sufficiently represent the characteristics of ITIPs and thus, they need to be modified. Hence, in the IS literature single assumptions are modified and comply with our relaxed assumptions *(A1')*-*(A4')*, but never more than one assumption.

Finance and Economics Literature

(A1'): In the Finance and Economics literature, Brennan and Schwartz (1985) and Tourinho (1979) initially used the BSM in their ROA approaches. McDonald and Siegel (1986) were the first to modify the assumption (A1) by using GMR[14]. The idea of modeling the underlying as GMR was taken up by Metcalf and Hassett (1995). Following the laws of economic theory they argue that as soon as the value of a project rises, more and more companies will start to invest in similar projects. This suggests that a higher supply always leads to a reduction in price and thus a reduction in dcif. The impact of GMR on the value of a perpetual American option is also considered by Sarkar (2003) who states that because of the lower and more stable long-run variance[15], there is a significant (mostly negative) impact, with the result that it is generally inappropriate to use GBM instead of GMR. In the context of long-run European options the

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[13] The Margrabe Model (Margrabe 1978) allows dcof following GBM, but not for unhedgeable risks.

[14] GMR complies with *(A1')* as it cannot turn negative due to its "Geometric" feature. GMR does not have linearly growing mean and variance, instead the mean converges to a long-term mean and the variance stabilizes around the mean depending on the speed of mean reversion.

[15] This is due to the Mean Reversion feature, where the process is always drawn back to its long-term mean reducing the possible variation of the process along its mean.

impact of GMR on the option value is even stronger, with the result that the reduced variance of GMR significantly reduces the real option value. Schwartz (1997) and Schwartz and Smith (2000) assume dcif of a natural resource to follow a Mean Reversion process with uncertain long-term mean (modeled as Brownian motion). They seem to achieve a more realistic description of the dcif time-series of natural resource investments. Epstein et al. (1998) justify the use of GMR outside the valuation of natural resources by arguing that GMR is also the most appropriate process to describe a company's future earnings. Dias and Rocha (1999) model the value of oil as GMR representing normal information but add jumps to account for abnormal information, and check implications for the optimal investment timing and the option value in relation to GBM. Other applications of Mean Reversion for dcif are developed for projects such as shipping (Bjerksund and Ekern 1995) or start-up venture financing (Willner 1995), and are presented in Trigeorgis (1995). Another alternative to GBM is implemented by Ewald and Wang (2007) who argue that GMR, as used by Dixit and Pindyck (1994), Metcalf and Hasset (1995), and Sarkar (2003), has the property of its Mean Reversion speed being proportional to the level of dcif (i.e., the higher the value of dcif, the higher is the Mean Reversion speed). However, while this seems to be economically questionable, it can be compensated through the use of the slightly different Cox-Ingersoll-Ross Mean Reversion model[16] (Cox et al. 1985), and is one of the most prominent processes used to model interest and exchange rates. Another process suggested by Dias and Nunes (2011) on account of its more realistic economic features in comparison to the original GBM is the CEV-diffusion[17] (Bekaert and Wu 2000, Cox 1975; for applications in the real option literature see, for example, Choi and Longstaff (1985) who value agricultural projects). Various authors suggest empirical tests to determine and distinguish GBM from other processes. The modifications of assumption (A1) presented in this paragraph so far comply with our relaxed assumption *(A1')* as the discussed stochastic processes result in a non-negative probability distribution. Other approaches in Finance and Economics literature modify assumption (A1) by using additive stochastic processes to model dcif such as Arithmetic Brownian Motion, or Ohrnstein-Uhlenbeck Mean Reversion (Alexander et al. 2012, Miao and Wang 2007). These processes can turn negative and thus, do not comply with our relaxed assumption *(A1')*.

(A2'): McDonald and Siegel (1986) and Pindyck (1993) assume dcof to be uncertain and follow GBM. Blenman and Clarke (2005) allow dcif and dcof to have a constant elasticity[18] relation driven by GBM. Elliott et al. (2007) deviate from this dependence between dcif and dcof and assume dcof to switch between two regimes, representing respectively a low cost and a high cost state of the economy. They show that in the classical framework of a real investment the probability of an earlier investment increases and thus, the expected option value increases, as well. Similarly to dcif there are many more possible ways to model dcof, one of which being (exponential) Mean Reversion plus jumps. This case is treated by Jaimungal et al. (2013; see below). To conclude this subsection, we note that in the Finance and Economics literature many modifications of assumption (A2) have been made where dcof follow processes similar to those discussed in the dcif subsection (GBM, GMR, plus jumps). These modifications comply with our relaxed assumption *(A2')*.

(A3'): Another strand of literature is dedicated to modifications of assumption (A3). Merton (1998) considers incomplete markets in the sense of incomplete information about the underlying's value and values investments where dcif can only be observed after the option is exercised. Similarly to Flesaker (1991) he concludes that the less observable dcif the lower the value of the real option. Extensions of this approach are presented by Childs et al. (2001), who additionally assume that information for determining the value of dcif can be costly when purchased, and Guthrie (2007), who shows that both higher information cost and lower amounts of information have the effect of lowering the option value (both in the case of dcif following either GBM or GMR). Up to this point, the remaining unhedgeable risks were assumed to be eliminated by the option holder through diversification. However, several new valuation approaches suggest the use of utility functions (Henderson and Hobson 2004). Henderson (2004; 2007) assumes that dcif of an investment project follow GBM and are imperfectly correlated[19] with another GBM

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[16] The Cox-Ingersoll-Ross process is quite similar to GMR regarding its variance as proportional to the level of dcif, but it involves a constant Mean Reversion speed.

[17] In a CEV-Process (Constant Elasticity of Variance) the volatility depends on the level of dcif. Hence, the higher the level of dcif the higher is the volatility of the process.

[18] Referring to a constant ratio of change between the values of the underlying and the strike.

[19] A correlation of one is equal to a complete market, a smaller correlation means that only parts can be hedged, and a correlation of zero means that the investment cannot be hedged at all and thus, all risk remains with the option holder.

representing the value of a portfolio of traded assets, which is used for hedging purposes. Given exponential utility and constant absolute risk aversion she is able to calculate the value of a perpetual American option. The value depends on the correlation between the underlying and the replicating portfolio as well as the risk aversion in the following way: The higher the risk aversion and the lower the correlation between non-traded and traded assets, the lower the option value. Hugonnier and Morellec (2007) note that the option value is reduced, mainly because investment happens earlier to resolve unhedgeable risk, depending on the risk aversion and with the possibility of the option being rendered completely worthless. Thus, for different utility functions a real option valuation under unhedgeable risks has already been considered. These modifications comply with our relaxed assumption *(A3')*. However, there is a strong difference between incomplete markets and the assumption of non-traded assets. As mentioned by Lander and Pinches (1998) or Myers and Majd (1990) the existence of a perfectly correlated "twin-security" (Smith and Nau 1995) or "twin-portfolio" (Thijssen 2011) still allows for perfect hedging and thus, a risk-neutral valuation. In the case of incomplete markets as stated in the relaxed assumption *(A3')* there is no perfectly correlated twin-security and hence, the private/project specific risk remains and has to be taken into account by considering a decision maker's risk preference.

(A4'): This leaves us with modifications of assumption (A4). Brach (2003) suggests to value real options using a random maturity and Blanchet-Scalliet et al. (2005) suggest to use an uncertain maturity being Poisson distributed. However, they do not present approaches to value real options considering an uncertain option runtime.

There are also a few approaches in Finance and Economics literature that comply with more than one of our relaxed assumptions *(A1')-(A4')*. Ewald and Yang (2008) assume that their underlying investment evolves as GMR that is imperfectly correlated with a traded asset represented by GBM. Thus, they modify assumption (A1) by assuming that their underlying investment evolves as GMR, and assumption (A3) by treating incomplete markets similarly to Henderson (2004; 2007). The result on the option value is slightly more complex than in the cases treated by Henderson (2004; 2007) due to the increased number of parameters, but also yields the insight that the lower the correlation and the higher the risk aversion parameter, the lower the option value. Jaimungal et al. (2013) assume dcif and dcof to follow correlated (exponential) Mean Reversion processes that may even include jump components. Thus, they modify assumption (A1) and assumption (A2). They state that, depending on the many parameters, no clear implication on the option value in relation to the standard case of certain dcof can be given.

Table 2 summarizes all approaches according to their compliance with the relaxed assumptions *(A1')-(A4')*.

(A1')	***(A2')***	***(A3')***	***(A4')***	**Articles in the Finance and Economics Literature**	**Articles in the IS Literature**
*GBM+ jumps**	*Certain*	*Complete Market*	*Certain*	*Articles where the BSM is used, for example: Brennan and Schwartz (1985); Dixit and Pindyk (1994)*; Myers and Majd (1990); Tourinho (1979)*	*Articles where the BSM is used, for example: Benaroch and Kauffman (1999); Benaroch et al. (2006); Heinrich et al. (2011); Klaus et al. (2014); Su et al. (2009); Taudes (1998)*
			Uncertain		
		Incomplete Market	*Certain*	*Childs et al. (2001); Guthrie (2007); Henderson (2004; 2007); Hugonnier and Morellec (2007); Merton (1998)*	*Balasubramanian et al. (2000); Benaroch and Kauffman (2000); Diepold et al. (2011); Hilhorst et al. (2006)*
			Uncertain		

	Uncertain (GBM)	*Complete Market*	*Certain*	*Blenman and Clark (2005); Elliott et al. (2007); McDonald and Siegel (1986); Pindyck (1993)*	*Angelou and Economides (2008); Bardhan et al. (2004); Dos Santos (1991); Kauffman and Kumar (2008)*; Kumar (1996); Kumar (2002); Kumar (2004)*; Schwartz and Zozaya-Gorostiza (2003); Taudes (1998); Wu et al. (2009)*
			Uncertain		
*GMR+ jumps**	*Certain*	*Complete Market*	*Certain*	*Dias and Nunes (2011); Dixit and Pindyk (1994); Epstein et al. (1998); Ewald and Wang (2007); Metcalf and Hassett (1995); Sarkar (2003); Schwartz (1997); Schwartz and Smith (2000)*	
			Uncertain		
		Incomplete Market	*Certain*	*Ewald and Yang (2008)*	
			Uncertain		
	Uncertain (GMR)	*Complete Market*	*Certain*	*Jaimungal et al. (2013)**	
			Uncertain		

Table 2. Contributions treating assumptions *(A1')-(A4')*

To sum up, in the IS literature we identified some approaches, which modify single assumptions of the BSM and comply with our relaxed assumptions. The same holds for the Finance and Economics literature where we further identified a few approaches that are based on two modified assumptions that comply with our relaxed assumptions. However, we found no approach that complies with assumption *(A4')* and no approach that complies with more than two of our relaxed assumptions *(A1')-(A4')*. Nevertheless, adapting and enhancing approaches from Finance and Economics could be a push towards a well-founded valuation of managerial flexibilities in ITIPs due to a better representation of their characteristics.

Research Agenda and Conclusion

"A major challenge for IS research lies in making models and theories that were developed in other academic disciplines usable in IS research and practice" (Benaroch and Kauffman 1999). According to this statement, we argued that standard financial option pricing models are not generally applicable in the context of ITIPS, due to their restrictive assumptions. Thus, we relaxed the assumptions of the BSM to better represent the characteristics of ITIPs and validated the relaxed assumptions by interviews with IT executives from industry. Subsequently, we discussed ROA approaches from IS, Finance, and Economics according to their fit to the valuation of managerial flexibilities in ITIPs. Our findings are: (I) By relaxing the assumptions of the BSM, the option value and project selection decisions may change (cf., Table 1); (II) Several approaches from the Finance and Economics literature comply better with our relaxed assumptions compared to existing approaches in the IS literature (cf., Table 2). (III) No existing ROA approach complies with all our relaxed assumptions (cf., Table 2).

To pave the way to a well-founded valuation of managerial flexibilities in ITIPs, we suggest the following research agenda:

(I) Up to now the assumptions of financial option pricing models are rarely validated as to whether they adequately represent the characteristics of ITIPs. In future research different stochastic processes need to be empirically tested according to their fit to dcif and dcof of various types of ITIPs (cf., Benaroch and Kauffman 1999). This can be investigated by gathering data for dcif and dcof for different ITIPs and testing which stochastic process adequately represents their evolution over time for the respective ITIP.

(II) As there exists no option valuation approach in the IS literature allowing for arbitrary modifications of the BSM assumptions to represent the characteristics of ITIPs, we recommend to analyse whether real option approaches from Finance and Economics (e.g., Ewald and Yang 2008; Jaimungal et al. 2013) may be adapted and extended to comply with all relaxed assumptions mentioned above in order to value uncertain ITIPs.

(III) Finally, we suggest investigating the effects of different modifications of the BSM assumptions on the option value of an uncertain ITIP. For that purpose a simulation model can be developed to represent different modified assumptions that comply with our relaxed assumptions. Consequently, such a simulation model could be used to value different real options presented in the IS literature, like the provided examples of Taudes (1998), Benaroch et al. (2006), or Heinrich et al. (2011). In doing so, the impact of modifications of the BSM assumptions on the option value and the potential mispricing resulting from the BSM and its underlying assumptions may be revealed.

We want to conclude with the generalizability and the breadth of the results of our review. We deduced our relaxed assumptions from the existing ROA discussions in the literature and the characteristics of ITIPs. However, the relaxed assumptions by themselves seem to be general enough in order to fit to a range of other real investments such as, for example, in the area of natural resources, or supply chains. Hence, the results seem to have a broader relevance well beyond ITIPs alone.

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