Online Appendix for the Article

DECISION SUPPORT FOR IT INVESTMENT PROJECTS – A REAL OPTION ANALYSIS APPROACH BASED ON RELAXED ASSUMPTIONS

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Prescriptive Knowledge

Existing ROA approaches based on modified assumptions

As ROA approaches were not only developed in the field of IS, it was important that we included the Finance and Economics literature in our literature review as both of these disciplines offer focused methodological discussions on extensions in their ROA approaches. The findings are categorized in Table 1 in respect of their compliance with the relaxed assumptions (A1')-(A4'). Following, we discuss ROA approaches from IS and then from Finance and Economics literature in respect to their compliance with our relaxed assumptions (A1')-(A4').

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).

(A2'): Modifications of assumption (A2) 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 (A2').

(A3'): In contrast, a modification of assumption (A3) 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[1]. 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

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

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 (A3). 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 (A3'). 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.

(A4'): To the best of our knowledge, there exist no ROA approaches in the IS literature that relax assumption (A4) in the context of uncertain ITIPs.

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 that comply with our relaxed assumptions (A1')-(A4'), but never more than one assumption. There is still room, therefore, for improving the existing approaches to strive towards a well-founded valuation.

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[2]. 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[3], 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

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[2] 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.

[3] 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.

long-run European options the 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[4] (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[5] (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, amongst them Marathe and Ryan (2005) who apply their empirical test to four different projects (results given in parenthesis): Electric Power Consumption (GBM), Airline Passenger Enplanement (GBM), Cell Phone Revenues (not GBM), and Internet Hosts (not GBM), with the latter two showing features of a Mean Reversion process. We find that many modifications to GBM have already been treated in the Finance and Economics literature. Ozorio et al. (2012) and Wang and Driver (2004) collect and illustrate the impact of Mean Reversion and many other stochastic processes (adding jumps) on the option value for several different examples. 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'): Another strand of literature is dedicated to modifications of assumption (A2). 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

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[4] 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.

[5] 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.

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[6] with another GBM 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 (A2'). 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 (A2') 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.

(A3'): 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[7] 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 (A3) 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 (A3').

(A4'): This leaves us with modifications of assumption (A4). To take the uncertainties of an uncertain option runtime into account, Brach (2003) suggests to value real options using a random maturity and Blanchet-Scalliet et

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[6] 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.

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

al. (2005) suggest an uncertain maturity being Poisson distributed. Though, these approaches do not value options in the context of real investments.

Following, we summarize all approaches from Finance and Economics that modified more than one of the BSM assumptions. 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 (A2) 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 (A3). 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. These approaches comply with more than one of our relaxed assumptions (A1')-(A4').

Table 1 categorizes all approaches according to the relaxed assumptions.

Table 1 Contributions treating the relaxed assumptions *(A1')-(A4')*

(A1')	*(A2')*	*(A3')*	*(A4')*	**Articles in IS, Finance & Economics Literature**
GBM+ jumps[8]*	*Complete Market*	*Deterministic*	*Certain*	*Articles where the BSM is used, for example: Benaroch and Kauffman (1999), Benaroch and Kauffman (2000), Benaroch et al. (2006), Brennan and Schwartz (1985), Dixit and Pindyk (1994)*, Heinrich et al. (2011), Klaus et al. (2014), Myers and Majd (1990), Su et al. (2009), Taudes (1998), Taudes et al. (2000), Tourinho (1979)*
			Uncertain	
		Stochastic (GBM)	*Certain*	*Angelou and Economides (2008), Bardhan et al. (2004), Blenman and Clark (2005), Dos Santos (1991), Elliott et al. (2007), Kauffman and Kumar (2008)*, Kumar (1996), Kumar (2002), Kumar (2004)*, McDonald and Siegel (1986), Pindyck (1993), Schwartz and Zozaya-Gorostiza (2003), Taudes (1998), Wu et al. (2009)*
			Uncertain	
	Incomplete Market	*Deterministic*	*Certain*	*Balasubramanian et al. (2000), Childs et al. (2001), Diepold et al. (2011), Guthrie (2007), Henderson (2004; 2007), Hilhorst et al. (2006), Hugonnier and Morellec (2007), Merton (1998)*
			Uncertain	
		Stochastic	*Certain*	
			Uncertain	
*GMR+ jumps**	*Complete Market*	*Deterministic*	*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	
		Stochastic (GMR)	*Certain*	*Jaimungal et al. (2013)**
			Uncertain	
	Incomplete Market	*Deterministic*	*Certain*	*Ewald and Yang (2008)*
			Uncertain	
		Stochastic	*Certain*	
			Uncertain	

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 some approaches that are based on two modified assumptions that comply with our relaxed assumptions. However, we found no approach based on at least three modified assumptions that comply with our relaxed assumptions (A1')-(A4'). Nevertheless, adapting and enhancing approaches from Finance and Economics could be a

[8] Articles that include jumps are denoted with *.

push towards a well-founded valuation of managerial flexibilities in ITIPs due to a better representation of their characteristics.

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