REAL OPTIONS IN AGILE SOFTWARE DEVELOPMENT: HANDLING THE PARADOX OF FLEXIBILITY AND BEHAVIOURAL STICKINESS IN PROJECT VALUATION

Research in Progress

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Abstract

Agile software development (ASD) increases project flexibility. While the induced real option values (ROVs) are widely discussed in information technology (IT) literature and used for project management (PM) decisions in practice, behavioural deformations as discussed in naturalistic decision making (NDM) theory such as overoptimism or an escalation of commitment might mislead PM e.g. to abandon unsuccessful projects later than rationally appropriate. Hence, the impact of imperfect, noisy information about the project and behavioural shortcomings should be anticipated in project decisions by adjusting ROVs. However, while behavioural finance gains much momentum, there is no correspondence to that in IT research. Therefore, this paper provides following design science research (1) basic concepts of NDM that should be included in IT project valuation, (2) a base for modelling behaviourally induced consequences for project investment valuation in a multi-period setting, (3) for illustration a simulation study with a sequence of abandonment options in ASD and (4) recommendations for PM how to integrate behavioural deformations in real life decisions. It therefore contributes to descriptive and prescriptive decision and PM theory as well.

Keywords: Agile Software Development, Behavioural Science, Project Management, Real Options

1 Introduction

Agile software development (ASD) as introduced in the "Agile Manifesto" in 2001 aims to foster the ability to cope with volatility by rapidly adapting to changing requirements (Anderson, 2003; for literature reviews Dybå and Dingsøyr, 2008; Dingsøyr et al., 2012; Hoda et al., 2017). ASD, which is subdivided into several time-fixed iterations, increases flexibility compared to traditional development models. One important opportunity of agile projects is to adjust or abandon the project after the realisation and valuation of each iteration – either by the developer or by the customer in case of outsourcing (Mahanti, 2004; Racheva and Daneva, 2008). This additional flexibility, i.e. the possibility to react to changing market conditions (Dixit and Pindyck, 1994; Trigeorgis, 1996), should add a real option value (ROV) to the development project. Real option analysis (ROA) has become a standard tool for grasping the flexibility of investment decisions in general (Dixit and Pindyck, 1994; Kogut, 1991; Myers, 1977; Trigeorgis, 1995) and of information technology (IT) investment projects in special (e.g. Benaroch, 2018; Benaroch, Shah, et al., 2006; Campbell, 2002; Fichman et al., 2005; Kumar, 2002; Taudes, 1998). Quite like the rather restrictive assumptions of ROA, decision making (DM) literature has developed from a normative model of rational behaviour: classical DM (CDM) theory (e.g. Lipshitz, Klein, Orasanu, & Salas, 2001). However, there is strong evidence of behavioural biases in DM (Barberis and

Thaler, 2003; Kahneman, 2003; Kahneman and Tversky, 1979; Thaler, 1999): Decision makers frequently do not systematically generate alternative options or evaluate them neglecting probability and utility estimates. Since the flexibility of ASD might be overvalued, e.g. due to abandoning unsuccessful projects later than rationally appropriate and hence paradoxically not using flexibility, IT project management (PM) has to consider such shortcomings. However, literature dealing with their influence on investment valuation and hence the actual flexibility of IT projects and ASD in particular is missing.

This paper in the tradition of design science research (e.g. Hevner et al., 2004; Peffers et al., 2007) is the first to model ASD ROA in a sequential multi-period setting under noisy project information and behavioural influences as well. It therefore contributes to literature by extending the canonical IT ROA based on CDM and supports IT PM in practice by allowing to anticipate "real life" DM. At first, state-of-the-art-background is given. Then, the idea of grasping informational and behavioural biases on ROV of ASD projects is pointed out focussing on flexibility given by project abandonment. For better understanding of its implication, the model is numerically exercised in a simulation study. Recommendations for IT PM and fields of further research conclude the paper.

2 Literature Review

2.1 Behavioural Insights into the Perceived Value of Project Flexibility

To understand the value of flexibility, it is important to look at the nature of DM. Over the last decades, a transition from a classical, normative perspective to a behavioural point of view can be observed (Lipshitz et al., 2001). CDM presupposes a utility maximizing individual and regards DM as choosing among concurrently available alternatives (Bazerman and Mannix, 1989) by maximizing expected utility (von Neumann and Morgenstern, 1947). CDM requires rather rigorous assumptions to hold, for instance perfect competition or subjective probabilities to be consistent with objective ones; as a normative approach it does not need a theory of human behaviour, because it only focuses on the way "how people *ought* to behave, not how people *do* behave" (Simon, 1959, p. 254).

In his behavioural model of rational choice *Simon* (1955) replaces the "economic man" by a decision maker looking for a satisfying choice, not an optimal one. This bounded rationality approach has seen a broad acceptance in research (Gigerenzer and Selten, 2002; Raab and Gigerenzer, 2015) and is one of numerous concepts describing DM (Sipp and Carayannis, 2013). Others are the incrementalist view describing DM as a step-by-step process (Lindblom, 1959), and the organisational procedure approach taking decisions as the result of standardized procedures of an organisation (March, 1978) that also contains the risk of taking decisions at the cost of innovation (Das and Teng, 1999). This is contrasted by emphasizing personality, management style and experience as influential factors in the process of DM in the individual differences approach (Keen and Morton, 1978). The concept of naturalistic DM (NDM) points out context and experience: decision makers try to recognize specific situations, their context and possible outcomes. The more experienced they are, the easier it is for them to form a scenario incorporating the impact of the decision alternatives (Klein, 1999). One explanation on NDM is the recognition-primed decision model, which describes decisions as a blend of intuition (pattern matching) and analysis – the mental simulation of the effect of choosing one or another decision alternative (Klein 2008). References to *Kahneman* (2003) are obvious.

NDM has also developed a strong impact on research in project DM (Cicmil et al., 2006; Sauer and Reich, 2009; Svejvig and Andersen, 2015). Project models are seen as only partial models of a complex reality and a focus on explaining the actuality of PM in contrast to normative PM can be observed (Stingl and Geraldi, 2017; Winter et al., 2006). Most frequently discussed topics are escalation of commitment, overoptimistic plans and forecasts and the failure to respond adequately to early warning signs:

(1) Escalation of commitment (Brockner, 1992; Staw, 1976, 1981) is a frequently described phenomenon about projects, that never seem to terminate, continuing to absorb resources without reaching their objectives (Aegerter Alvarez et al., 2011; Du et al., 2007; Jani, 2011; Keil, Mann, et al., 2000; Keil, Tan, et al., 2000; Magalhães and White, 2016; Meyer, 2014; Oorschot et al., 2013; Winch, 2013). Projects are continued despite significant cost overruns and delays. Cognitive limitations like self-justification

(Jani, 2008), project completion or sunk cost effects (Arkes and Blumer, 1985; Magalhães and White, 2016) serve as possible explanations. The sunk cost effect has already been explained by prospect theory (Kahneman and Tversky, 1979) and describes throwing good money after bad, since decision makers inflate their estimate on project success when having incurred sunk cost (Arkes and Blumer, 1985).

(2) One reason for overoptimistic plans and forecasts (Chapman et al., 2006; Flyvbjerg, 2007, 2013; Pinto, 2013) is optimism bias describing the overestimation of positive outcomes and the underestimation of negative ones. Underestimating risks may be due to the influence of perceived control over project risks (Du et al., 2007; Jani, 2011) as well as cultural influence (Keil, Tan, et al., 2000). The impact of optimism bias on forecasts has also been studied in experimental settings (e.g. Kutsch et al., 2011). The pluralistic approach does not only claim cognitive limitations, but supposes opportunistic behaviour of individuals or groups to exploit information asymmetries by omitting or falsifying relevant information; especially in public projects, opportunistic behaviour is frequently found (Flyvbjerg, 2007; Pinto, 2013). Despite its critical nature research on opportunistic behaviour in PM seems to be rather rare (Clegg and Kreiner, 2014; Stingl and Geraldi, 2017).

(3) The importance of weak signals has been shown by *Ansoff* (1975) long ago. Despite proposals to integrate early warning signs in PM (e.g. Nikander and Eloranta, 2001), projects continue to fail. A variety of reasons is mentioned trying to explain the failure to respond adequately to early warning signs (Haji-Kazemi et al., 2015): the difficulty to identify early warning signs (Williams et al., 2012), a combination of cognitive biases and organisational pressure (Lovallo and Kahneman, 2003), a systematic fallacy in underestimating time, costs and risks while at the same time overestimating the benefits of a project (Flyvbjerg, 2013) or the normalisation of deviance that describes situations, where the unexpected becomes expected and accepted (Pinto, 2013).

2.2 Behavioural Influence as Blank Spot in Traditional ROA for IT Investments

The focus of IT literature dealing with project flexibility is on identifying and valuing embedded real options in IT investments (Chen et al., 2009). *Benaroch et al.* (2006) map IT investment risks to different types of real options, assigning relevant literature. While research on behavioural science is increasingly widespread in general, only first attempts have been made to examine behavioural influences on IT PM (for an overview Cunha et al., 2016). For example, *Drury et al.* (2012) analyse obstacles to DM in ASD teams, such as an unwillingness to commit to decisions or conflicting priorities. While there is empirical evidence that IT project managers exhibit cognitive biases in ROA (Tiwana et al., 2007) and that exercise and abandonment decisions are influenced by social and reputational effects (Coff and Laverty, 2007), literature integrating behavioural effects in IT ROA is still missing. Either recent attempts to relax the rather restrictive assumptions of the canonical ROA based on the Black-Scholes-Model for IT investment projects (for an overview Mueller et al., 2016) remain within the logic of CDM and mainly deal with the transferability of methods used for financial options to IT ROA taking up a long lasting discussion in general ROA literature (Adner and Levinthal, 2004; Amram and Kulatilaka, 1998; Brealey et al., 2010; Kogut and Kulatilaka, 2004). Most recently, *Benaroch* (2018) deals with the impact of proactive risk management, i.e. uncertainty-reducing mitigations i.a. by learning (e.g. Koussis et al., 2007; Miller and Park, 2009; Otim and Grover, 2012), on IT investment ROVs by transforming the probability distribution of investment outcomes. However, learning remains restricted to unnoisy information and bias-free. Also, due to imprecise (noisy) information about the value of an asset at decision time, managers tend to underinvest in good and overinvest in bad projects (Trigeorgis and Reuer, 2017). Noisy information about the current value of an asset (contemporaneous uncertainty: Posen et al., 2018) is one of the key differences to financial options, where efficient markets provide objective information and only prospective uncertainty about future values matters. It requires managers to rely on their subjective beliefs on the value of an asset and opens the path to behavioural influences (Posen et al., 2018), since in a sequential decision setting subjective beliefs will influence DM over time through learning (Posen and Levinthal, 2012). In sum, valuing IT project flexibility is paradoxically detached from real life DM, which implicates behavioural stickiness to some extent, esp. by not using or misusing this flexibility due to an escalation of commitment or overoptimism. Our paper is the first explicitly modelling noisy information and behavioural shortcomings in IT ROA of ASD.

3 Modelling

3.1 Real Option Valuation of Agile Software Developments

Usually, IT investments and specifically ASD projects include nested real options such as growth, defer or change-scale options (e.g. Benaroch, Lichtenstein, et al., 2006), of which we focus on abandonment options. Due to ongoing customer feedback, an ASD project started at t = 0 may be abandoned within the planning horizon T after each time-fixed iteration I_i (i = 1, 2 …, T) with duration $\Delta\tau = 1$ at $\tau \in \{1, 2, \dots, T\text{-}1\}$. Without executing abandonment alternative A_τ the project will be carried on and induce costs $c_{\tau+1}$ for the next iteration (see Figure 1). For simplification, we assume $c = c_i$ as constant and certain, a risk-free interest rate of zero to separate behavioural effects from timing effects and that the net present value of project cash inflows (NPCI) S_T will only be available after having finished all T iterations without any cash inflow coming from possible intermediate results.

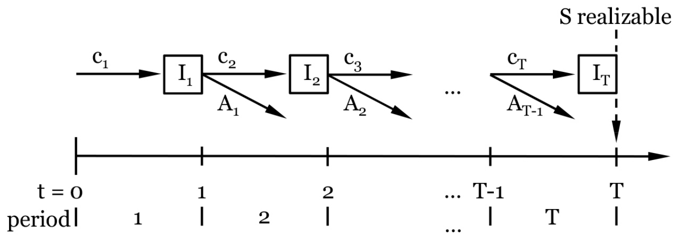

Figure 1: Abandonment options in ASD

The decision to start an ASD at t = 0 can be interpreted analogously to a growth option. However, while a typical growth option (e.g. introduction of an ERP solution) with option price C at the execution time $\tau > 0$ enables a follow-up investment (e.g. implementation of a workflow management system) with cash outflow K_τ as strike price and opens immediately S_τ (e.g. Taudes, 1998), here it opens a sequence of prolongation/abandonment options. If the project is prolonged at τ, the due iterations costs c can be interpreted as option price. This option gives the right to abandon at $t = \tau + 1 < T$ or to prolong for further iteration costs c. Hence, the decision problem is similar to that of compound or sequential exchange options, which can be handled by modelling the value of pseudo-American timing options (Carr, 1988). However, in our case, executing the option at any time τ will never deliver S_T immediately. Due to this characteristic, the below presented decision logic differs from financial exchange options.

3.2 Integration of Behavioural Influence into Real Option Valuation

Project abandonment can incur two types of decision errors: (i) Timing errors due to prospective uncertainty, which are inevitable even under CDM. A rational decision maker will abandon at t = τ, if $S_{T|\tau} < [T - \tau] \cdot c$. This is wrong, if $S_{T|T} - [T - \tau] \cdot c > 0$, and vice versa for the decision to continue the project (below we use $\square_{T|\tau} \equiv \square_\tau$). If the project is abandoned at any τ, its return is $-\tau \cdot c$, otherwise $S_T - T \cdot c$. At τ only outstanding project costs $[T - \tau] \cdot c$ and the terminal value of S_T are relevant for the decision: As the project proceeds, an increasing part of total development costs is sunk costs and hence irrelevant for decision purposes. (ii) The second type of project error is due to contemporaneous uncertainty and might be caused by imperfect, noisy information $\hat{S}_\tau$ about the value of an IT project or additionally by one or several of the afore mentioned behavioural deformations, e.g. overoptimism about the project outcome (Posen et al., 2018). One way for PM to deal with noisy information is to successively update its belief ω_τ of S_τ by exponential smoothing to new information (Brown, 1963):

(1) $\omega_\tau = (1 - \alpha)^\tau \cdot S_0 + (1 - \alpha)^{\tau-1} \cdot \alpha \cdot \hat{S}_1 + \cdots + \alpha \cdot \hat{S}_\tau$.

Exponential smoothing can be interpreted as a kind of learning (Cyert and March, 2001; Posen et al., 2018). IT PM could determine the smoothing factor α ($0 \le \alpha \le 1$) i.a. by minimizing squared estimation errors between unnoisy information S_τ and beliefs ω_τ using data of realized projects. In practice, α oftentimes will be chosen intuitively or even will remain implicit if project managers are not conscious of their respective subjective weighting of project information. Hence, beliefs could differ widely from unnoisy information.

4 Simulation Study

For illustration, we suppose an ASD with (only) three iterations (T = 3) and $c_1 = c_2 = c_3 = 1$. We assume correspondently to standard IT ROA literature (for a discussion of assumptions used in IT ROA and alternative models Mueller et al., 2016) that the NPCI S_T follows a geometric Brownian motion, hence

(2) $S_t = S_{t-1} \cdot exp\left(\left[\mu - \frac{1}{2} \cdot \sigma^2\right] \cdot \Delta t + \sigma \cdot \sqrt{\Delta t} \cdot \vartheta_t\right)$

for t = 1, 2, 3 with μ = 0, $S_0 = 3$, $\Delta t = t - t + 1 = 1$, σ as prospective uncertainty and ϑ_t as independent draw from the standard normal distribution (e.g. Brigo et al., 2007). The value of an ASD consists of economic value and ROV (e.g. Kim & Sanders, 2002; Taudes, 1998). Since our expected net present value $E(S_T - T \cdot c)$ is zero, we focus on the ROV. Noisy information on the NPCI $\hat{S}_t$ shall be given by

(3) $\hat{S}_t = \hat{S}_{t-1} \cdot exp\left(\left[\mu - \frac{1}{2} \cdot \sigma^2\right] \cdot \Delta t + \sigma \cdot \sqrt{\Delta t} \cdot \vartheta_t + \hat{\sigma} \cdot \sqrt{\Delta t} \cdot \hat{\vartheta}_t\right)$,

where $\hat{\vartheta}_t$ are realisations of standard normally distributed random variables and $\hat{\sigma}$ is contemporaneous uncertainty (Posen et al., 2018). To analyse the key features of our model, we use Monte Carlo simulation with 100,000 replications i to determine for each i project values S_t (2) and $\hat{S}_t$ (3). Then, noise-free information S_t is used to obtain benchmarks for CDM as reference for canonical IT ROA: Using the Black-Scholes model and setting the project ROV zero at τ for each iteration, delivers critical project values S_1^* and S_2^*, with which rational decision makers will compare the simulated project values to decide whether to prolong (if $S_\tau^* \geq S_\tau$) or to abandon (if $S_\tau^* < S_\tau$) the project. The opportunity costs of a timing error at τ are in case of a

- (too) early abandonment: $S_T - (T - \tau) \cdot c$;
- (too) late abandonment: $\begin{cases} (\check{\tau} - \tau) \cdot c, if\ finally\ abandonded\ at\ \check{\tau}\ (\tau < \check{\tau} < T) \\ -S_T + (T - \tau) \cdot c, otherwise. \end{cases}$

Table 1 shows key figures of canonical IT ROA for different levels of prospective uncertainty σ. The value of project flexibility measured by the ROV is a non-decreasing function of the riskiness of the associated investment decision (Chen et al., 2009; Merton, 1973). Surprisingly, the opportunity costs and especially the percentage of late abandonments are higher than those of early abandonments. This could be due to the sunk cost effect and unlike to the explanation given by prospect theory, which relies on inflation effects of $\hat{S}_\tau$, rationally induced: Since outstanding project costs as a sum of option prices decrease over time, critical values S_τ^* will decrease as well, hence a prolongation becomes more likely.

σ	ROV	opportunity costs due to …abandonments early	late	error-free ROV	quota of … abandonments early	late	project duration
0.0	0.000	0.000	0.000	0.000	0.0%	0.0%	3.000
0.2	0.001	0.004	0.043	0.048	1.0%	14.3%	2.945
0.4	0.078	0.051	0.154	0.283	5.3%	25.6%	2.582
0.6	0.226	0.104	0.229	0.558	6.5%	28.1%	2.284
0.8	0.400	0.144	0.279	0.823	6.4%	29.2%	2.068
1.0	0.574	0.171	0.311	1.056	5.7%	29.7%	1.902
1.2	0.725	0.194	0.324	1.244	4.8%	29.3%	1.764

Table 1: Key figures (means) of noise-free abandonment decisions

To distinguish the impact of noise and behavioural shortcomings on CDM ROVs, we first analyse "noisy", but rational deciding on $\hat{S}_\tau$ instead of S_τ. Only then, behavioural influences are taken into account. To deal with contemporaneous uncertainty ($\hat{\sigma} > 0$) under NDM, an "ideal" learning rate α^* is determined by $\sum_i\left((S_{1_i} - \omega_{1_i}(\alpha))^2 + (S_{2_i} - \omega_{2_i}(\alpha))^2\right) \rightarrow min!$ based on (1) and used for belief updating. For illustration, we focus on optimism bias, which can be modelled by adjusting α to

(4) $\alpha^{adjusted} = \begin{cases} \alpha^* \cdot (1+\beta), if\ \hat{S}_\tau > S_\tau^* \\ \alpha^*/(1+\beta), otherwise \end{cases}$

with optimism parameter $\beta \in (0;1]$ (Posen et al., 2018). If PM perceives $\hat{S}_\tau > S_\tau^*$ and hence, that the project will succeed, $\beta > 0$ will increase this optimism by a higher weighting of the actual positive outlook and will decrease pessimism, if $\hat{S}_\tau \leq S_\tau^*$ doesn´t promise success. Belief values ω_τ then are adjusted accordingly. For all three cases of biased DM, which are built on each other – noisy information is the base, followed by belief updating and overoptimism – overall return of the sequence of ASD options is determined, depending on the realized decision and opportunity costs of erroneous DM. In the case of several subsequent timing errors, here only the opportunity costs of the first one are taken into account to avoid redundancies. E.g., even if it's wrong to continue at $\tau = 1$, it could then be wrong to stop at $\tau = 2$ due to the irrelevance of sunk costs.

Table 2 depicts additional opportunity costs due to deviating timing decisions under noise-free (unbiased) and noisy (biased) project information due to contemporaneous uncertainty. If, for example, the ASD project should be abandoned at $\tau = 1$ (A_1) but is abandoned late at $\tau = 3$ (A_3) due to noisy information, additional costs of $2 \cdot c$ occur. If the same project would be kept up to project termination (PT) at T, additional costs calculate to $-S_T + (T-1) \cdot c$. If the sign of the respective sums of opportunity costs between the two types of timing errors differs, biased DM "corrects" timing errors of unbiased decisions to some extent. While the first type of timing error is inevitable due to a given prospective uncertainty, the second one could be anticipated in PM by correcting ROVs.

		unbiased decision					
		A_1	A_2	A_3	...	PT	
biased decision	A_1	0	-c	-2c	...	S_T-(T-1)·c	early abandonment
	A_2	c	0	-c	...	S_T-(T-2)·c	
	A_3	2c	c	⋮	...	S_T-(T-3)·c	
	⋮	⋮	⋮	⋮	⋱	⋮	
	PT	-S_T+(T-1)·c	-S_T+(T-2)·c	-S_T+(T-3)·c	...	0	
		late abandonment					

Table 2: Additional opportunity costs due to timing deviations

Table 3 shows the impact of noise on ROVs under CDM, for which the column $\hat{\sigma} = 0$ serves as reference measure. Contemporaneous uncertainty $\hat{\sigma} > 0$ deteriorates the value of project flexibility in every case and even negative net effects (grey shadowed) occur due to additional opportunity costs. Noise induces up to σ = 1 a higher ratio of additional early abandonments. In the case of $\sigma = \hat{\sigma} = 0.8$, e.g., 17.3 % additional early and 13.8 % additional late abandonments occur that induce additional opportunity costs of 0.18 and 0.07, hence ROV deteriorates to 0.40 – 0.18 – 0.07 = 0.15. The deteriorating effect becomes the higher, the higher contemporaneous uncertainty is in respect to a given prospective uncertainty.

$\hat{\sigma}$ / σ	**ROVs including opportunity costs**							**ratio of additional late/early abandonments (%)**						
	0.0	*0.2*	*0.4*	*0.6*	*0.8*	*1.0*	*1.2*	*0*	*0.2*	*0.4*	*0.6*	*0.8*	*1*	*1.2*
0.0	0.00	-0.02	-0.16	-0.29	-0.39	-0.45	-0.50	---	0.0	0.0	0.0	0.0	0.0	0.0
0.2	0.00	-0.03	-0.14	-0.25	-0.34	-0.41	-0.46	---	14.6	6.5	4.5	3.7	3.3	3.1
0.4	0.08	0.05	-0.03	-0.14	-0.23	-0.30	-0.36	---	59.6	42.5	34.7	30.7	28.5	27.1
0.6	0.23	0.20	0.13	0.04	-0.06	-0.14	-0.20	---	80.4	69.7	62.7	58.4	55.5	53.7
0.8	0.40	0.38	0.32	0.24	0.15	0.05	-0.02	---	90.7	86.1	82.1	79.8	77.6	76.7
1.0	0.57	0.55	0.51	0.43	0.35	0.26	0.18	---	97.1	98.8	97.4	96.6	96.3	96.2
1.2	0.73	0.72	0.67	0.61	0.54	0.46	0.38	---	108.1	107.1	109.8	112.0	113.2	114.3

Table 3: Project DM under noise

Table 4 shows results of DM under noise with belief updating: Additional early abandonments almost totally disappear, but additional late abandonments increase. Learning reduces opportunity costs of noise the more, the higher the ratio $\hat{\sigma}/\sigma$ is. However, this goes along with a deterioration for an increasing prospective uncertainty σ and a total offset of ROV by opportunity costs for numerous combinations of

$\hat{\sigma}$ and σ, hence an apparent loss of flexibility values. Table 5 (left half) delivers reasons. The figures show the mean project duration of DM without learning. The results are shaded in grey, if the project duration for a specific $\hat{\sigma}$ and σ is three iterations under the assumption of learning. Since all other project durations for $\hat{\sigma} > 0$ are longer as well, learning prolongs project duration under noise. This can be explained by the learning rate α: Without learning, the higher overall volatility by increasing $\hat{\sigma}$ reduces the mean project duration by an increasing number of early abandonments. Learning as expressed by exponential smoothing induces lower values of α for increasing contemporaneous uncertainty to give more weight to less volatile prior values – remember the fixed initial value $S_0 = 3$. This induces stickiness: On the one hand belief updating is too "slow", on the other by heavily extending project duration due to sticky belief values abandonment flexibility is not used.

σ \ $\hat{\sigma}$	ROVs including opportunity costs							additional late abandonments in %						
	0.0	*0.2*	*0.4*	*0.6*	*0.8*	*1.0*	*1.2*	*0*	*0.2*	*0.4*	*0.6*	*0.8*	*1*	*1.2*
0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	2.7	2.7	2.7	2.7	2.7	2.7
0.4	0.08	0.05	0.00	0.00	0.00	0.00	0.00	0.0	12.6	21.4	21.4	21.4	21.4	21.4
0.6	0.23	0.19	0.01	0.00	0.00	0.00	0.00	0.0	12.2	36.9	38.0	38.0	38.0	38.0
0.8	0.40	0.36	0.07	0.00	0.00	0.00	0.00	0.0	12.5	45.4	50.7	50.7	50.7	50.7
1.0	0.57	0.53	0.00	-0.01	-0.01	-0.01	-0.01	0.0	14.6	59.9	60.6	60.6	60.6	60.6
1.2	0.73	0.66	-0.03	-0.03	-0.03	-0.03	-0.03	0.0	18.3	68.7	68.7	68.7	68.7	68.7

Table 4: Project DM under noise with learning

σ \ $\hat{\sigma}$	project duration without learning							ROVs including opportunity costs						
	0.0	*0.2*	*0.4*	*0.6*	*0.8*	*1.0*	*1.2*	*0*	*0.2*	*0.4*	*0.6*	*0.8*	*1*	*1.2*
0.0	3.00	2.96	2.69	2.48	2.35	2.26	2.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.2	2.95	**2.83**	2.60	2.43	2.32	2.24	2.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.4	2.58	**2.53**	**2.41**	2.31	2.23	2.18	2.13	0.08	0.05	0.00	0.00	0.00	0.00	0.00
0.6	2.28	**2.26**	**2.22**	2.17	2.13	2.09	2.07	0.21	0.19	0.13	0.00	0.00	0.00	0.00
0.8	2.07	**2.06**	**2.05**	2.03	2.01	1.99	1.98	0.37	0.35	0.27	0.00	0.00	0.00	0.00
1.0	1.90	**1.90**	**1.90**	1.90	1.90	1.89	1.89	0.53	0.51	0.38	-0.01	-0.01	-0.01	-0.01
1.2	1.76	**1.77**	**1.77**	1.78	1.78	1.79	1.80	0.68	0.65	0.38	-0.03	-0.03	-0.03	-0.03

Table 5: Project DM under noise without learning (left) and with optimism bias $\beta = 0.5$ (right)

Surprisingly, optimism bias doesn't always deteriorate project decisions under noise. Table 5 shows some ROVs higher than those of unbiased learning. Hence, the induced stickiness of learning not to abandon an ongoing project must be offset to some extent. The left half of Table 5 confirms that: Bold are mean project durations that are shorter than those of unbiased learning. However, the reduction in late abandonments doesn't totally enhance ROVs compared to unbiased learning as shows columns for $\hat{\sigma} = 0.2$ and $\hat{\sigma} = 0.4$, instead optimism bias is advantageous for the higher contemporaneous uncertainty.

5 Discussion and Conclusions

Literature on IT project ROA is not dealing with how to integrate noise or behavioural shortcomings, hence how to valuate "real world" flexibility. Our model and numerical example provide insights into the extension of the canonical IT project ROA by integrating informational noise, learning and optimism bias in a multi-period setting. It is shown, that there is an antagonism between the potential and the actual flexibility in ASD due to a behaviourally induced stickiness. Our paper is the first, performing IT project ROA under NDM assumptions. Main findings are, that (1) an explanation of abandoning projects in practice later than appropriate might be wrong learning: The type of learning – here the in literature widespread exponential smoothing – favours giving less weight to newer, more volatile information. Then, based on a low learning rate α beliefs ω_τ induce too late abandonment due to the higher weighting of the fixed value expectation at project start. Hence, the inherent flexibility of ASD isn't reasonably used, project managers erroneously stick to prolong the project. This explains rationally (irrational) escalation of commitment. (2) Behavioural biases will induce additional erroneous timing. However, over-optimism doesn't come on top of a rational, noise-free decision base and therefore is always deteriorating the value of flexibility. In contrary, "over"optimism may correct to some extent the kind of pessimism induced by a (too) careful learning function. (3) The results of Table 3 and Table 5 (left) show, that increasing contemporaneous uncertainty has negative effects on the value of flexibility (Posen et al., 2018) by weakening the commitment to the project. This might even induce negative ROVs when including opportunity costs – erroneously used flexibility turns to be killing a project's value. However, learning doesn't always offset this deterioration since project managers could become over-committed. This might be coincidentally solved by additional behavioural bias – or consciously, by either a more substantiated information base, which decreases noise, or a "better" learning of PM.

This illustrates, that PM has to consider noise, since it significantly deteriorates ROVs. Since substantiating of the information base will be costly, an enhancement of belief updating is preferable. Hence, further research has to be done to analyse the impact of different learning functions on decision stickiness. Besides, an active PM could intend to mitigate uncertainty to some extent (Benaroch, 2018). However, applying appropriate techniques could be an investment decision by itself. For PM it could be easiest to accept contemporaneous uncertainty, but to anticipate its possible impact in project decisions. For this, it simply has to turn the logic of our simulation study round. If PM is aware of noise or possible biases, it has to adjust its own or the project team beliefs to the extent of the assumed biases in order to rerun the simulation model to calculate behaviourally adjusted ROVs at τ as decision base. In practice, simple estimates for the average overoptimism β, for which the values have to be corrected, given a subjectively chosen α, can easily be captured out of realized projects by comparing the ongoing adjustment of targets and forecasts with actual data. Doing so, our model supports descriptive and prescriptive DM at the same time. Besides, it rationally explains the sunk-cost effect to some extent.

While in line with DSR our paper focuses on conceptualisation, practical IT PM needs a valid parametrisation for implementation. However, if not subjectively chosen or based on empirical data given by behavioural literature, all relevant parameters can be determined in an experimental setting even with the project team members (Bryman, 2015; Bryman and Bell, 2015; Saunders et al., 2015). E.g., to fix the learning factor α test persons could be asked in a within-subject-study (Charness et al., 2012) to decide whether a fictional ASD shall be continued or not. For this, critical values S_τ^* and $S_{0_i}, \hat{S}_{1_i}, \dots, \hat{S}_{\tau_i}$ of one ASD decision sequence i could be presented to determine upper and lower bounds α_i out of each abandonment decision. After the decision, S_{T_i} could be presented so that probands are likely to adjust α_{i+1} until it presumably converges to a steady state by experience.

Directions of further research are manifold. E.g., our model could be tested on a real case study. Doing so, relaxing the assumption of iteration costs will make the model even more realistic, e.g. because staffing of the agile project may change – which is e.g. explicitly modelled by the rational unified process (Kruchten, 2003). Therefore, different cost structures for the iterations should be modelled. This will result in a learning behaviour for costs too; however, it is most likely, that the learning rate for costs will be different to the one for NPCI. Further, we assume the number of iterations of the ASD to be fixed. Depending on the performance of the development team the number of iterations effectively necessary will vary – it is a random variable too. Regarding the context of ASD, attention should also be payed to the fact, that iterative software development aims to deliver customer value in each iteration (Beck et al., 2001). Developing e.g. a patentable user interface or a reusable algorithm like audio compression would influence the abandonment decision, if selling the technology would be more attractive than continuing the ASD. Hence, the ROV-modelling could be drawn nearer to classical compound options.

References

Adner, R. and Levinthal, D.A. (2004), “What Is Not A Real Option: Considering Boundaries for the Application of Real Options to Business Strategy”, *Academy of Management Review*, Vol. 29 No. 1, pp. 74–85.

Aegerter Alvarez, J.F., Pustina, A. and Hällgren, M. (2011), “Escalating commitment in the death zone: New insights from the 1996 Mount Everest disaster”, *International Journal of Project Management*, Vol. 29 No. 8, pp. 971–985.

Amram, M. and Kulatilaka, N. (1998), *Real Options: Managing Strategic Investment in an Uncertain World*, Financial Management Association, Boston, Mass.

Anderson, D. (2003), *Agile Management for Software Engineering: Applying the Theory of Constraints for Business Results*, Prentice Hall, Upper Saddle River, NJ.

Ansoff, H.I. (1975), “Managing Strategic Surprise by Response to Weak Signals”, *California Management Review*, Vol. 18 No. 2, pp. 21–33.

Arkes, H.R. and Blumer, C. (1985), “The psychology of sunk cost”, *Organizational Behavior and Human Decision Processes*, Vol. 35 No. 1, pp. 124–140.

Barberis, N. and Thaler, R. (2003), “A Survey of Behavioral Finance”, in Constantinides, G.M., Harris, M. and Stulz, R.M. (Eds.), *Handbook of the Economics of Finance*, Elsevier, Amsterdam, pp. 1051–1121.

Bazerman, M.H. and Mannix, E.A. (1989), “Rational choice in an uncertain world, Robyn Dawes, San Diego: Harcourt Brace Jovanovich. 1988”, *Journal of Behavioral Decision Making*, Vol. 2 No. 1, pp. 63–64.

Beck, K., Beedle, M., van Bennekum, A., Cockburn, A., Cunningham, W., Fowler, M., Grenning, J., et al. (2001), “Manifesto for Agile Software Development”, available at: http://agilemanifesto.org/ (accessed 14 August 2017).

Benaroch, M. (2018), “Real Options Models for Proactive Uncertainty-Reducing Mitigations and Applications in Cybersecurity Investment Decision Making”, *Information Systems Research*, available at:https://doi.org/10.1287/isre.2017.0714.

Benaroch, M., Lichtenstein, Y. and Robinson, K. (2006), “Real Options in Information Technology Risk Management: An Empirical Validation of Risk-Option Relationships”, *MIS Quarterly*, Vol. 30 No. 4, pp. 827–864.

Benaroch, M., Shah, S. and Jeffery, M. (2006), “On the Valuation of Multistage Information Technology Investments Embedding Nested Real Options”, *Journal of Management Information Systems*, Vol. 23 No. 1, pp. 239–261.

Brealey, R., Myers, S. and Allen, F. (2010), *Principles of Corporate Finance*, 10th ed., McGraw-Hill, New York, NY.

Brigo, D., Dalessandro, A., Neugebauer, M. and Triki, F. (2007), *A Stochastic Processes Toolkit for Risk Management*, SSRN Scholarly Paper No. 1109160, Social Science Research Network, Rochester, NY, available at: https://papers.ssrn.com/abstract=1109160 (accessed 14 March 2017).

Brockner, J. (1992), “The Escalation of Commitment to a Failing Course of Action: Toward Theoretical Progress”, *The Academy of Management Review*, Vol. 17 No. 1, pp. 39–61.

Brown, R.G. (1963), *Smoothing, Forecasting and Prediction of Discrete Time Series.*, Prentice-Hall, Englewood Cliffs, N.J., available at: https//catalog.hathitrust.org/Record/001512022 (accessed 2 May 2017).

Bryman, A. (2015), *Social Research Methods*, 5th ed., Oxford University Press, Oxford; New York.

Bryman, A. and Bell, E. (2015), *Business Research Methods*, Oxford University Press, Oxford; New York.

Campbell, J.A. (2002), "Real options analysis of the timing of IS investment decisions", *Information & Management*, Vol. 39 No. 5, pp. 337–344.

Carr, P. (1988), "The Valuation of Sequential Exchange Opportunities", *The Journal of Finance*, Vol. 43 No. 5, pp. 1235–1256.

Chapman, C., Ward, S. and Harwood, I. (2006), "Minimising the effects of dysfunctional corporate culture in estimation and evaluation processes: A constructively simple approach", *International Journal of Project Management*, Vol. 24 No. 2, pp. 106–115.

Charness, G., Gneezy, U. and Kuhn, M.A. (2012), "Experimental methods: Between-subject and within-subject design", *Journal of Economic Behavior & Organization*, Vol. 81 No. 1, pp. 1–8.

Chen, T., Zhang, J. and Lai, K.-K. (2009), "An integrated real options evaluating model for information technology projects under multiple risks", *International Journal of Project Management*, Vol. 27 No. 8, pp. 776–786.

Cicmil, S., Williams, T., Thomas, J. and Hodgson, D. (2006), "Rethinking Project Management: Researching the actuality of projects", *International Journal of Project Management*, Vol. 24 No. 8, pp. 675–686.

Clegg, S. and Kreiner, K. (2014), "Fixing concrete: inquiries, responsibility, power and innovation", *Construction Management and Economics*, Vol. 32 No. 3, pp. 262–278.

Coff, R.W. and Laverty, K.J. (2007), "Real Options Meet Organizational Theory: Coping with Path Dependencies, Agency Costs, and Organizational Form", *Real Options Theory*, Vol. 24, Emerald Group Publishing Limited, pp. 333–361.

Cunha, J.A.O.G., Moura, H.P. and Vasconcellos, F.J.S. (2016), "Decision-Making in Software Project Management: A Systematic Literature Review.", *Procedia Computer Science*, Vol. 100, pp. 947–954.

Cyert, R.M. and March, J.G. (2001), *A Behavioral Theory of the Firm*, 2nd ed., Blackwell Business, Cambridge, Mass. [u.a.].

Das, T. k. and Teng, B.-S. (1999), "Cognitive Biases and Strategic Decision Processes: An Integrative Perspective", *Journal of Management Studies*, Vol. 36 No. 6, pp. 757–778.

Dingsøyr, T., Nerur, S., Balijepally, V. and Moe, N.B. (2012), *A Decade of Agile Methodologies: Towards Explaining Agile Software Development*, Elsevier, available at: http://www.sciencedirect.com/science/article/pii/S0164121212000532 (accessed 4 April 2017).

Dixit, A. and Pindyck, R. (1994), *Investment under Uncertainty.*, Princeton University Press.

Drury, M., Conboy, K. and Power, K. (2012), "Obstacles to Decision Making in Agile Software Development Teams", *Journal of Systems and Software*, Vol. 85 No. 6, pp. 1239–1254.

Du, S., Keil, M., Mathiassen, L., Shen, Y. and Tiwana, A. (2007), "Attention-shaping tools, expertise, and perceived control in IT project risk assessment", *Decision Support Systems*, Vol. 43 No. 1, pp. 269–283.

Dybå, T. and Dingsøyr, T. (2008), "Empirical studies of agile software development: A systematic review", *Information and Software Technology*, Vol. 50 No. 9, pp. 833–859.

Fichman, R.G., Keil, M. and Tiwana, A. (2005), "Beyond valuation: 'Options thinking' in IT project management.", *California Management Review*, Vol. 47 No. 2, pp. 74–96.

Flyvbjerg, B. (2007), "Policy and Planning for Large-Infrastructure Projects: Problems, Causes, Cures", *Environment and Planning B: Planning and Design*, Vol. 34 No. 4, pp. 578–597.

Flyvbjerg, B. (2013), "Quality control and due diligence in project management: Getting decisions right by taking the outside view", *International Journal of Project Management*, Vol. 31 No. 5, pp. 760–774.

Gigerenzer, G. and Selten, R. (2002), *Bounded Rationality: The Adaptive Toolbox*, MIT Press, Cambridge, Mass.

Haji-Kazemi, S., Andersen, B. and Klakegg, O.J. (2015), "Barriers against effective responses to early warning signs in projects", *International Journal of Project Management*, Vol. 33 No. 5, pp. 1068–1083.

Hevner, A.R., March, S.T. and Park, J. (2004), "Design Science in Information Systems Research", *MIS Quarterly*, Vol. 28 No. 1, pp. 75–105.

Hoda, R., Salleh, N., Grundy, J. and Tee, H.M. (2017), "Systematic literature reviews in agile software development: A tertiary study", *Information and Software Technology*, Vol. 85, pp. 60–70.

Jani, A. (2008), "An experimental investigation of factors influencing perceived control over a failing IT project", *International Journal of Project Management*, Vol. 26 No. 7, pp. 726–732.

Jani, A. (2011), "Escalation of commitment in troubled IT projects: Influence of project risk factors and self-efficacy on the perception of risk and the commitment to a failing project", *International Journal of Project Management*, Vol. 29 No. 7, pp. 934–945.

Kahneman, D. (2003), "Maps of Bounded Rationality: Psychology for Behavioral Economics", *The American Economic Review*, Vol. 93 No. 5, pp. 1449–1475.

Kahneman, D. and Tversky, A. (1979), "Prospect Theory: An Analysis of Decision under Risk", *Econometrica*, Vol. 47 No. 2, pp. 263–291.

Keen, P.G.W. and Morton, M.S.S. (1978), *Decision Support Systems: An Organizational Perspective*, Addison-Wesley Pub. Co.

Keil, M., Mann, J. and Rai, A. (2000), "Why Software Projects Escalate: An Empirical Analysis and Test of Four Theoretical Models", *MIS Quarterly*, Vol. 24 No. 4, pp. 631–664.

Keil, M., Tan, B.C.Y., Wei, K.-K., Saarinen, T., Tuunainen, V. and Wassenaar, A. (2000), "A Cross-Cultural Study on Escalation of Commitment Behavior in Software Projects", *MIS Quarterly*, Vol. 24 No. 2, pp. 299–325.

Kim, Y.J. and Sanders, G.L. (2002), "Strategic actions in information technology investment based on real option theory", *Decision Support Systems*, Vol. 33 No. 1, pp. 1–11.

Klein, G. (1999), *Sources of Power: How People Make Decisions*, Revised ed., MIT Press, Cambridge, Mass.

Kogut, B. (1991), "Joint Ventures and the Option to Expand and Acquire", *Management Science*, Vol. 37 No. 1, pp. 19–33.

Kogut, B. and Kulatilaka, N. (2004), "Response: Real Options Pricing and Organizations: The Contingent Risks of Extended Theoretical Domains", *The Academy of Management Review*, Vol. 29 No. 1, pp. 102–110.

Koussis, N., Martzoukos, S.H. and Trigeorgis, L. (2007), "Real R&D options with time-to-learn and learning-by-doing", *Annals of Operations Research*, Vol. 151 No. 1, pp. 29–55.

Kruchten, P. (2003), *Rational Unified Process: An Introduction*, 3rd ed., Addison-Wesley, Amsterdam.

Kumar, R.L. (2002), "Managing risks in IT projects: an options perspective", *Information & Management*, Vol. 40 No. 1, pp. 63–74.

Kutsch, E., Maylor, H., Weyer, B. and Lupson, J. (2011), “Performers, trackers, lemmings and the lost: Sustained false optimism in forecasting project outcomes — Evidence from a quasi-experiment”, *International Journal of Project Management*, Vol. 29 No. 8, pp. 1070–1081.

Lindblom, C.E. (1959), “The Science of ‘Muddling Through’”, *Public Administration Review*, Vol. 19 No. 2, pp. 79–88.

Lipshitz, R., Klein, G., Orasanu, J. and Salas, E. (2001), “Taking stock of naturalistic decision making”, *Journal of Behavioral Decision Making*, Vol. 14 No. 5, pp. 331–352.

Lovallo, D. and Kahneman, D. (2003), “Delusions of success. How optimism undermines executives’ decisions”, *Harvard Business Review*, Vol. 81 No. 7, pp. 56–63, 117.

Magalhães, P. and White, K.G. (2016), “The sunk cost effect across species: A review of persistence in a course of action due to prior investment”, *Journal of the Experimental Analysis of Behavior*, Vol. 105 No. 3, pp. 339–361.

Mahanti, A. (2004), “Challenges in Enterprise Adoption of Agile Methods - A Survey”, *CIT. Journal of Computing and Information Technology*, Vol. 14 No. 3, pp. 197–206.

March, J.G. (1978), “Bounded Rationality, Ambiguity, and the Engineering of Choice”, *The Bell Journal of Economics*, Vol. 9 No. 2, pp. 587–608.

Merton, R.C. (1973), “Theory of Rational Option Pricing”, *The Bell Journal of Economics and Management Science*, Vol. 4 No. 1, pp. 141–183.

Meyer, W.G. (2014), “The Effect of Optimism Bias on the Decision to Terminate Failing Projects”, *Project Management Journal*, Vol. 45 No. 4, pp. 7–20.

Miller, L.T. and Park, C.S. (2009), “A Learning Real Options Framework with Application to Process Design and Capacity Planning”, *Production and Operations Management*, Vol. 14 No. 1, pp. 5–20.

Mueller, M., Stoeckl, S., Zimmermann, S. and Heinrich, B. (2016), “Decision Support for IT Investment Projects - A Real Option Analysis Approach Based on Relaxed Assumptions”, *Business & Information Systems Engineering*, Vol. 58 No. 6, pp. 381–396.

Myers, S.C. (1977), “Determinants of corporate borrowing”, *Journal of Financial Economics*, Vol. 5 No. 2, pp. 147–175.

von Neumann, J. and Morgenstern, O. (1947), *Theory of Games and Economic Behavior*, Princeton.

Nikander, I.O. and Eloranta, E. (2001), “Project management by early warnings”, *International Journal of Project Management*, Vol. 19 No. 7, pp. 385–399.

Oorschot, K.E. van, Akkermans, H., Sengupta, K. and Wassenhove, L.N.V. (2013), “Anatomy of a Decision Trap in Complex New Product Development Projects”, *Academy of Management Journal*, Vol. 56 No. 1, pp. 285–307.

Otim, S. and Grover, V. (2012), “Resolving uncertainty and creating value from the exercise of e-commerce investment options.”, *Information Systems Journal*, Vol. 22 No. 4, pp. 261–287.

Peffers, K., Tuunanen, T., Rothenberger, M.A. and Chatterjee, S. (2007), “A Design Science Research Methodology for Information Systems Research”, *Journal of Management Information Systems*, Vol. 24 No. 3, pp. 45–77.

Pinto, J.K. (2013), “Project management, governance, and the normalization of deviance”, *International Journal of Project Management*, Vol. 32 No. 3, pp. 376–387.

Posen, H.E., Leiblein, M.J. and Chen, J.S. (2018), “Towards a behavioral theory of real options: Noisy signals, bias, and learning”, *Strategic Management Journal*, Vol. 39, pp. 1112–1138.

Posen, H.E. and Levinthal, D.A. (2012), "Chasing a Moving Target: Exploitation and Exploration in Dynamic Environments", *Management Science*, Vol. 58 No. 3, pp. 587–601.

Raab, M. and Gigerenzer, G. (2015), "The power of simplicity: a fast-and-frugal heuristics approach to performance science", *Frontiers in Psychology*, Vol. 6, available at:https://doi.org/10.3389/fpsyg.2015.01672.

Racheva, Z. and Daneva, M. (2008), "Using Measurements to Support Real-option Thinking in Agile Software Development", *Proceedings of the 2008 International Workshop on Scrutinizing Agile Practices or Shoot-out at the Agile Corral*, ACM, New York, NY, USA, pp. 15–18.

Sauer, C. and Reich, B.H. (2009), "Rethinking IT project management: Evidence of a new mindset and its implications", *International Journal of Project Management*, Vol. 27 No. 2, pp. 182–193.

Saunders, M., Lewis, P. and Thornhill, A. (2015), *Research Methods for Business Students*, 7th ed., Financial Times Prent., New York.

Simon, H.A. (1955), "A Behavioral Model of Rational Choice", *The Quarterly Journal of Economics*, Vol. 69 No. 1, pp. 99–118.

Simon, H.A. (1959), "Theories of Decision-Making in Economics and Behavioral Science", *The American Economic Review*, Vol. 49 No. 3, pp. 253–283.

Sipp, C.M. and Carayannis, E.G. (2013), "Literature Review", *Real Options and Strategic Technology Venturing*, Springer New York, pp. 15–38.

Staw, B.M. (1976), "Knee-deep in the big muddy: a study of escalating commitment to a chosen course of action", *Organizational Behavior and Human Performance*, Vol. 16 No. 1, pp. 27–44.

Staw, B.M. (1981), "The Escalation of Commitment To a Course of Action", *Academy of Management Review*, Vol. 6 No. 4, pp. 577–587.

Stingl, V. and Geraldi, J. (2017), "Errors, lies and misunderstandings: Systematic review on behavioural decision making in projects", *International Journal of Project Management*, Vol. 35 No. 2, pp. 121–135.

Svejvig, P. and Andersen, P. (2015), "Rethinking project management: A structured literature review with a critical look at the brave new world", *International Journal of Project Management*, Vol. 33 No. 2, pp. 278–290.

Taudes, A. (1998), "Software Growth Options", *Journal of Management Information Systems*, Vol. 15 No. 1, pp. 165–185.

Thaler, R. (1999), "Mental Accounting Matters", *Journal of Behavioral Decision Making*, Vol. Vol. 12, pp. 183–206.

Tiwana, A., Wang, J., Keil, M. and Ahluwalia, P. (2007), "The Bounded Rationality Bias in Managerial Valuation of Real Options: Theory and Evidence from IT Projects", *Decision Sciences*, Vol. 38 No. 1, pp. 157–181.

Trigeorgis, L. (1995), *Real Options in Capital Investment: Models, Strategies, and Applications*, Greenwood Publishing Group.

Trigeorgis, L. (1996), *Real Options. Managerial Flexibility and Strategy in Resource Allocation*, New., MIT Press, Cambridge, Mass.

Trigeorgis, L. and Reuer, J.J. (2017), "Real options theory in strategic management", *Strategic Management Journal*, Vol. 38 No. 1, pp. 42–63.

Williams, T., Jonny Klakegg, O., Walker, D.H.T., Andersen, B. and Morten Magnussen, O. (2012), "Identifying and Acting on Early Warning Signs in Complex Projects", *Project Management Journal*, Vol. 43 No. 2, pp. 37–53.

Winch, G.M. (2013), “Escalation in major projects: Lessons from the Channel Fixed Link”, *International Journal of Project Management*, Vol. 31 No. 5, pp. 724–734.

Winter, M., Smith, C., Morris, P. and Cicmil, S. (2006), “Directions for future research in project management: The main findings of a UK government-funded research network”, *International Journal of Project Management*, Vol. 24 No. 8, pp. 638–649.