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Research paper

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Acknowledgments

Abstract

To generate competitive advantages through investments in emerging IT innovations, an economically well-founded investment strategy is of decisive importance, since timing and extent of investment amounts considerably determine the associated risk and return profile. Due to the uncertainty about emerging IT innovations, an early market entry time is associated with high risk, but offer high returns. A later market entry may carry lower risk but only offers lower returns. To take advantage of both investment strategies while reducing their disadvantages, a mix of both investment strategies can be advantageous. Companies often choose strict early or later investment strategies since an adequate assessment of possible combiniation opportunities and risks is not carried out in advance and company- and innovation-specific factors are neglected. Thus, we develop a quantitative optimization model enabling the determination of an optimal investment strategy and budget allocation to the two different investment strategies in the sense of maximizing the investment´s overall NPV supplementing previous studies by considering company- and IT innovation-specific factors. We show that strict investment strategies are often disadvantageous, that the amount of the investment budget influences the innovation´s expected NPV and that the company's innovativeness has a strong influence on the innovation budget allocation.

Keywords: IT Management, IT Innovations, IT Investments, Economic Value of IT.

1 Introduction

The role of information technology (IT) in the field of innovation has often been discussed (Melville et al., 2004) and studied for decades (Johannessen, 1994; Bengtsson and Ågerfalk, 2011). As we are in an era of new technological advances and high competition, the question of how a company can keep pace with competition through organizational innovation and maintain sustainable long-term success (Sedera et al., 2016) is still of central interest. Given trends such as smart manufacturing, internet of things (IoT), mobile computing, social media and the proliferating digitalization, most emerging innovations are inseparably intertwined with information technology. For a majority of companies, investments in emerging IT innovations have become an indispensable challenge since such investments require substantial financial funds and at the same time, pose considerable risks (Lu and Ramamurthy, 2010; Swanson and Ramiller, 2004). However, such investments require substantial financial funds and at the same time, pose considerable risks given that many emerging IT innovations are likely to be failing because of missing customer acceptance due to missing fulfillment of customer expectations and needs (Lu and Ramamurthy, 2010; Swanson and Ramiller, 2004). Thus, investments in emerging IT

innovations have to be mindfully managed through economically well-founded evaluation approaches, as ignoring such investments can limit the inherent benefits of applications that the underlying technologies can offer (Nwankpa et al., 2013).

Therefore, in a first step it is helpful to consider the concept of "hype cycles" by Gartner Inc. (e.g., Panetta, 2017), according to which the uncertain development of an emerging IT innovation is characterized by different stages of maturity. At the beginning of an "*emerging*" innovation´s development the innovation is often accompanied by rumors and hypes (Abrahamson, 2009) and investments are associated with high risks (Zhou et al., 2005; Wind and Mahajan, 1997). Over time, the IT innovation becomes more and more sophisticated turning into a "*mature*" innovation. In this way, the innovation gains more and more acceptance by customers which leads to a broader diffusion and adoption making investments less risky (Dos Santos, Brian L and Peffers, 1995). As soon as the innovation has been widely accepted by customers, it has been established, i.e., "institutionalized". However, the Gartner Hype Cycle does not provide any economic guidance with regard to the question of when to invest into a certain IT innovation. In particular, it provides neither information on opportunities and risks nor information on the economic potential of IT innovations. To be able to make economically well-founded investment decisions, adequate valuation approaches have to be developed that carefully consider the chances and risks of IT innovations with different maturity. This is of essential importance, as the chance and risk profile of such investments considerably changes over the life cycle of the respective IT innovation.

Because of their novelty and immaturity, emerging IT innovations offer companies that invest as *first mover* (FM) the chance to achieve a high level of awareness among customers (Mittal and Swami, 2004). Because of their high level of awareness, FM can quickly generate high market shares (Robinson, 1988; Kerin et al., 1992) and build up much knowledge due to their early market entry. This can lead to a technological leadership and enables them to "impose significant knowledge barriers that early adopters have to overcome" (Schmalensee, 1980; Ravichandran and Liu, 2011), in order to compete successfully against established FM. In contrast, later investments as *late mover* (LM) in mature IT innovations are often associated with lower risks since the development and adoption status of the underlying technology are already visible (Meade and Islam, 2006; Dos Santos, Brian L and Peffers, 1995). Mistakes that FM made in the development of emerging IT innovations are well known by LM and can thus be avoided (Hippel, 1982). Furthermore, LM rely on already partially developed technologies and continues to develop it further, which induces lower costs than completely redeveloping an innovation Dos Santos, Brian L and Peffers, 1995). Additionally, they benefit from an already existing pool of customers, whose expectations and needs are already known, thereby reducing the risk that the innovation will fail (Dos Santos, Brian L and Peffers, 1995).

Given the complex trade-off and owing to management uncertainty, e.g., due to the lack of relevant data, companies often tend to apply a strict black-or-white investment strategy (i.e., a pure FM or LM). However, a "mixed" investment strategy (i.e., one part of an investment budget is allocated to a FM investment and the other part to a LM investment) entails the possibility of combining the advantages of an FM and an LM strategy and avoiding their disadvantages at the same time to reach a superior risk and return profile and outperform strict FM or LM strategies. Therefore, an economically well-founded ex-ante evaluation, regarding an optimal allocation of the budget to emerging and mature innovations is needed at an early stage since FM advantages cannot be realized later on once an IT innovation emerges. Beside the chances and risks of the different investment strategies (emerging vs. mature) it is also important to identify relevant specifics of the underlying IT innovation (e.g., estimated market impact in different scenarios) and the company (e.g., company's ability to innovate successfully) that can significantly influence the investment decision. This allows us to cover various essential framework conditions to derive fundamental hypotheses regarding scenarios in which investing as FM in an emerging innovation is beneficial towards investing as LM in a "mature" innovation.

To the best of our knowledge, there is no quantitative optimization model, combining relevant company- and innovation-specific parameters, success- and failing-probabilities and considering a "mixed" investment strategy to calculate the optimal allocation of an investment budget for emerging and mature IT innovations to maximize the NPV´s of the underlying investments. Conducting sensitivity and scenario

analyses, we aim to uncover relations between the identified parameters thus enabling a deeper understanding of how different parameters influence the optimal allocation of an investment budget. Thereby, we contribute to one of the fundamental research questions in IT innovation literature of *when* and *to what extent* a company should invest in an emerging IT innovation with deriving the following two research questions (RQ´s):

RQ1: *How can a company determine the optimal strategy for investments in an emerging IT innovation regarding the expected NPV?*

RQ2: *How do different company- and IT innovation-specific factors influence the optimal strategy and the expected NPV of investments in an emerging IT innovation?*

The remainder of this paper is organized as follows. Following a discussion of the relevant literature in section 2, section 3 develops our quantitative optimization model. Section 4 presents the model's solutions, exemplary applications, and sensitivity analyses. Section 5 summarizes the findings and limitations and provides suggestions for future research.

2 Theoretical Background and Related Literature

In this section, we draw on IT innovation literature to define IT innovation and its possible development inspired by the concept of hype cycles. We also discuss the literature on investments in emerging IT innovations and parameters influencing decisions regarding optimal investment strategies. Thus, this section lays the theoretical foundation for our quantitative optimization model.

2.1 IT Innovations

Swanson (1994) defines IT innovations as "innovations in the organizational application of digital computer and communications technologies (now commonly known as information technology)." Garcia and Calantone (2002) define (IT-)innovation as the generation and/or acceptance of ideas, processes, products, and services that are new to the company or the company´s customers. It is a generalized view of innovation taking into account innovation occurring in all kind of organizations. It goes beyond the definitions that stated innovation as "new to the world" (Garcia and Calantone, 2002). We refer to a definition of Crossan and Apaydin (2010) that stated innovation as the "production or adoption, assimilation, and exploitation of a value-added novelty in economic […] spheres; renewal and enlargement of products, services, […]; development of new methods of production; and establishment of new management systems". This definition includes internally initiated innovations, as well as adopted innovations.

Basically, we can distinguish two types of innovations. Depending on their "newness", innovations can be incremental *(mature)* or breakthrough *(emerging)*. Mature innovations refer to minor changes in technology or simple product improvements. In contrast, emerging innovations are novel, unique, or state-of-the-art technological advances in a product category (Wind and Mahajan, 1997; Zhou et al., 2005). Emerging innovations are highly risky to pursue (Zhou et al., 2005). On the one hand an emerging innovation may be technologically risky because developing state-of-the-art technology is extremely expensive and requires substantial investments (Wind and Mahajan, 1997). However, even if an innovation may be technologically straightforward, it can be extremely risky on the market side because the consumers acceptance is highly uncertain (Christensen and Bower, 1996).

An innovation's development over time can be explained by Gartner Inc.'s concept of hype cycles (for the current version, see Panetta, 2017), which illustrates the possible developments of an emerging IT innovation through several stages. The development begins with a *technology trigger* with excess publicity, leading to over-enthusiasm and investments often influenced by bandwagon behavior. Thus, within their lifecycle of adoption (Rogers, 2003), IT innovations are often "hyped," that is, accompanied by waves of discourse or rumors about the innovation itself and its adoption and diffusion (Abrahamson and Fairchild, 1999). This hype typically reaches a peak of *inflated expectations* before it fades away in a *trough of disillusionment*. For our upcoming model, we summarize these first three stages within a

first of two development periods by mapping them through the first of two consecutive discrete points in time and refer to investments within these first three stages as FM-investments.

However, in this early stage, substantial adoption is missing, and evaluation with reliable estimations of future evolution is almost impossible owing to the hype that might fade in the absence of long-term productivity. Today, IT innovations such as Connected Homes, Blockchain and Machine Learning can be classified as *emerging IT innovations* (Panetta, 2017). In contrast, *mature IT innovations* have already been adopted by a substantial part of the market (Rogers, 2003), demonstrating that they were not just a hype and exhibiting stable development (Fenn and Raskino, 2008). Thus, their future evolution can be roughly estimated. For instance, virtual or augmented reality can be classified as mature IT innovations (Panetta, 2017). Only a few technologies will reach the status *"mature"* at the end of the first period of development and are worthy of further investment and hard work to understand the technology's applicability, risks, and benefits, leading to a *slope of enlightenment* followed by a *plateau of productivity* (Fenn and Raskino, 2008; Wang, 2010). For our upcoming model, we summarize these two stages within the second of two development periods by mapping two consecutive discrete points in time and refer to investments within these two stages as LM-investments. Finally, *institutionalized IT innovations* are innovations that have been established in the market and acquired mass adoption beyond the plateau of productivity. Also, they have crossed the chasm from being an IT innovation to an established technology. As the Gartner Hype Cycle only provides information about the current development status of an innovation and is not suitable for planning investments due to a lack of information about opportunities, risks and economic potential, we develop a mathematical model that calculates an optimal allocation of an investment budget to emerging and mature innovations on the basis of investment-related information specific to the innovation, market and company, which we will motivate and explain in more detail in the upcoming section.

2.2   Investments in IT Innovations

The advent and massive proliferation of digitalization and its corresponding IT applications (e.g., mobile computing, cloud computing, social media, etc.), fueled by the consumerization of IT (Harris et al., 2012) provided companies with flexible and cost-effective opportunities to innovate (Vodanovich et al., 2010). Technology advancements over the past few years have assisted companies in innovation through a variety of helpful improvements and decision support systems (e.g. improved decision-making capabilities, increased customer connectedness, increased number of communication channels, enhanced communication facilities) (Huber, 1990; Brynjolfsson, 2011; Kumar et al., 2010; Bharadwaj, 2000; Nambisan, 2016). Therefore, investments in emerging IT innovations are beneficial to (Melville *et al.*, 2004) and essential for companies (Clark and Guy, 1998; Nadler and Tushman, 1999).

However, investments in new IT innovations remain a risky challenge, e.g. due to uncertainty about future market penetration and the literature does not provide any information on how an investment budget should be allocated optimally to IT innovations of different stages of maturity. Therefore investments are often driven by market pressure and bandwagon behavior (Häckel et al., 2017), thus lacking an economically well-founded decision calculus. In order to avoid investments on a gut feeling when choosing an optimal investment strategy, but considering the peculiarities of IT innovations (e.g., probability of institutionalization, expected economic impact of technology, or market innovativeness) and the current development status according to the Gartner Hype Cycle, our optimization model includes parameters that reflect these peculiarities and the current development status. To ensure that the investment decision is also optimal in an economic sense, we select the maximum net present value of the underlying investments as an optimality criterion. By applying such a model, complex interdependencies between key factors can be mapped and considered in investment decisions. Furthermore, we also consider company-specific factors (e.g., company size, investment budget, structure, and agility) influence the risk and return profile of investments in emerging IT innovations. Thus, a company's ability to understand, successfully adopt, and implement IT innovations are key factors as the introduction of new technologies imposes "substantial burden on the adopter regarding the knowledge needed to understand and use them effectively" (Ke and Wei, 2006). This ability to be a successful innovative company can

be designated as a company's *"innovator profile"*. Companies that fit this profile are expected to innovate more easily, effectively, and economically (Fichman, 2004b). Furthermore, systematic innovators have more experience in selecting and implementing IT innovations in an early phase and can better evaluate new applications (Swanson and Ramiller, 2004). Thus, a company's success with investments in emerging IT innovations depends on not only on the underlying technology's customer acceptance but also the company's innovator profile (Fichman, 2004b). We incorporate the key capabilities mentioned by Ke and Wei (2006) and denoted as innovator profile in our model in the form of a further parameter. That makes it possible to consider effects caused by a high respectively low innovator profile mentioned by Fichman (2004b) on the optimal allocation of an investment budget.

When choosing a suitable investment strategy, the timing of the investment plays also a major role. Thus, depending on the investment timing, innovation investments undergo different risk and return profiles and some prior studies focused on the evaluation of emerging IT innovations and the effects on IT innovation investment strategies. For instance, Dos Santos and Pfeffers (1995) demonstrated advantages of engagements in emerging IT innovations given the possibility of adding over-proportional value. Lu and Ramamurthy (2010) examined investment strategies in stable and dynamic settings and demonstrated that proactive IT innovation leaders who regularly engage in emerging IT innovations outperform reactive IT innovators in overall performance and cost efficiency.

Wang (2010) found that companies improved their performance and gained a better reputation owing to over-proportional returns resulting from long-term competitive advantages based on investments in emerging IT innovations. Using game theory, Hoppe (2000) showed that under certain conditions, even second-mover strategies could be advantageous because of spillover effects. However, these studies neither incorporate the risk of non-institutionalization, nor provide advice about the extent and timing of investments, nor explain how an investment budget should be allocated between emerging and mature IT innovations. In a first approach, Häckel *et al*. (2013) considered the risk of a failing emerging IT innovation and examined the error resulting from fixed investment strategies regarding the allocation of periodical IT innovation investment budgets; however, they did not analyze the concrete decision situation of a company that aims to optimize the budget allocation over time for an emerging IT innovation.

However, there is a lack of quantitative approaches that investigate optimal "mixed" strategies e.g. in terms of timing and budget allocation that entail the possibility of a beneficial combination of an FM and LM investment to reach a superior risk and return profile and may outperform strict FM or LM strategies.

Furthermore, other insights into whether an investment strategy for an innovation will be successful are often based on statistical evaluations of historical data of similar companies with similar investment behavior (FM vs. LM). Therefore, by using those studies recommendations for a certain investment strategy can be given under known conditions. However, since these results cannot be generalized and transferred to other scenarios, investment strategy decisions cannot be made on economically well-founded basis in previously never occurred environmental scenarios.

In sum, the current status in relevant research primarily reveals gaps by either neglecting relevant (company-specific) parameters, focusing on strict investment strategies or building up on historical data which cannot be generalized and applied on different companies or scenarios.

Thus, drawing on related literature, the present study develops a quantitative optimization model to determine an optimal investment strategy considering relevant parameters in sense of calculating an optimal allocation of an investment budget to emerging and mature IT innovations. Using findings from prior research, we analyze the impact of different company- and IT innovation-specific influencing factors using exemplary applications and sensitivity analyses. This can provide new insights and propositions for future research and empirical testing.

3 Model

We consider a company that has decided to invest in an emerging IT innovation. Before making an investment decision, the company must determine the optimal strategy regarding timing and allocation

of an available amount of "innovation budget" to maximize the innovation´s expected NPV. Our model covers strategies for a *„first mover"* investment in an emerging IT innovation, a *"late mover"* investment in a mature IT innovation, and the possibility of a mixed investment strategy, which might enable a superior combination of the LM and FM risk and return profiles. To cover the possibility of the IT innovation developing over time, the model's time frame comprises three points in time. An FM investment is possible at the first point in time wherein the IT innovation emerges, and an LM investment is possible at the second point in time. At the third point in time, the development of the IT innovation is complete, and its final destiny becomes obvious.

Assumption 1 – Initial Situation

At $t = 0$, a company chooses a strategic budget $B \in \mathbb{R}^+$ for an investment in an emerging IT innovation. At the same time, the company must determine the share $x \in [0; 1]$ of B invested at $t = 0$ (FM investment). The other share of budget $(1 - x)$ is saved for a possible investment at $t = 1$ (LM investment).

The provided budget serves as a basis for the planning of investments and should be immediately planned when a new IT innovation emerges to enable investments with the potential for FM advantages. If the budget is not completely exhausted in the FM investment, the remaining funds can be reserved for a possible LM investment in the same IT innovation. Therefore $x = 1$ represents a strict FM strategy, $x = 0$ is a strict LM strategy and $x \in (0; 1)$ a mixed strategy.

Assumption 2 – Uncertainty about IT Innovation's Development

a) Possible Scenarios for Development: The development of an IT innovation is uncertain and broken down into two periods: from $t = 0$ to $t = 1$ (period one) and from $t = 1$ to $t = 2$ (period two). Within both periods, a positive (upside: "u") and negative (downside: "d") scenario is possible, whereas a positive scenario within period one implies a development into a mature IT Innovation and a positive scenario within the period two implies a development into an institutionalized IT Innovation. However, a negative development in both periods implies a failing IT Innovation. After a negative development within the first period, a second period of development is not considered because the IT innovation has failed. At $t = 2$, the IT innovation's development is completed and one of the scenarios $s \in \{uu, ud, d\}$ is realized.

The breakdown of an IT innovation's development in two periods is inspired by Gartner's hype cycle (Fenn and Raskino, 2008) and enables an appropriate depiction of an IT innovation's development within our quantitative model. It covers the entire process from when an IT innovation emerges to the outcome (Wang, 2010). Thus, relevant changes in the characteristics of an IT innovation, which should be accounted for in an economically well-founded evaluation, can be adequately considered (e.g., decreasing uncertainty about the possible long-term success of an IT innovation).

b) Probabilities of the Development Periods: The uncertainty about the future IT innovation development is described by the probability $p_t \in [0; 1]$ with $t \in \{0; 1\}$ for positive (u) development and $(1 - p_t)$ for negative (d) development within the first and second period. The probability for a positive development is considerably lower in the first than in the second period $(p_0 < p_1)$.

The probability of positive development in the first period (p_0) indicates the probability of an emerging IT innovation is becoming a mature one. This probability is rather low since many emerging innovations fail after the first period of development when the hype vanishes (Gourville, 2006). When the IT innovation has survived the first period, it demonstrates marketability thus far and the first indications of market acceptance can be observed (e.g., sales of beta-versions or results of customer surveys). Meanwhile, other competitive IT innovations have already failed within the first period and thus, only those IT innovations that passed the first "endurance test" reach the second period of development and thus the risk of investing in a failing technology is getting lower. Therefore, the probability of a positive development in the second period (p_1) is considerably higher than the probability (p_0). The probabilities for the upside and first and second downside scenarios $s \in \{uu, ud, d\}$ can be calculated by the probabilities $p_t \in [0; 1]$ designated for the two periods of development (Fig. 1).
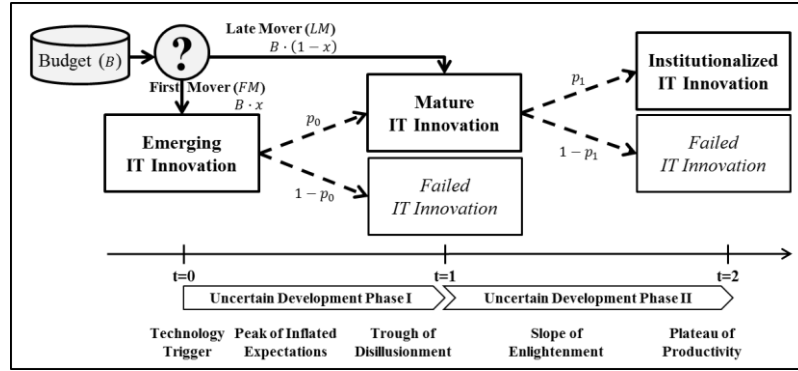
Figure 1.   *Overview of the model's decision situation*

Assumption 3 – Achievable Future Cash Flows

a) Parameters of Cash Flow Functions: *The resulting cash flow $CF_j(ep_j^s, B, x)$ depends on the invested share x of budget B, the budget B itself and the investment's economic potential $ep_j^s \in \mathbb{R}$, $s \in \{uu, ud, d\}$, $j \in \{FM, LM\}$. For the upside scenario ($s = uu$), an FM investment is associated with higher economic potential than an LM investment ($ep_{FM}^{uu} > ep_{LM}^{uu}$). On the other hand, for downside scenarios $s \in \{ud, d\}$, the FM investment's economic potential (ep_{FM}^{ud} and ep_{FM}^d) is equal or less than an LM investment (ep_{LM}^{ud}). In addition, the economic potentials for the upside scenario are considerably higher than those for the downside scenarios:*

$$ep_{FM}^{uu} > ep_{LM}^{uu} > ep_{LM}^{ud} \geq ep_{FM}^{ud} = ep_{FM}^d. \qquad\qquad 1.$$

Economic potentials as IT innovation-specific factors depict the extent of possible long-term returns. They cover the IT innovation's expected market impact according to factors such as consumers' acceptance, market competition, or the probability of easy integration into the company's existing IT infrastructure (Fichman, 2004c; Haner, 2002; Moser, 2011). The factors influence the extent of resulting cash flows and can be estimated through market analyses or internal and external educated guesses by technical experts or those with comprehensive market experience and an appropriate understanding of the emerging innovations´ potential.

If the emerging IT innovation becomes institutionalized in the long run, the investments result in positive cash flows. The highest possible cash flow results from an FM investment since these investments tend to generate higher cash flows for a company owing to FM advantages (Lu and Ramamurthy, 2010; Wang, 2010). Therefore, for the upside scenario, the economic potential of an FM investment (ep_{FM}^{uu}) is higher than that for an LM investment (ep_{LM}^{uu}).

For the downside scenarios, there are three possible cases depicted by our assumption (eq. 1): low positive, zero, or negative cash flows when the IT innovation fails. Thus, the factors covering economic potentials within the cash flow functions are also positive, zero, or negative. First, low positive cash flows are possible if there are no inevitable cash outflows in the future but low cash inflows, for example, if the IT innovation can be partly used or exploited otherwise. Since an FM investment is associated with a deeper engagement in the IT innovation, what impedes a quick switch to another use of the IT innovation, an LM investment enables slightly higher positive cash flows. Second, if no future cash inflows or outflows are possible when the IT innovation fails, this leads to zero cash flows. Thus, the economic potentials are the same: $ep_{LM}^{ud} = ep_{FM}^{ud} = ep_{FM}^d = 0$. Third, negative cash flows are possible if future inevitable cash outflows occur, for example, owing to reputational damages or performed organizational changes. Thereby, the cash flows of a FM investment are lower (i.e., more negative) than those for an LM investment due to a longer and deeper engagement. In addition to the described possible cash flows, necessary investment expenditures are also considered in our NPV approach (assumption 5). Thus, even for low positive cash flows, the NPV of the investment can become negative.

b) Course of Cash Flow Functions: *The cash flow $CF_j(ep_j^s, B, x)$ follows a strictly monotonically increasing and concave function.*

A monotonically increasing, concave function is suitable to depict an increasing but diminishing marginal utility according to production theory (Stiglitz, 1993), which is appropriate for cash flows resulting from investments in an emerging IT innovation for several reasons. First, the monotonically increasing course depicts that a higher investment leads to deeper engagement, making deeper understanding and broader implementation possible (Fichman, 2004b; Kimberly, 1981; Melville *et al*., 2004). Second, a first engagement in an IT innovation enables entering a market or becoming reasonably familiar with a technology (Lu and Ramamurthy, 2010; Stratopoulos and Lim, 2010), and therefore, creates a higher marginal cash flow than an increase in an already high investment, which is depicted by the function's concavity. Owing to the diminishing marginal utility a pure "more is better" approach might not hold true for every amount of investment since it is possible that at a certain point the marginal investment exceeds the resulting marginal cash flow.

c) Resulting Cash Flows: Cash flow CF_t^s with $s \in \{uu, ud, d\}$ is the sum of cash inflows and outflows at $t \in \{0; 1; 2\}$, resulting from the FM and LM investment. At $t = 2$, it comprises cash flows $CF_j(ep_j^s, B, x)$ with $j \in \{FM, LM\}$ (Cash flows can be interpreted as the present value at $t = 2$ for all possible cash flows generated in the future by the investments):

$$CF_2^s = CF_{FM}(ep_{FM}^s, B, x) + CF_{LM}(ep_{LM}^s, B, x = 0) - CF_{LM}(ep_{LM}^s, B, x). \qquad 2.$$

Regardless of the point in time, both FM and LM investments belong to the same IT innovation. Therefore, an LM investment reinforces the company's possible FM investment in the IT innovation. As initial investments enable higher marginal cash flows than additional investments, the amount of FM investment, as an initial investment in the emerging IT innovation, must be accounted for when calculating the LM investment's cash flow. Therefore, the cash flow resulting from an LM investment with the invested amount of an FM investment ($CF_{LM}(ep_{LM}^s, B, x)$) is subtracted from the cash flow that would result from an LM investment from the entire budget (i.e., $CF_{LM}(ep_{LM}^s, B, x = 0)$) to calculate the correct cash flow from an investment of the remainder budget as an LM investment (Fig. 2).
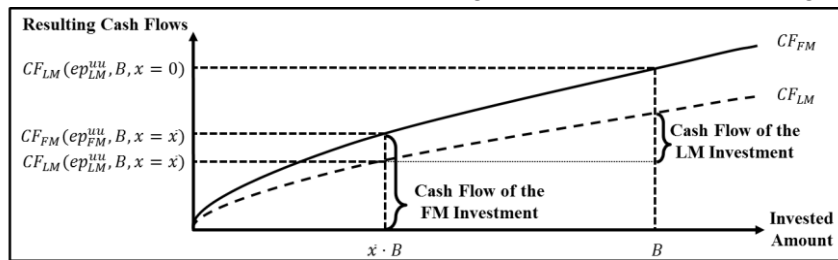

Figure 2.   Resulting cash flows in an upside scenario (illustrative)

In addition to the described IT innovation-related specifics, successful engagement in an emerging IT innovation depends on a company's ability to innovate economically and successfully, that is, the company's innovator profile.

Assumption 4 – Innovativeness of the Company

The cash flows resulting from investments in emerging IT innovation for the upside scenario are multiplied by a company-specific factor $i \in \mathbb{R}^+$, indicating the company's innovator profile.

The innovator profile i allows us to consider the company's ability to engage in an IT innovation economically, quickly, and efficiently (Swanson and Ramiller, 2004; Fichman, 2004b). If the company is more innovative, it is generally likely to implement the emerging IT innovation more successfully and generate higher cash flows if the IT innovation becomes institutionalized. The innovator profile reflects a company's innovativeness relative to the market's average innovativeness. Thus, for an average innovative company, $i = 1$; for a below average company, $i < 1$; and for an above average one, $i > 1$. Of course, the impact of the innovator profile only applies to the upside scenario, as a company's individual innovativeness does not matter if the IT innovation fails and vanishes from the market.

The company's possible investments and resulting cash flows for the different scenarios with their associated probabilities are presented in Table 1.

Scenario	Probabilities	CF_0^s	CF_1^s	CF_2^s
uu	$p_0 \cdot p_1$	$-(x \cdot B)$	$-((1-x) \cdot B)$	$[CF_{FM}(ep_{FM}^{uu}, B, x) + CF_{LM}(ep_{LM}^{uu}, B, x=0) - CF_{LM}(ep_{LM}^{uu}, B, x)] \cdot i$
ud	$p_0 \cdot (1-p_1)$	$-(x \cdot B)$	$-((1-x) \cdot B)$	$CF_{FM}(ep_{FM}^{ud}, B, x) + CF_{LM}(ep_{LM}^{ud}, B, x=0) - CF_{LM}(ep_{LM}^{ud}, B, x)$
d	$(1-p_0)$	$-(x \cdot B)$	---	$CF_{FM}(ep_{FM}^{d}, B, x)$

Table 1.   Possible scenarios with resulting cash flows and associated probabilities

Assumption 5 – Objective Function

The company is a risk-neutral decision maker and aims at maximizing the expected NPV $E[NPV(x)]$ of the investments in the emerging IT innovation. It is calculated as the sum of expected cash flows $E[CF_t^s]$ with $t \in \{0; 1; 2\}$ and $s \in \{uu, ud, d\}$, discounted with a constant risk-free interest rate $r \in [0,1]$.

$$\max_x E[NPV(x)] = CF_0^s + \frac{E[CF_1^s]}{1+r} + \frac{E[CF_2^s]}{(1+r)^2} \; s.t.. \; x \in [0,1]; s \in \{uu, ud, d\}. \qquad 3.$$

Assume a risk-neutral decision maker is reasonable since investments in new technologies are associated with higher risks than investments that deal with, for example, infrastructure, operational data, and routine processes (Maizlish and Handler, 2005; Ross and Beath, 2002). Therefore, an extensive risk aversion would prevent necessary and useful investments in innovations. The company can maximize the expected NPV by determining the optimal investment strategy indicated by optimal share x^* of the budget ($x = 1$ represents a strict FM strategy, $x = 0$ a strict LM strategy, and $0 < x < 1$ a mixed strategy). A strict FM strategy allows for high cash flows within the upside scenario and bears the risk of rather low or even negative cash flows in the downside scenarios. By contrast, a strict LM strategy possibly results in lower cash flows in the upside scenario or budget saving if the IT innovation is stranded in the first period of development. A mixed strategy, that is, a combination of both strict strategies' chances and risks, possibly leads to a higher expected NPV. The decision is influenced by the amount of strategic budget, success probabilities, and economic potentials of investments regarding the different possible scenarios, and the company's innovator profile.

4   Model Analysis

In this section, we analyze the model using exemplary applications and sensitivity analyses. First, we analyze different parameter settings (Table 2) depicting the characteristics of possible real-world scenarios regarding the expected NPV and optimal investment strategy. We then examine the impacts of the input parameters on NPV and optimal investment strategy using sensitivity analyses, by changing the values of one parameter, ceteris paribus (Saltelli *et al.*, 2008). Conclusively we derive further insights and illustrate the connection to the assumptions by computing and analyzing its analytical solution.

Exemplary application

Parameter	B	ep_{FM}^{uu}	ep_{LM}^{uu}	ep_{LM}^{ud}	ep_{FM}^{ud}	ep_{FM}^{d}	i	p_0	p_1	r
Values of baseline scenario	500	1,000	500	0	0	0	1	0.1	0.6	0.1
Lower scenario (.) ↓	250	500	250	-10	-20	-20	0.5	0.1	0.6	0.1
Upper scenario (.) ↑	750	1,500	750	20	10	10	1.5	0.1	0.6	0.1

Table 2.   Parameter values for the scenario analyses

As functions for the expected cash flows, we use standard root functions as they perfectly cover the characteristic of diminishing marginal cash flows (For example the upside scenario's cash flow at $t = 2$ is: $CF_2^{uu} = [ep_{FM}^{uu} \cdot (B \cdot x)^{0.5} + ep_{LM}^{uu} \cdot (B)^{0.5} - ep_{LM}^{uu} \cdot (B \cdot x)^{0.5}] \cdot i.$) .

Expected NPV and Optimal Solution for Different Scenarios: Applying the parameter values of the baseline scenario, the optimal solution, that is, the optimal ex-ante allocation of budget B to the FM and LM strategy is $x = 0.37$. That is, with an investment of 37% ($x^* \approx 0.37$) of the budget at $t = 0$ and saving of 63% for an investment at $t = 1$, the company achieves a maximum expected NPV of 677.99 monetary units (Fig. 3).
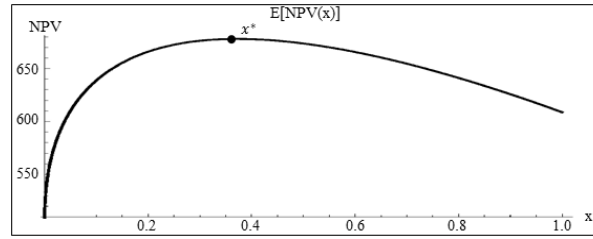
Figure 3. Expected NPV and optimal solution for the baseline scenario

Fig. 3 indicates that there is one optimal solution. However, the curve's course indicates that a deviation toward the LM strategy is more critical than that of the FM strategy. Thus, the impact of FM advantages over-compensates the impact of the LM strategy's lower risk, that is, the loss of FM advantages due to the reduced allocation toward the FM strategy is more substantial than the reduction of uncertainty. Moreover, compared to a strict FM or LM investment strategy, it becomes rather obvious that a mixed strategy is advantageous as the expected NPV reaches its maximum value.

Scenario analysis

To further analyze the scenarios, we combine the parameter values of Table 2 that considerably fluctuate around the values of the baseline scenario to cover a broad range of possible scenarios. Since we distinguish between company- and IT innovation-specific input parameters, we combine parameters settings depicting different types of companies and IT innovations. The results are shown in Figure 4.
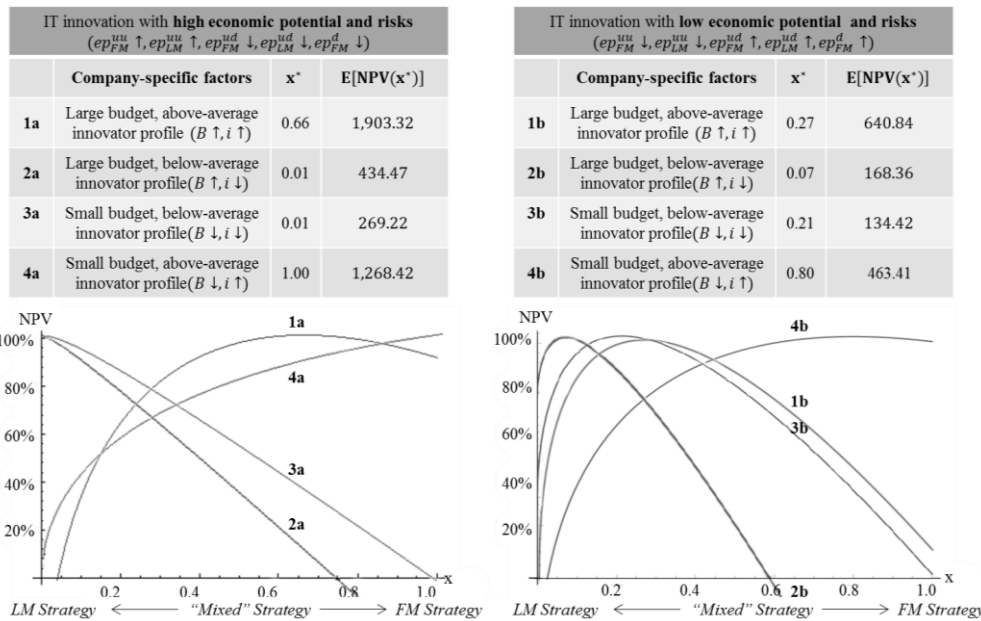

Figure 4. Overview of results for different scenarios

Regarding company-specific parameters, we assume a company to have a considerably large or small budget and an innovator profile above or below the market average. Furthermore, by varying the IT innovation's economic potentials as IT innovation-specific factors, we cover two interesting IT innovation-related scenarios. First, the emerging IT innovation seems to be a disruptive technology; that is, on the one hand, an engagement bears the possibility of extraordinarily high returns (depicted by choosing the upper limit values for economic potentials in the upside scenario) if the IT innovation becomes institutionalized. On the other hand, it is characterized by the risk of losing more than the budget (depicted by choosing the lower limit values for economic potential in the downside scenarios) if the IT innovation unsuccessfully vanishes from the market (left part of Fig. 4). Second, the IT innovation seems to be a considerable improvement over existing technologies but is not a disruptive technology; that is, on the one hand, it bears the possibility of high, but not exceptional returns (depicted by choosing the lower limit values for economic potentials in the upside scenario) if the IT innovation becomes institutionalized. On the other hand, it is characterized by a lower risk (depicted by choosing the upper

limit values for economic potential in the downside scenarios) if the IT innovation unsuccessfully vanishes from the market (right part of Fig. 4). The success probabilities do not vary as they are assumed to be average probabilities that depict the average fraction of IT innovations that become institutionalized, regardless of the IT innovation's possible impact. To test the model's sensitivity for different situations, we combine different company- and IT innovation-related settings, resulting in the different decision situations (Fig. 4).

For a company with a large budget and above-average innovator profile, the optimal investment strategies x^* (0.66 and 0.27) and the related optimal expected NPVs $E[NPV(x^*)]$ (1,903.32 and 640.84) are rather different. As for the disruptive IT innovation, because of the company's high innovativeness and FM investment's high economic potential for the upside scenario, an allocation of the budget's majority to the FM strategy can be advantageous. Thus, given its high innovativeness, the company can risk acting like a FM to engage in the disruptive IT innovation as it is more likely to be successful and achieve high possible cash flows. In contrast, for the evolutionary IT innovation, a high FM investment is not useful because there are no considerable FM advantages due to the lower economic potential, not even through high innovativeness; therefore, a strategy with focus a on a LM investment is advantageous. However, a higher budget enables deeper engagement and higher cash flows for both IT innovation-specific scenarios compared to the initial situation.

For a company with a large budget but below-average innovativeness, the results significantly differ. Regardless of the IT innovation-specific scenario, the optimal investment strategies x^* (0.01 and 0.07) considerably change toward the LM strategy and the optimal expected NPVs $E[NPV(x^*)]$ (434.47 and 168.36) largely decrease. This shows that below-average companies should rather invest as an LM as they cannot realize the possible FM advantages owing to the lack of knowledge regarding a successful implementation of new technologies. In addition, the expected NPVs show that even a high budget and optimal investment strategy cannot compensate for the disadvantages of low innovativeness. Moreover, the company must invest carefully as the expected NPVs can even be negative for wrongly chosen FM strategies. In this case, the risk of losing a high budget over-compensates for the possibility of cash flows, which are low owing to the company's inability to successfully adopt new technologies.

Also, changing the budget to a lower limit, indicating a below-average company with few financial funds, compared to the previous scenario, the optimal investment strategy x^* for the disruptive IT innovation is the same (0.01) and marginally changes for the evolutionary IT innovation (0.21). Moreover, the optimal expected NPVs decrease for both types of IT innovations (269.22 and 134.42) owing to the decreased budget. Because of the low innovativeness, the company should rather invest as an LM, especially in the case of disruptive technologies. For evolutionary IT innovation, the company should not completely rely on an LM strategy; rather, it can risk acting like an FM investor and allocate an appropriate share of the budget to FM investments, since the risk within the downside scenarios is considerably lower than that for disruptive IT innovation. Overall, a company with a low budget and below-average innovativeness can reach positive expected NPVs and does not face a high risk of negative NPVs such as the below-average company with a high budget.

Finally, we continue to assume a company with low available financial funds but with above-average innovativeness. As argued, this depicts the situation start-up companies are faced with, as they regularly have lower financial funds available than traditional companies but are often agile and more innovative. An examination situation 4a and 4b (s. Fig. 4) reveals that optimal investment strategies x^* become almost completely reversed (1 and 0.8) and the optimal expected NPVs considerably increase (1,268.42 and 463.41) compared to the previous analysis. Hence, for both types of IT innovations, strict FM strategies are advantageous, enabling high expected cash flows. In particular, for investments in disruptive IT innovations, small start-ups can monetize possible FM advantages, investing all available financial funds strictly as an FM (taking the risk of possibly going bankrupt). In addition, even for the evolutionary IT innovation, a FM strategy is advantageous, given the lower risk in the downside scenarios and the positive impact of above-average innovativeness on the expected cash flows. Thus, the innovativeness of a company has a considerable positive impact on the optimal investment strategy and expected NPV, even if the company does not have substantial financial resources at its disposal.

Model analysis conclusions

From the analyses of the initial scenario and different company- and IT innovation-specific scenarios, we draw the following conclusions:

- a below-average innovative company should rather choose an LM strategy;

- an above-average innovative company should rather choose an FM strategy, except if it has a large budget at its disposal and the IT innovation is evolutionary;

- a company with a large budget at its disposal should rather choose an LM strategy, except if it is above-average innovative and the IT innovation is a disruptive one;

- a company with a small budget at its disposal should rather choose an FM strategy if it is above-average innovative and an LM strategy if it is below average;

- as for expected NPV, the impact of the company's innovativeness is stronger than that of the budget; and

- for evolutionary IT innovations, an LM strategy is advantageous, except if the company has a small budget at its disposal and is above average innovative.

Also, the analyses indicate that the optimal investment strategy and the resulting expected NPVs are rather sensitive to different scenarios. Therefore, for the decision regarding the optimal investment strategy, a mindful consideration of company- and IT innovation-specific factors is inevitable.

To enable a better understanding of how the amount of budget influences the decision, we analyzed its isolated impact on the optimal strategy and expected NPV. For the sensitivity analyses, based on the baseline scenario, we show an alteration of the parameter value for budget B. As depicted on the left-hand side of Fig. 5, a higher budget leads to a higher expected NPV and a decreasing share allocated to the FM investment (right-hand side of Fig. 5).
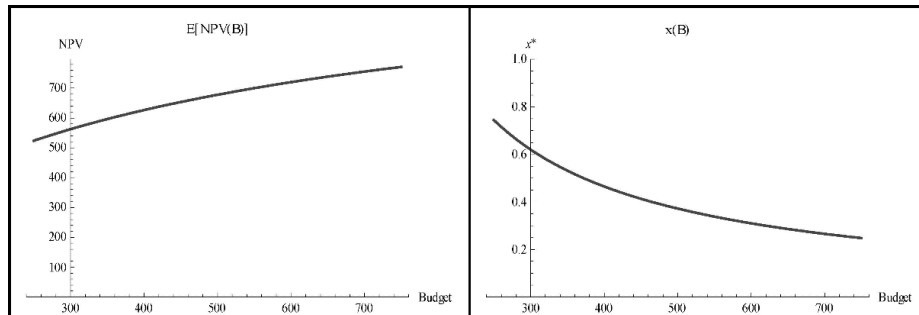

Figure 5.   Influence of budget on expected NPV and optimal solution

The concave increase of the expected NPV demonstrates the cash flows' characteristic of diminishing marginal cash flow; that is, the achievable additional marginal cash flows decrease with an increase in the invested budget. Interestingly, the decreasing allocation to the FM investment indicates that a company with higher financial funds can afford to wait longer, observe the emerging IT innovation's development, and act more as an LM investor. As the budget increases in absolute value, it is possible to save a higher share of the budget for an LM investment without a considerable reduction of the FM investment's amount. Moreover, a company with low available funds would rather invest as an FM investor to maintain the possibility of high cash flows owing to FM advantages.

To derive further insights and illustrate the connection to the assumptions we specified the objective function by inserting all the parameters for different possible scenarios and computed the first derivation of the objective function with respect to x. In sum we can state that for an optimal solution, the risk and return profiles of both investment strategies have to be balanced. Furthermore, increasing one of the economic potential factors of the FM or LM investment strategy should increase the budget share allocated to the respective strategy. An increase in the success probabilities (separately or together) should increase the budget share allocated to the FM strategy; and an increased innovator profile should increase the budget share allocated to the FM strategy.

5 Conclusions, Limitations, and Suggestions

Decisions regarding a strategy for investments in an emerging IT innovation are often not based on economically well-founded evaluations and analyses, as the market for IT innovations is characterized by intense competition, unclear impacts, and an environment influenced by the hype surrounding an emerging IT innovation. In this context, research can provide valuable insights into the ex-ante determination of optimal investment strategies using quantitative models. In addition to studies analyzing the optimal allocation of recurring IT innovation budgets, it is important to investigate factors affecting decisions regarding optimal strategies for investments in a given emerging IT innovation. To provide insights into causal relationships and analyze key factors, we consider relevant specifics of the company (e.g., budget and innovator profile) and IT innovation (e.g., success probabilities and economic potential) within our quantitative optimization model. By considering these factors, we contribute to central research questions in IT innovation theory, that is, *when* and *to what extent* should a company invest in an emerging IT innovation (Swanson and Ramiller, 2004). As for company-specific factors, first, our analyses show that the amount of available budget positively impacts expected NPV (a higher budget enables higher investments). Second, a higher budget offers a company the opportunity to defer an investment and first observe the IT innovation's development. Therefore, a company with sufficient financial funds does not need to invest its entire budget immediately. Third, the most relevant factor for successful engagement in an emerging IT innovation is the innovativeness of the company. Fourth, broad knowledge and experience regarding how to successfully innovate enables a company to engage in an emerging IT innovation at an early stage and monetize possible FM advantages. Thus, the expected NPV considerably increases, which emphasizes steady organizational learning to improve and maintain a company's innovativeness (Häckel *et al*., 2017). Fifth, our analyses show that even with low financial funds, a remarkable expected NPV can be achieved if the company's ability to innovate is above average. IT innovation-specific factors elucidate that first, for investments in an emerging IT innovation that seems rather evolutionary, an LM strategy is almost always the appropriate investment strategy. Even in this case, a highly innovative company with a low budget should choose a strict FM strategy to monetize FM advantages. Second, far more interesting are rather disruptive emerging IT innovations. Thus, company-specific characteristic, particularly the company's innovativeness, mainly determine the respective optimal strategy and therefore, the risk a company should take. By applying our model to allocate an investment budget, we see that it is advantageous to invest part of our innovation budget in emerging IT innovations, which essentially corresponds to earlier qualitative and empirical studies by Wang (2010), Lu and Ramamurthy (2010) or Dos Santos and Pfeffers (1995). These showed that investments in emerging IT innovations lead to improved company performance. On the other hand, our results show that an LM strategy is meaningful for a below-average innovative company, which supports findings from Hoppe (2000), stating that an LM strategy advantageous, e.g. in the case of a low success probability for an emerging innovation. To reinforce the model's validity and our conclusions, further research in a given organizational context or using empirical data might be valuable (Hevner et al., 2004; Wacker, 1998). Furthermore, our model and its findings may not be practically applicable without adjustments. For example, investments are often not infinitely divisible. Thus, in reality, a possible investment strategy closest to the theoretically optimal solution would have to be chosen. Moreover, further research focusing on some of the limiting aspects might be useful. In particular, the determination of input parameters using empirical and benchmark analyses or educated assessments using experts or consultants and a subsequent analyzation by deep learning methods such as Genetic Algorithm or Neural network algorithm to ensure an expedient data basis could be helpful. A further promising direction for future research could be the development of an integrated portfolio approach that comprehensively depicts investments in different emerging IT innovations. To analyze effects of the real world more precisely, a dynamic multi-period model might be valuable. Such a model could e.g. consider learning effects that reflect the experience a company can gain by a steady and continuous engagement in IT innovations. Despite the model's limitations which offer possibilities for future research, our results and the theoretically sound economic approach contribute to improving a company's decision and further development of a quantitative theory regarding investments in emerging IT innovations.

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