NISHAD MATAWLIE

Through Mind and Behaviour to Financial Decisions

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Vanuit verstand en gedrag naar financiële beslissingen

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To my mother and my grandmother

Voor mijn moeder en mijn grootmoeder

मातृ देवो भवः

I pay my respects to the power of wisdom and knowledge.

Knowledge destroys the darkness of ignorance,
knowledge leads to the path of growth and progress.
— Vedas

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The PhD trajectory is a journey of learning, which only gets better, very quickly, along the way. I can sure say that it has been an awesome expedition. This journey taught me about research, several interesting topics, academia, people, life but also about myself. I would like to take this opportunity to sincerely thank some amazing people who played a significant (***) role in this wonderful journey.

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Finally, with all my heart, I thank my loving mother for her unconditional love, care, support, patience, guidance, and help, not only in the past few years but during my whole life. Without you I would not have been where I am today. You taught me to never give up, to believe in my own capabilities, to always be modest, to invest in life, that wisdom and knowledge are priceless, and so much more. Words are not enough to show my appreciation for you, I am truly proud to be your son. Thank you for being my guru, role-model and hero. Thank you for giving me all the tools and lessons to succeed in life. Thank you for always being there. Thank you for everything. Ma, je bent de beste, deze is voor jou.

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Nishad R. Matawlie

September, 2020

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Introduction

Financial decisions are made by maximizing value, whether that is shareholder value, portfolio value, profits value, or personal value. In the process of financial decision making, one may follow economic theory, may apply a decision rule, or may determine value through financial modelling. These financial decision-making tools are built on rational theory. However, often enough we observe choices which are against the lines of rational theory. Then, behavioural decision theory may be able to explain these choices. With that thought, I investigate how *behavioural* traits affect the *mind* in financial decision making. This dissertation presents three theoretical essays, grounded in mathematical and financial foundations, and accompanied by some empirical evidence, which explain how behavioural traits cause particular (corporate) financial decisions to deviate from what rational theory dictates.

Background

Many theories apply when modelling financial decisions. Traditional capital budgeting theory prescribes to invest in a project if it has a positive net present value (NPV). Real options theory incorporates a dynamic approach to investment opportunities and adds the value of flexibility to the static NPV. By considering the investment decision as analogous to the exercise of an option, the financial option pricing paradigm can be applied in valuing investment decisions (Dixit & Pindyck, 1994). Game theory studies the strategic interaction of multiple agents and is used to include strategic considerations in financial decision making. Hence, the combination of real options and game theory into real option games applies to investment decisions in competitive environments (Smit & Trigeorgis, 2004). Auction theory uses game theory to develop optimal equilibrium bidding strategies for bidders in auctions. All these mentioned theories and more assume rationality of decision-making agents.

Rationality of agents is since a long time described as maximizing expected value (the sum of probability weighted outcomes)[1]. In that sense, an agent should be indifferent between (i) receiving €100,- with certainty and (ii) the 50:50-gamble of receiving €200,- or nothing; after all, the expected values in terms of money are equal. Empirical and experimental evidence, however, show that some agents prefer proposal (i) while others prefer

[1] *Pascal's wager*, a seventeenth-century philosophical and mathematical argument, even applies the concept of expected value maximisation to the question of believing or disbelieving in God.

proposal (ii) and that these preferences differ with the amounts of money involved and the level of wealth of the player. Expected utility theory is a decision theory capable of explaining these differences by positing that agents maximize expected utility (relative to current wealth) rather than expected value[2] (Von Neumann & Morgenstern, 1947). When probabilities are known, expected utility theory is often deemed the hallmark of rationality. According to the expected utility hypothesis, differences in preferences arise due to differences in risk attitudes, thereby distinguishing between risk-seeking, risk-averse, and risk-neutral attitudes. Expected value maximisation is then just a special case of expected utility maximisation, with utility being linear and risk attitude therefore being neutral.

However, there are many examples and observations where choices are in violation with utility theory[3]. This led to the rise of other descriptive rather than normative decision theories, thereby incorporating behavioural traits of agents stemming from psychological insights. Prospect theory (Kahneman & Tversky, 1979; Tversky & Kahneman, 1992) is a descriptive behavioural decision theory that mathematically formalizes several behavioural traits which affect decision making. Prospect theory encompasses several elements that are based on observed behaviour. First, individuals tend to be risk-averse towards gains but risk-seeking towards losses. Second, individuals evaluate these gains and losses relative to a certain reference point instead of current wealth. Third, individuals engage in probability weighting such that the objective probabilities are over- or underweighted and are also differently weighted dependent on whether these probabilities correspond to gains or losses. Finally, individuals suffer from loss aversion, which means that losses of the same magnitude 'hurt' more than gains are 'enjoyed'. In this way, prospect theory is able to explain

[2] Discussion about expected value theory was triggered among more with Bernoulli's *St. Peterburg's paradox*

[3] *The Allais paradox* is a choice problem which shows the inconsistency of actual observed choices with the predictions of expected utility theory.

certain decisions which utility theory fails to capture.

Additional to behavioural traits, decision-making is also affected by cognitive biases of the decision maker. Behavioural biases such as overconfidence, can affect the rational process in such a way that decisions following from rationality are altered completely. Overconfidence manifests in several forms such as excessive confidence with regard to having accurate information (miscalibration); believing that one is better than the reference group (above-average effect); or overestimating the ability to control events over which one has limited influence (illusion of control) (Ben-David et al., 2013). The following chapters each investigate how either overconfidence affects rational financial decision making or how behavioural decision theory in the form of prospect theory is able to explain observed (corporate) financial decision-making anomalies.

Outline

Chapter 2 investigates the effect of CEO overconfidence on the decision between acquisition strategies. The CEO of the acquiring company can choose to acquire a controlling stake in the target firm directly, or on the other hand, the CEO can choose to follow a toehold strategy. With a toehold strategy, a minority stake is acquired first, which is extended to a controlling stake only when circumstances develop favourably.

Many previous studies have showed the benefits of a toehold strategy. For instance, a toehold can help to overcome the free-rider problem or take-over defences such as fair price clauses in single bidder cases (Shleifer & Vishny, 1986; Tirole, 2010). Toeholds reduce competition and target resistance and are associated with lower bid premiums and lower target stock price run-ups (Betton & Eckbo, 2000). When rivals are involved, a toehold increases the likelihood of winning a bidding contest (Betton et al., 2009). Moreover, a toehold allows for testing the waters instead of an immediate plunge in the deep of a full-scale acquisition. Given the myriad of benefits, the number of observed toehold strategies is however, remarkably low (Betton et al., 2009). I propose a behavioural explanation for the low usage of toeholds. I hypothesize that CEO overconfidence negatively affects the likelihood of employing a toehold strategy.

Extending the minority stake to a controlling stake resembles the exercise of a call option. Therefore, I model the toehold strategy with a continuous-time real options model and show that where moderate confidence increases the likelihood of a toehold strategy, overconfidence leads to choosing the direct acquisition over the toehold strategy. The finding that moderate confidence can be beneficial for the firm whereas overconfidence is not, is in line with multiple studies such as Goel & Thakor (2008); Campbell et al. (2011); Hirshleifer et al. (2012). I empirically investigate whether there are indications that confirm the prediction of my theory. Using empirical measures for overconfidence, I find a significant negative relation between the likelihood of a toehold strategy and CEO overconfidence, which thus supports the theory.

Chapter 3 investigates the matter of how objects are sold through auctions or negotiations. Classical economic theory (Bulow & Klemperer, 1996) dictates that the seller should opt for an auction since the bidding among competitors will drive bids up and therefore maximizes expected revenues for the seller. Still, we observe many sales through negotiations. Often these negotiations precede subsequent auctions, which only take place in case of a failed negotiation. I therefore compare a direct auction with a sequential selling mechanism, where a seller starts with a negotiation and proceeds to the auction only in case of a failed negotiation. Organizing an auction is costly under the title of *search costs,* which encompass all direct and indirect costs associated with the auction.

I use *auction theory* to model and compare the selling mechanisms. It just so happens that the Nobel prize in economic sciences of this year (2020) was awarded to Paul Milgrom and Robert Wilson (both from Stanford University), for their improvements to *auction theory* and inventions of new auction formats.

When choosing a selling mechanism, sellers may intuitively imagine that starting off with a negotiation seems as a free possibility of avoiding a costly auction. By modelling the sequential selling mechanism first in a rational framework through auction theory, I show that there exists a substantial difference between the expected pay-offs of the direct auction and the auction following upon a failed negotiation. This difference, which is named the *'negotiation penalty'*, also exists between the direct auction and the complete sequential selling mechanism. The rational model therefore confirms that a rational seller should choose the direct auction rather than the sequential mechanism to maximize expected value. However, this does not explain why sellers still opt for the sequential mechanism. By integrating prospect theory (PT) in the auction theory models of the sequential mechanism and direct auction, I show that for a PT agent it is possible to prefer the sequential selling mechanism over a direct auction. By using a dataset on corporate transactions through any of the selling procedures, I find empirical indications for my theoretical claims on the negotiation penalty, preferences and the effects of search costs on preferences.

Chapter 4 develops a theory of real options (RO) integrated with prospect theory (PT): The PT-RO framework. Many investment decisions can be modelled with real options theory (Dixit & Pindyck, 1994). An intuitive and tractable framework to represent investment decisions as real options is the binomial tree, which is also widely used for pricing financial options (Cox & Ross, 1976). However, the valuation of real options through the financial options paradigm relies on the crucial assumption of complete markets: For investment decisions, this means that the pay-offs should be replicable by traded assets. This strong assumption is not plausible in many cases. Investments in R&D or angel investments in start-ups are examples of incomplete markets settings where the replicability condition does not hold.

The dynamics of the investment outcomes, represented as a real option tree, resemble compound prospects of obtaining outcomes with certain probabilities. By integrating prospect theory and real option theory in a binomial tree framework, I can analyze investment behaviour in incomplete markets settings and explain investment behaviour. I analyze several investment settings represented through (compound) real options and examine the investment behaviour of PT agents. I find that anomalies regarding project investments, such as overinvestment and escalation of commitment, are explainable through the combination of real option theory and prospect theory. Furthermore I analyze how the PT components such as probability weighting and reference point dependence affect decision making. This hopefully encourages more future research on the integration of valuation theory with behavioural theory.

All in all, this dissertation examines the impact of behavioural traits and biases on financial decision making. It shows that behavioural biases such as overconfidence affect decision making such that it can alter choices. By considering behavioural traits through behavioural decision theory, it is possible to explain several anomalies in financial decisions. These findings do not only contribute to academic literature and our understanding of decision processes, but also have relevant implications for executives, policy makers, and all financial decision-making individuals. This dissertation contributes to the ongoing discussion of the plausibility of the rationality assumption of individuals and contributes to illustrate the relevance of the behavioural side of economics and management.

Declaration of Contribution

Chapter 2: This chapter is based on a joint work with Han Smit and has benefited from comments from Patrick Verwijmeren, Sebastian Gryglewicz, Sjoerd van Bekkum, Sebastian Pfeil and seminar participants at Erasmus Research Institute of Management, Tinbergen Institute, Behavioural Finance Conference (2016), Real Options Conference (2017), Portugese Finance Network (2018) and European Financial Management Conference (2019). This paper has been awarded the *Real Options Conference 2017 best PhD student paper award*. The idea and concept are developed by my co-author. The mathematical modelling, literature review, data work and empirical analysis have been done by me and the writing is a joint work with my co-author.

Chapter 3: This chapter is based on a paper which started as a collaboration with Sebastian Gryglewicz and Han Smit, but which became an independent work after I had an idea for an alternative approach and worked this out. It has benefited from fruitful discussions with Sebastian Gryglewicz and Peter Wakker and has benefited from comments from Patrick Verwijmeren and other seminar participants at Erasmus Finance Day (2018). I am grateful to Peter Wakker, whose invaluable comments have helped to improve this paper significantly. All the work for this paper as it is now has been conducted independently.

Chapter 4: This chapter is based on joint work with Han Smit. The idea for this paper has been developed together with my co-author, the writing is joint work, and the mathematical modelling, programming, and analysis have been done by me. Again for this paper I am grateful to Peter Wakker, whose invaluable comments have helped to improve this paper enormously.

The over-weening conceit which the greater part of men have of their own abilities, is an ancient evil remarked by the philosophers and moralists of all ages.

Adam Smith

2

Do Overconfident CEOs Ignore the Toehold Option?*

The neglect of toehold strategies - where the bidder acquires a minority stake in a target before making a bid to acquire control - is considered puzzling in the context of widespread evidence that the majority of direct control acquisitions fail to deliver value for the acquirer on announcement[1]. While ac-

*This chapter is based on Matawlie & Smit (2020a).

[1] For instance, only 5% of the total acquisitions executed by listed US companies was a toehold in a target company in the period 2004-2013. Source: Thomson One Banker.

quisitions create value overall, the sellers seem to get the better half, with acquirers' announcement returns on average close to zero[2]. Sequencing an acquisition with a toehold may help to even this imbalance and to improve poor acquirer returns, yet toehold strategies are rarely executed. Building on the seminal work of Baldwin (1982); Dixit & Pindyck (1994) and others on the sequencing of irreversible investment under uncertainty, this study presents a real options model for toehold strategies.

A strand of literature shows that a toehold can grant its owner several advantages in acquiring full control of the target[3], which seems to be in conflict with their observed rare use in practice. This phenomenon is part of the *Toehold Puzzle* (Betton et al., 2009). At the same time, *'Hubris'* (Roll, 1986) and overconfidence (Camerer & Lovallo, 1999; Malmendier & Tate, 2005a) are well-documented explanations of decision-maker's behavior, such as overbidding and excess entry, but until now they have not been proposed as possible explanation for the rare use of toeholds. Acquirer CEO's decision-making can be affected by biases, in the sense that synergies can be perceived higher than they in reality are. This study integrates insights from the toehold, real option and behavioral strands of corporate finance literature in an attempt to explain the rare use of toeholds. To our best knowledge, this study is the first to link the limited use of toehold strategies to CEO overconfidence. In particular, we formulate the following research question: *'Can the rare use of toehold acquisitions be explained by CEO overconfidence?'*

To answer this question, we develop a real options model for toehold strategies to model the choice between a toehold strategy versus a majority acquisition. Real options

[2] For instance, see Bradley et al. (1988); Stulz et al. (1990); Leeth & Borg (2000); Malmendier & Tate (2008).

[3] For instance, it can mitigate the free-rider problem (Shleifer & Vishny, 1986), it increases the probability of a successful offer (Hirshleifer & Titman, 1990) and it can possibly lead to lower bid premiums (Bulow et al., 1999; Betton & Eckbo, 2000).

and dynamic models analyze the sequence and timing of irreversible investment under uncertainty (Baldwin, 1982; Bernanke, 1983; Dixit & Pindyck, 1994; Titman et al., 1985, e.g.,); value flexibility (Triantis & Hodder, 1990) and growth options (Myers, 1977; Berk et al., 1999), and analyze mergers and acquisitions (e.g., Lambrecht, 2004; Morellec & Zhdanov, 2005; Toxvaerd, 2008; Morellec & Schürhoff, 2011; Gorbenko & Malenko, 2017)). While there are several models for the timing and terms of mergers and acquisitions, it is remarkable that the real option provided by a toehold is a relatively unexplored territory in the real options literature,, as buying a toehold has a natural similarity with obtaining a call option. Hence, in a two-stage acquisition process, a bid for control on the remaining shares can be made when uncertainties are resolved. The immediate plunge in the deep of a full-scale acquisition contrasts with a toehold strategy which (like a call option) allows for testing the waters first, before exercising and make an offer for control.

It is common in the real options literature to analyze phenomena from the perspective of a framework with rational agents. That while some financial phenomena can plausibly be understood using models in which agents are not fully rational (Barberis & Thaler, 2003). Hence, another specific contribution to the real options literature is that we allow for bounded rationality in toehold decisions. With our model, we show how CEO overconfidence affects choice-making between a toehold strategy and a direct control acquisition. Based on the real options model, we hypothesize that CEOs who are overconfident by having a different perception of realizable synergies, are consequently more likely to (overly) eager execute control acquisitions, avoiding more vigilant toehold option strategies.

Furthermore, our study relates to the literature on theory and evidence of the use of toeholds (e.g., Shleifer & Vishny, 1986; Hirshleifer & Titman, 1990; Burkart, 1995; Singh, 1998; Bulow et al., 1999, and others). Besides the real options literature, this study aims to contribute to the toehold literature by introducing and integrating insights from the behavioral finance literature on CEO overconfidence to a well-documented phenomenon as the 'toehold puzzle'. Overconfidence not only has implications for overbidding, overinvestment, financing, and performance[4], but may also influence the trade-off of a CEO to execute a direct control acquisition or conduct a toehold strategy instead.

Only a few papers test the empirical predictions of real options models: for instance, Quigg (1993) in the area of land development and Giaccotto et al. (2007) on the embedded value of real options in lease contracts. We do also empirically investigate whether there are indications of the validity of the predictions following from our real options model. For that purpose, we use different measures for CEO overconfidence. First, we rely on measures of overconfidence based on investment behavior regarding personal option portfolios of CEOs (Malmendier & Tate, 2005a, 2008)[5]. Next, to examine the robustness of our findings obtained with the option portfolio overconfidence measure, we use two different measures of overconfidence, which are based on the external perception of CEOs by high-quality newspapers (Malmendier & Tate, 2008) and self-importance through salary differences (Hayward & Hambrick, 1997).

We use a dataset of nearly 9700 acquisitions by S&P1500 companies in the period 2004-2013. Given an acquisition, we find an economically and statistically significant negative relationship between measures of CEO overconfidence and the likelihood of conducting a possible toehold strategy versus a direct control acquisition. We confirm that

[4]CEO overconfidence can for instance account for corporate investment distortions (Malmendier & Tate, 2005a), frequent and unsuccessful merger decisions (Malmendier & Tate, 2008), explain dividend decisions (Deshmukh et al., 2013), and corporate financing policies (Malmendier et al., 2011).

[5]Malmendier and Tate link CEO overconfidence, as measured through their option portfolio behavior, to a variety of corporate investment decisions and investment-cash flow sensitivity.

overconfident CEOs are less likely to choose the toehold strategy and acquire immediate controlling stakes instead. Furthermore, consistent with the literature (Choi, 1991; Le & Schultz, 2007), we find higher abnormal announcement returns for toeholds than for immediate control acquisitions. The insights of the model and empirical findings suggest that overconfidence of CEOs contributes to forgoing toehold strategies when choosing between acquisition strategies.

This chapter is structured as follows, Section 2.1 develops the toehold real options model. Section 2.2 conducts an empirical analysis. Finally, in Section 2.3 follows a discussion and Section 2.4 concludes.

2.1 A Theory of CEO Overconfidence and Toehold Neglect

This section develops a theory of how CEO overconfidence affects the likelihood of choosing a toehold strategy as acquisition strategy over the direct acquisition. We first review the literature on real options, toeholds and overconfidence. Next, we develop a dynamic real options model for the toehold strategy and show how CEO overconfidence affects the choice between acquisition strategies.

2.1.1 Literature

In the real option literature there is a variety of dynamic models on acquisitions (e.g. Lambrecht, 2004; Morellec & Zhdanov, 2005; Toxvaerd, 2008; Morellec & Schürhoff, 2011; Gorbenko & Malenko, 2017) and on divestment and abandonment (Berger et al., 1996; Lambrecht & Myers, 2007; Aretz & Pope, 2018)[6]. As confirmed by the literature, taking

[6]Other real options models involve models on competition (e.g., Grenadier, 1996, 2002; Lambrecht & Perraudin, 2003; Smit & Trigeorgis, 2004; Aguerrevere, 2009); on incomplete information and signaling (e.g., Grenadier, 1999; Grenadier & Wang, 2005; Grenadier & Malenko, 2011;

a toehold option first can grant its owner several advantages over an immediate full acquisition. In a widely held target firm, other shareholders want to free-ride the synergy value created by a successful takeover. A toehold may mitigate the free-rider problem (Grossman & Hart, 1980; Shleifer & Vishny, 1986) because the toehold holder can gain on the shares (s)he already owns and thus benefits from 'seller advantages'.

A toehold also increases the probability of a successful offer, and it does so, even if the toehold owner is competing with a stronger rival, (Hirshleifer & Titman, 1990; Burkart, 1995; Singh, 1998). In common value auctions, a toehold enables its owner to win an auction inexpensively, using her information advantage[7] and potential position as a seller (Bulow et al., 1999), which allows the acquirer to avoid low returns due to the winners' curse in common value auctions (Thaler, 1988).

In addition, a toehold provides an acquirer with the much needed edge in a takeover battle. Its ownership position sends a clear signal of commitment to potential rivals and conveys a higher bidder valuation of the target. A toehold owner can consequently bid more aggressively, and wins a bidding war far more often than not, which is empirically confirmed (Betton & Eckbo, 2000)[8]. This leads to fewer bids by competitors, decreasing the premium required to capture the target (Bulow et al., 1999; Betton & Eckbo, 2000).

Grenadier et al., 2014; Morellec & Schürhoff, 2011; Bouvard, 2012); on leasing (Grenadier, 1995); on temporary and permanent shocks (Grenadier & Malenko, 2010); on capital structure (Lambrecht & Myers, 2008); on real options under general processes (Boyarchenko, 2004); on biased agents (Grenadier et al., 2016); and on stock returns (Grullon et al., 2012; Gu et al., 2017).

[7] In particular, when the toehold is associated with a board seat it provides an insider position in the target firm. The buyer can exert corporate control even before the full bid has commenced, reduce window-dressing and valuation uncertainty. The strongest value enhancements occur for those firms that have a product relation, especially in industries with high uncertainty and corresponding research costs (Allen & Phillips, 2000).

[8] If the rival ends up with the target, the high premium will also be paid for the minority stake holder; and even when rival bidders also have a toehold, the probability of them winning a bidding war deteriorates in a co-moving fashion with the size of the rival's minority stake (Dasgupta & Tsui, 2003; Betton & Eckbo, 2000).

Given their benefits, it is remarkable to observe rare use of toeholds in practice[9].

We build a real option model where, by taking a toehold position, the acquisition is temporarily staged, and the acquirer can benefit from seller advantages when extending to a controlling stake. We consider a toehold as a real option to acquire a controlling stake in the target firm. For our real options model of toehold acquisitions, we build on the reduced-form models for corporate takeovers by Lambrecht (2004) and Morellec & Zhdanov (2005). Next, we extend their framework by incorporating bounded rationality, by building on the work of Hackbarth (2008, 2009). Therewith we extend the real options literature to the context of toehold acquisition strategies under bounded rationality of the decision maker. In our model, CEO overconfidence is expressed through the synergy factors. We use the real options model to analyze how overconfidence of the CEO affects choice-making between the two acquisition strategies.

The choice between a sequential toehold strategy or an immediate control acquisition is determined by the CEO's perception of future success of the takeover, translated in an expectation of the synergies. Overconfident CEOs have the potential to suffer from miscalibration, where they underestimate levels of risk or uncertainty (Hackbarth, 2008, 2009). Miscalibration relates to the overprecision cognitive bias. This is translated into an underestimation of the variance of possible outcomes or having a too narrow confidence

[9] Several reasons presented in literature fail to properly explain the rare use. Legislative rulings such as disclosure rules and anti-trust regulations are not a big obstacle. In addition, increased liquidity makes it now easier to dispose a stake. Entrenchment and a hostile reception by incumbent target management can form an obstacle so does the elimination of surprise on a takeover. As the purchase portrays a clear and outspoken commitment, this also results in information for rivals, who can now anticipate their bidding strategy. For publicly listed companies, information of this kind can lead to run-ups in stock prices in particular when they are illiquid. Betton et al. (2008) find that purchases of target stocks increase run-ups significantly, however, that same research shows that while this offers a theoretically compelling argument, it is not sufficient to exceed the advantages.

interval for an uncertain event[10]. This bias is in line with other facets of overconfidence such as the better-than-average effect and overestimation effects, where individuals overestimate their own personal skills and the degree of control over future outcomes. Positive recent performances or the successful completion of earlier deals can build executive overconfidence, leading them to underestimate their chances of failure in future acquisitions (Gervais & Odean, 2001). Another element of executive overconfidence is the self-attribution bias (Billett & Qian, 2008), when successes are attributed to personal skills, but failures are seen as stemming from bad luck, a bias that is also likely to be reinforced by the successful completion of a deal (Malmendier & Tate, 2005b).

Overconfident CEOs tend to undertake multiple acquisitions within a short time, and are less likely to stage acquisitions; however, these subsequent overconfidence-driven acquisitions are likely to produce negative outcomes (Doukas & Petmezas, 2007; Malmendier & Tate, 2008). Overconfident executives engage in acquisitions to release target firms from ineffective incumbent management, believing they have the power to improve the firm's performance once they gain control of it (Brown & Sarma, 2007). Immediate control acquisitions can therefore follow from the beliefs of overconfident executives that they possess superior capabilities compared to target management to run a company and can thereby realize high synergies. In particular, this bias is often used to strengthen the rationale of an acquisition decision when executives are highly committed (Heaton, 2002) and when they believe that the success of the deal is within their personal control (Langer, 1975). CEO overconfidence leads to overestimation of future forecasts and due to overoptimistic forecasts of environmental, industry, and company variables growth, the synergistic value is most likely to be overestimated. Therefore, CEOs prefer full acqui-

[10]Related to overconfidence, is over-optimism, where an individual is irrationally optimistic about uncertain future events.

sitions when they have overconfident expectations of total synergistic gains (Kahneman & Lovallo, 1993; Hayward & Hambrick, 1997). These findings support the notion that overconfidence leads to overestimation of the synergy factors by a CEO.

2.1.2 A Dynamic Model for Toehold Strategies

In this section, we present our dynamic model for toehold acquisition strategies. We assume constant risk-free rate, risk-neutral agents, continuous time and consider a complete probability space $(\Omega, \mathcal{F}, \mathcal{F}_{t\geq 0}, \mathbb{P})$.

Consider two firms, the bidder (B) and the target (T), with capital stocks K and Q, respectively. The (stock market) valuations per unit of capital are X_t and Y_t, respectively[11], which follow independent stochastic processes with the following dynamics:

$$dA_t = \mu_A A_t dt + \sigma_A A_t dW_t^A, \qquad A = X, Y, \tag{2.1}$$

with constant volatility $\sigma_A > 0$ and growth rate $\mu_A < r$, where r denotes the risk-free rate. Furthermore, W_t^X and W_t^Y are standard Brownian motions. We assume that the stochastic processes are uncorrelated, however this can be perceived differently. Let ρ represent the possible correlation between the Brownian motions W_t^X and W_t^Y, such that $dW_t^X dW_t^Y = \rho dt$. The firm values of the bidder and of the target are then given by $V^B(X) = KX$ and $V^T(Y) = QY$ respectively.

We follow the reasoning of Shleifer & Vishny (2003)[12] and Morellec & Zhdanov (2005) by assuming that the combined value per unit capital $S(X, Y)$ is a linear combination of pre-takeover values. We thereby assume the existence of synergistic opportunities where

[11] These can also be viewed as present values of all future cash flows.

[12] The model that we develop here is a dynamic version of the acquisition model of Shleifer & Vishny (2003), which we extended with the possibility of a toehold strategy.

both the acquirer and target may benefit from transferring synergies[13]. Then we describe the post-takeover value of the combined firm as:

$$V^C(X,Y) = S(X,Y)(K+Q) \tag{2.2}$$

$$= V^B(X) + V^T(Y) + (K+Q)(\alpha(X+Y) - \gamma Y) \tag{2.3}$$

$$S(X,Y) = (\theta + \alpha)X + [(1-\theta) - (\gamma - \alpha)]Y \tag{2.4}$$

Here is $\theta = \frac{K}{K+Q}$ and α denotes the synergy factor, furthermore γ represents a limit of what target T can realistically contribute on synergies. These synergy factors are uncertain. The bidder and target have estimates of these synergy factors, which are $(\hat{\alpha}, \hat{\gamma})$ and $(\check{\alpha}, \check{\gamma})$ for the bidder and target respectively. Rational bidders and targets have unbiased estimates, such that, for instance, $\mathbb{E}^B(\hat{\alpha}) = \alpha$.

The Direct Control Acquisition

We first consider the direct control acquisition. Let $\phi > \frac{1}{2}$ be the final desired controlling stake in the target, we consider the case where $\phi = 1$, however the model can also be written down for general $\phi > 1/2$. The takeover price for the direct control acquisition is proportional to the target firm value as in Shleifer & Vishny (2003)[14]: $(1+\psi)QY$, where typically $\psi \geq 0$. Therefore, the surplus or part of the total takeover gains of the direct

[13] Firms may transfer lever or resources, expertise, capabilities or know-how (e.g., a distribution network or a brand name) such that the combined firm is worth more than the sum of its parts).

[14] Our results translate to the case where the takeover price for the direct control acquisition is modelled as a fraction $(1-\xi)$ of the combined firm value V^C, as in Morellec & Zhdanov (2005).

acquisition for the bidding firm after restructuring satisfies:

$$\begin{aligned}
\text{Bidder Surplus} &= \underbrace{V^T}_{\substack{\text{Standalone value}\\ \text{of the target}}} + \underbrace{V^C - V^B - V^T}_{\text{Total synergies}} - \underbrace{(1+\psi)V^C}_{\text{Acquisition price}} \\
&= (K+Q)(\alpha(X+Y) - \gamma Y) - Q\psi Y \qquad (2.5) \\
&= \left[V^C - V^B\right] - (1+\psi)V^T \qquad (2.6)
\end{aligned}$$

That means, the bidding firm obtains the standalone value of the controlling stake in the target firm, receives the total synergies and pays the takeover price[15]. Often the target firm will try to claim at least the proportion of synergies it contributes through the takeover premium (Tirole, 2010).

The Toehold Strategy

If the bidder B acquires a toehold, B owns a minority stake $\omega < \frac{1}{2}$ in the target firm with stand-alone value ωV^T. The minority stake will have been acquired against a premium ζ, such that the amount paid for the toehold was $\omega\zeta V^T$, where ζ typically (but not exclusively) ranges between $1 \leq \zeta \leq (1+\psi)$. Obtaining a controlling stake in the second stage of the toehold strategy is considered as option exercise, where the stake size increases from $\omega < \frac{1}{2}$ to $\omega = 1$.

We model the toehold analogous to a perpetual American call option on a (dividend paying) stock (e.g., see Dixit & Pindyck, 1994). The decision-maker can consider costs of holding the toehold option without exercising. These costs are expressed as lost 'dividends' in the form of missed synergies. Let $q = f(\alpha)$, with $\frac{df}{d\alpha} > 0$, be the continuous dividend

[15] The takeover price can be in cash or in stocks.

yield as a function of the synergy factor. Then, for the option value, it is possible using familiar standard arguments, to show that the value of the bidder's toehold strategy option $O(X_t, Y_t)$ solves the following partial differential equation (PDF):

$$(\mu_X - q)XO + \mu_Y YO + \frac{1}{2}{\sigma_X}^2 X^2 O_{XX} + \frac{1}{2}{\sigma_Y}^2 Y^2 O_{YY} + \rho\sigma_X\sigma_Y O_{XY} = rO, \tag{2.7}$$

where r denotes the risk-free rate and subscripts represent partial derivatives (we have omitted the time indicator t for convenience). Alternatively, the dividend yield can be equal to zero, i.e. $q = 0$, such that no extra costs of holding the option are considered. The PDE (2.7) is solved subject to the following boundary conditions:

$$\underbrace{O(X^*, Y^*)}_{\substack{\text{Option value at}\\ \text{moment of exercise}}} = \underbrace{(V^C(X^*, Y^*) - V^B(X^*) - V^T(Y^*))}_{\text{Synergistic value}} + \tag{2.8}$$

$$+ \underbrace{V^T(Y^*)}_{\substack{\text{Stand alone value}\\ \text{of target}}} - \underbrace{(1-\omega)(1+\psi)V^T(Y^*)}_{\text{Acquisition price}}$$

$$O_X(X^*) = (K + Q)\alpha \tag{2.9}$$

$$O_Y(Y^*) = (K + Q)[(1-\theta) - (\gamma - \alpha)] - Q(1+\psi)(1-\omega) \tag{2.10}$$

$$\lim_{(X/Y)\longrightarrow 0} \frac{O(X, Y)}{X} = 0 \tag{2.11}$$

Equation (2.8), the value-matching condition, shows that the option value of the minority stake should be equal to the payoff of the option at the moment of exercise, where (X^*, Y^*) represent the threshold levels of the capital stock values at which the option is exercised. The payoff of the toehold option consists of the standalone value of the remaining part of the target firm, plus the synergies (which are only obtained after a controlling stake is obtained) minus the acquisition price paid. Without a toehold, the negotiated takeover price is proportional to the total target firm value. However, when the bidder owns a toehold, the target cannot make demands over the part (ωV^T) that the toehold owner already possesses. The price is therefore expressed as a fraction equivalent to $(1-\omega)(1+\psi)V^T$ allowing the bidder to gain some of the seller advantages over its toehold.

The remaining equations (2.9) and (2.10) are the smooth pasting conditions, which guarantee optimality by requiring continuity of the slopes at the threshold levels. The last boundary condition (2.11) requires that the ratio of the option value to the present value of the bidder's cash flows approaches zero, as the ratio of the present value of the bidder's cash flows to the target's cash flows goes to zero (this is also known as the no bubbles condition).

The option value $O(X, Y)$ is linearly homogeneous in (X, Y). Therefore, if we let

$$R_t = \left.\frac{X_t}{Y_t}\right|_{(t\geq 0)},$$

we can describe the bidder's exercise strategy via the threshold R^*, at which (and above) it is optimal to exercise the toehold strategy option (that is, acquire a controlling stake). With the use of the boundary conditions, we derive the following for the option value of the toehold (for details, see Appendix A)

$$O(R) = \left[\left\{V^C(R^*) - V^B(R^*) - (1+\psi)V^T(1)\right\} + \omega\left\{(1+\psi V^T(1)\right\}\right]\left(\frac{R}{R^*}\right)^\beta. \tag{2.12}$$

In terms of X and Y, we have:

$$O(X,Y) = \Bigg[\underbrace{\Big\{V^C(X^*,Y^*) - V^B(X^*) - (1+\psi)V^T(Y^*)\Big\}}_{\substack{\text{Bidder surplus}\\ \text{without toehold}}} + \underbrace{\omega\Big\{(1+\psi)V^T(Y^*)\Big\}}_{\substack{\text{Seller advantages for}\\ \text{toehold holder:}\\ \text{proportion } \omega \text{ of target gains}}}\Bigg]\left(\frac{X/Y}{X^*/Y^*}\right)^{\beta}, \tag{2.13}$$

where $R^* = X^*/Y^*$. Equation (2.13) shows the option value of the toehold, which is the stochastically discounted value of the surplus that the acquirer obtains by exercising the toehold option. From this expression, we see that with a toehold strategy, the bidder gains from some seller advantages. The surplus that the bidder obtains now also includes components that otherwise would be completely received by the target in the case of an immediate full-scale acquisition strategy. Finally, the exercise threshold value is given by:

$$R^* = \frac{\beta}{\beta-1}\frac{(K+Q)(\gamma-\alpha) - [1-(1+\psi)(1-\omega)]Q}{(K+Q)\alpha} \tag{2.14}$$

and β is the positive root of the following quadratic equation:

$$\frac{1}{2}(\sigma_X^2 - 2\rho\sigma_X\sigma_Y + \sigma_Y^2)\beta(\beta-1) + [(\mu_X - q) - \mu_Y]\beta - (r-\mu_Y) = 0 \tag{2.15}$$

In order for the toehold option to exist and to be worthwhile, the threshold R^* should be positive and larger than R. A very large threshold R^* makes the probability of exercise lower and with that also makes the option value lower. The first term $\beta/(\beta-1)$ in (2.14) is certainly positive (since $\beta > 1$ holds). Thus, the existence of the toehold option value depends on the last term, which we denote as H:

$$H = \frac{(K+Q)(\gamma-\alpha) - [1-(1+\psi)(1-\omega)]Q}{(K+Q)\alpha}. \tag{2.16}$$

When H becomes negative, the toehold option does not exist, this can occur for large synergy levels α. This also indicates that a toehold strategy is not worthwhile in every setting, but that this depends on different factors. For instance, a high premium ψ contributes to the usefulness of the toehold.

The Toehold versus the Control Acquisition

The CEO of the bidding firm decides which strategy to follow by comparing the value of both strategies. The expected surplus of acquiring the target firm directly is equal to the combined firm value minus the bidding firm minus the price paid for the target firm. The expected surplus of a two-stage toehold acquisition strategy is equal to the option value minus the price paid for the toehold:

Toehold strategy surplus:

$$\left[V^C(X^*, Y^*) - V^B(X^*) - (1+\psi)(1-\omega)V^T(Y^*)\right] D(X,Y) - \omega\zeta V^T(Y) \tag{2.17}$$

Direct control acquisition surplus:

$$\left[V^C(X,Y) - V^B(X) - (1+\psi)V^T(Y)\right] \tag{2.18}$$

where we have again omitted subscripts t and $D(X,Y) = \left(\frac{X/Y}{X^*/Y^*}\right)^\beta = \left(\frac{R}{R^*}\right)^\beta = D(R)$ is the stochastic discount factor. In the special case that $D = 1$, $Y^* = Y_t$, and $\zeta =$

$(1+\psi)$, we see that the surpluses of both strategies are equal; in this case, a rational CEO should be indifferent between both strategies. In addition note that a direct acquisition can be seen as a special case of a toehold option, where the initial stake $\omega = 0$ and the stochastic discount factor $D = 1$.

As both strategies differ in their investments, we compare the returns of both strategies. From (2.17) and (2.18), we can derive the conditions for which it holds that the return on the toehold strategy is higher than the return of the direct control acquisition. The returns are obtained by dividing the surplus as in (2.17) and (2.18) by the total payment for a strategy, which is a current part plus a discounted part in case of the toehold:

Toehold strategy return $>$ *Direct acquisition return*

$$\frac{O(X,Y)-\omega\zeta V^T(Y)}{\left[(1+\psi)(1-\omega)V^T(Y^*)\right]D+\omega\zeta V^T(Y)} > \frac{V^C(X,Y)-V^B(X)-(1+\psi)V^T(Y)}{(1+\psi)V^T(Y)} \tag{2.19}$$

$$\frac{\left[V^C(X^*,Y^*)-V^B(X^*)\right]D}{\left[(1+\psi)(1-\omega)V^T(Y^*)\right]D+\omega\zeta V^T(Y)}-1 > \frac{V^C(X,Y)-V^B(X)}{(1+\psi)V^T(Y)}-1$$

$$\frac{\left[V^C(X^*,Y^*)-V^B(X^*)\right]D}{V^C(X,Y)-V^B(X)} > \frac{\left[(1+\psi)V^T(Y^*)\right]D}{(1+\psi)V^T(Y)}-\frac{\omega\left[(1+\psi)V^T(Y^*)D-\zeta V^T(Y)\right]}{(1+\psi)V^T(Y)} \tag{2.20}$$

$$\frac{\left[V^C(R^*)-V^B(R^*)\right]}{V^C(R)-V^B(R)} > 1+\omega\left[\frac{\zeta Y}{(1+\psi)Y^*D}-1\right] \tag{2.21}$$

From (2.20) we observe that in general, the toehold strategy is preferred over the direct acquisition when the stochastically discounted gross payoff at the moment of exercise relative to the direct gross payoff is large; particularly larger than the ratio of the discounted future takeover price over the direct acquisition price, minus the relative gain of having acquired the toehold at price ζ instead of at $1+\psi$.

Rewriting the inequality into (2.21) gives us more insights in which factors drive the preference for the toehold strategy. A large relative difference of $(1+\psi)$ over ζ makes the toehold strategy more attractive. Even when the target value at exercise through Y^* is (a bit) smaller than the current value Y_t, the toehold strategy can be worthwhile if $(1+\psi)$ is large relative to ζ (often ζ will be close to 1). Furthermore, with larger toeholdsizes ω, the toehold strategy also requires a larger gain of waiting in order to be attractive, which is expressed through the ratio of gross payoff obtained at R^* over the gross payoff at current level R_t. Finally, the stochastic discount factor D plays an important role. This factor D also represents the likelihood of exercising the option. Hence, a very low D will make the toehold option less valuable and unattractive[16].

Overconfidence in the Toehold Model

In many settings, it can be the case that the CEO perceives the value of the direct acquisition higher than of the toehold strategy, while the opposite holds. Roll (1986) in his seminal work on '*hubris*' cites optimistic estimates of "economies due to synergy and (any) assessments of weak management" as the primary causes of managerial hubris (Kahneman & Lovallo, 1993). If the CEO is overconfident, such that (s)he believes that under his/her guidance the takeover will be a great success and the acquiring company will contribute significantly to the synergies (i.e. the CEO structurally overestimates the synergy factor

[16]Note that when $\sigma_R \longrightarrow 0$ it follows that $D \longrightarrow 0$, that is, under absence of volatility (uncertainty), the real option has no value, which is a well known and intuitive result from general real option theory.

$\hat{\alpha} > \alpha$), we can derive that the CEO's judgement of the value of the toehold strategy relative to the direct acquisition will be affected in such a way that (s)he will be more likely to prefer the direct acquisition.

First, we list the derivatives of some toehold option components with respect to the synergy factor α (these can be obtained through logarithmic and implicit derivation):

$$\frac{\partial \beta}{\partial \alpha} = \frac{q\beta \frac{dq}{d\alpha}}{\sigma_R^2(\beta - 1/2) + \mu_R} \tag{2.22}$$

$$\frac{\partial R^*}{\partial \alpha} = R^* \left\{ \frac{\partial \beta}{\partial \alpha} \left[\frac{-1}{\beta(\beta - 1)} \right] - \frac{1}{\alpha} \left[\frac{1}{H} + 1 \right] \right\} \tag{2.23}$$

$$\frac{\partial D}{\partial \alpha} = D \left\{ \frac{\partial \beta}{\partial \alpha} \left[\ln R - \ln R^* + \frac{1}{\beta - 1} \right] + \frac{\beta}{\alpha} \left[\frac{1}{H} + 1 \right] \right\} \tag{2.24}$$

$$\frac{\partial O}{\partial \alpha} = O \left\{ \frac{\partial \beta}{\partial \alpha} \left[\ln R - \ln R^* \right] \right\} + (1 + R^*)(K + Q)D \tag{2.25}$$

Here again $H = \frac{\beta-1}{\beta} R^*$. We infer that the derivative of β with respect to α is likely to be positive. Furthermore, we observe that the threshold R^* decreases in α and that it decreases even harder when there are costs considered of holding the option: $q \neq 0$ and $\partial\beta/\partial\alpha > 0$. This is intuitive as large perceived synergies reflect high dividends in the option framework, giving the option holder even more incentive (compared to the case of $q = 0$) to exercise the option earlier. The derivative of the stochastic discount factor D with respect to α is most likely positive, the effect of decreasing R^* is dominant over increasing β. Finally, for the option value O in total, we can infer that it decreases in α in case of large R^* (lower option values) and increases when R^* is small (larger option values).

These findings show us that in case of feasible R^*, the stochastic discount factor D

increases in the synergy factor α, which contributes to making the toehold strategy more attractive according to (2.21). However, this increase is not unlimited as the threshold R^* decreases in α and as soon R^* becomes smaller than R or becomes negative, the option does not exist anymore. Hence, a small increase in α may increase the likelihood of a toehold strategy, however an irrational overestimation of α causes the option value to not exist.

Moreover, there may be more channels through which overconfidence is expressed. Hackbarth (2009) names underestimation of volatility (miscalibration) as characteristic of overconfidence[17] (although one can argue that volatility should be continuously observable, at least for the own firm). For the volatility parameters, we have that the derivative of β with respect to σ_Y is negative (see Appendix B). Hence, underestimating volatilities lead to a decrease of R^*, thereby increasing the likelihood of preferring the direct acquisition over the toehold strategy. For these factors it also holds that they work through in a similar way as α in the derivative of D:

$$\frac{\partial D}{\partial \sigma_A} = D\left\{\frac{\partial \beta}{\partial \sigma_A}\left[\ln R - \ln R^* + \frac{1}{\beta - 1}\right]\right\} \qquad A = X, Y. \tag{2.26}$$

Hence, (ceteris paribus) a moderate lower volatility may increase the likelihood of a toehold strategy, whereas severe miscalibration decreases the likelihood.

This all shows us that confidence is not a 'superfactor' which always leads to misjudgement and an immediate switch in strategies. After all, it would not be realistic to state that a small change in parameters always automatically leads to choosing the direct acquisition over the toehold. However, overconfidence is irrational behaviour; we show that overcon-

[17] Overestimation of the growth factor is viewed as characteristic of over-optimism rather than overconfidence (Hackbarth, 2009).

fidence does affect judgement, and that this can lead to alteration of strategy[18].

Our findings are in line with studies that state that a moderate level of CEO confidence can be beneficial for the firm, but overconfidence is not. Campbell et al. (2011) for instance, state that there is an interior optimum level of managerial optimism that maximizes firm value, but that overconfident CEOs do not maximize firm value. Overconfidence, which is expressed through one or a combination of the above channels, relates to irrational over- or under-estimation of parameters, which decreases the likelihood of choosing the toehold strategy. Moreover, overconfidence through multiple channels has an even stronger negative effect on this likelihood. We summarize our insights in the following proposition:

Proposition 1. *When choosing between a toehold strategy and a majority acquisition, an overconfident CEO of an acquiring firm is more likely to prefer the direct control acquisition over the toehold strategy.*

The model shows that a biased perception of the synergies (possibly in combination with other channels of overconfidence) affects choice-making between acquisition strategies. With this model, we do not postulate that toehold strategies are always better than direct control acquisitions. Which strategy is better, depends on the situation and multiple variables. However, we have showed that CEO overconfidence affects this judgement, and does so in favour of direct control acquisitions.

We have modelled the toehold strategy versus the direct acquisition in a stylized setting in order to investigate the effect of overconfidence on the preference between both strate-

[18]For example, with $R_t = 3.3$ the rational threshold can be $R = 4$. A moderate confident CEO may estimate $R^* = 3.5$ and prefer the toehold strategy, whereas an overconfident CEO may estimate $R^* = 3$, such that $R^* < R$ and the toehold option does not exist such that the direct control acquisition is preferred.

gies. Of course, multiple other factors are of importance in the context of an acquisition such as takeover defenses, managerial resistance, private benefits which all contribute to the probability of success of a takeover (Tirole, 2010). We considered a setting where an acquisition (either friendly or hostile) is certainly possible, and how overconfidence then affects the decision between acquisition strategies.

2.2 Empirical Investigation: Overconfidence and Toeholds

We now investigate whether there indeed is a significant relation between CEO overconfidence and the acquisition type. We have merely modelled the choice between acquisition strategies, not whether and when acquisitions should be conducted[19]. To that extent, we formulate the following empirically testable hypothesis, which follows from the proposition of our theoretic model.

Hypothesis 1. *Given an acquisition, the type of acquisition is less likely to be a minority stake relative to a direct control acquisition when the CEO of the acquiring firm is overconfident.*

We use several measures for overconfidence which are based on CEO personal portfolio behaviour, external perception, and self-importance. Especially measures based on personal portfolio behaviour enable us to compare overconfidence, where managers are unaware of sub-optimal acquisition decisions, to views that build on empire building and agency considerations. Agency considerations including empire-building motives are not likely to lead to sub-optimal execution behaviour in personal portfolios, and these predictions are thus different than those of overconfidence.

[19] See for instance Lambrecht (2004); Morellec & Zhdanov (2005) on the timing of acquisitions.

2.2.1 Data Collection

Starting point of the data collection process consisted of selecting all companies and their acquisitions that were part of the S&P Composite 1500 index for at least three years during the range of 2004-2013. After exclusion of companies due to missing figures for insider transactions and lack of information on important control characteristics, the resulting total number of companies in the data sample is 1197. The acquisitions by these firms and executives were collected from the ThomsonONE M&A database. This led to a total of 9430 announced acquisitions. These were identified as either majority or minority acquisitions, depending on the fraction acquired. Next, we identified those minority stake acquisitions that had a follow-up acquisition later on to gain a controlling stake. From these minority stakes (25%) we know for sure that they had the purpose to be a toehold. The remaining minority stakes are considered potential toeholds. Deal value information was included, but only available for a limited number of acquisitions (44%).

For every sample year, each company's CEO was selected with the use of the Execucomp Database, as was also the information on the number of directors. If information on the number of directors in a firm-year was absent, the number is assumed to be the average of all sample firm-years. For companies and years with missing data, the CEO names are hand-collected. Information on the options awarded to the executives of all companies was gathered from the Thomson Reuters Insider Filing Table 2 database. This includes information on the exercise price and the expiry date. Only options[20] were considered, leaving out the granting of ordinary shares, or the issue of restricted stocks. Observations with no information on the type of derivative were removed. Observations with no infor-

[20]Only type 4 forms were included and the following derivative types: OPTNS, ISO, CALL, NONQ, DIRO, DIREO, EMPO and SAR.

mation on the exercise price or expiration date were removed. Furthermore, from the Execucomp database we obtained information on the value and number of the options that are simultaneously in the money and unvested, but not exercised. Company financials which are used to construct control variables are collected from the Compustat database (elaboration on control variables follows in section 2.2.3).

Figure 2.1 shows the distribution of the acquisitions types in our sample over the years. The number of majority stake deals shows a drop after 2008, most probably due to the financial crisis, whereas the number of minority stake deals increases relatively in this period. The fraction of toeholds used is relatively low, around the 4-7%, with an average toehold size around 20%. We can verify of around 25% of these minority stakes that they have been used as toehold. The remaining minority stakes have not been exercised yet[21].

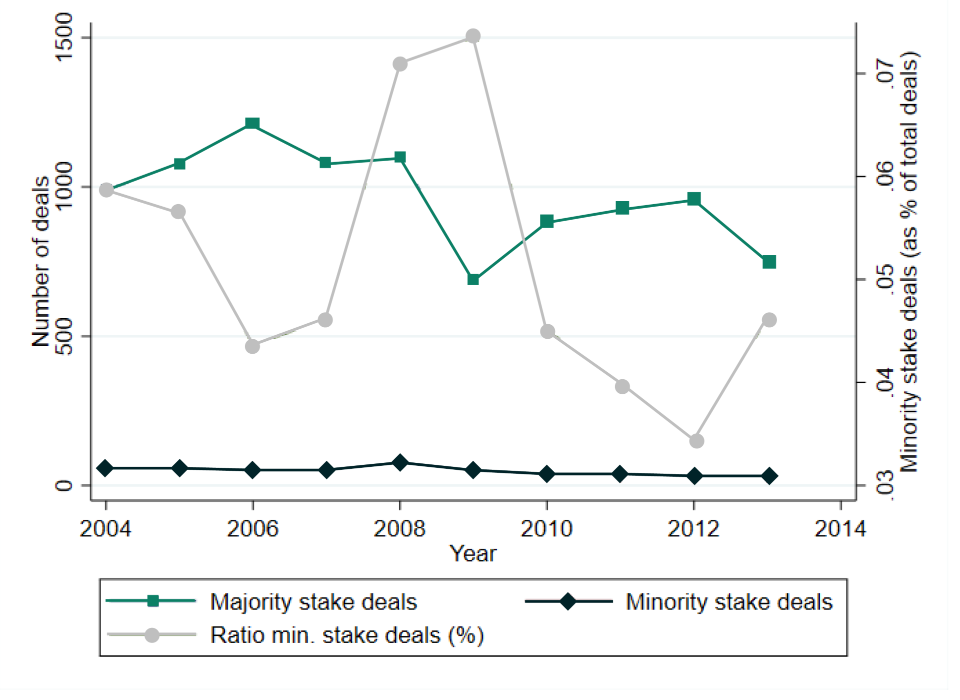
2.2.2 Measuring Overconfidence

As a behavioral bias, overconfidence is not easily observable[22]. However, previous research has successfully found indirect ways to measure executive overconfidence. In this study, we use measures based on option exercise behavior of executives (Malmendier & Tate, 2005a, 2008). Starting point is the level of exposure to risk that executives bear, while this could be mitigated. Idiosyncratic risk exposure offers an excellent insight into this risk equation. Normally, CEOs are under-diversified because of their human capital investments in the

[21] Not every minority stake acquisition of course has to be intended as part of a toehold strategy. Some minority stakes are held because of other strategic considerations. However, a minority stake at least offers the *option* to acquire a controlling stake later.

[22] Overconfidence has, in a methodological context (Kahneman & Tversky, 1982), been linked to excess entry into competitive markets (Camerer & Lovallo, 1999), increased trading activity (Deaves et al., 2008), and a source of distinction between entrepreneurial and managerial roles within organizations (Busenitz & Barney, 1997). Among other methodology, questionnaires targeted on executives are often used to measure overconfidence.

Figure 2.1: Acquisition types over time
This figure shows the distribution of acquisition types over the years in our sample period. Majority stake deals are defined as acquisitions where the acquired stake size is 50% or more (starting from no stake). A minority stake deal is defined as an acquisition where the acquired stake is less than 50% (while the total stake size owned is also less than 50%). The ratio of minority stake deals is expressed in percentages and is defined as the number of minority stake acquisitions in a year divided by the total number of acquisitions in the same year.



company they work for, as well as their often large holdings of company stock. If they are rational and not risk seeking, they will want to diversify this risk by selling these holdings. However, if they are overconfident, they expect future returns on their companies to be high, specifically higher than rationally can be accounted for. As a consequence, they will want to keep their company stock, because they believe that under their guidance, the company will flourish, and its stock price will continue to rise and outperform. Keeping their risks centred on their company's performance therefore reveals overconfidence, at least on average. To ensure robustness and reliability, we employ two different measures of overconfidence, based on personal option behaviour: *Longholder* and *Holder67*.

The *Longholder* CEO holds his/her options although they are in the money. An average option package granted to an executive has a duration of 10 years, with a maximum vesting period of 5 years. According to this measure, a CEO is overconfident, if the CEO keeps the options until the final year while being at least 40% in the money. This means the CEO has held on to the options long after the vesting period has ended. This portrays the neglect of the executive to diversify the holdings, even though the CEO is now able to. The *Longholder* variable is constructed using the option packages data described in section 2.2.1. The *Longholder* variable is a dummy with a value of 1, if an option is at least 40% in the money and kept until the last year until expiration. A CEO is classified as *Longholder* in every year in the sample if the right criteria are met at any point in time.

The *Holder67* variable considers the value of options that are kept by the CEO, while both in the money and with an expired vesting period. The *Holder67* variable looks at a different aspect of ownership consistence. Whereas the *Longholder* variable is, in its essence, focused on a time-oriented bias effect, the *Holder67* loosens that restriction. The *Holder67* is also a dummy and also uses the moneyness of the options held, but does not require that the options are hold until expiration. Instead, the *Holder67* variable considers all options that are no longer within their vesting period (and thus can be exercised). The threshold of the extent to which they are in the money is however, considerably higher. Following Malmendier & Tate (2005a), the threshold is set at 67%[23]. The calculations are similar to the approach adopted for the *Longholder* variable. The *Holder67* dummy is set at 1 when an executive has met this moneyness criterion for unvested options at least twice

[23] This percentage corresponds to a risk-aversion of three in a constant relative risk-aversion specification. The option moneyness thresholds (67% and 40%) are calculated using the Hall & Murphy (2002) framework for optimal option exercise prices given various measures of risk-aversion and portfolio diversification.

in the sample date range[24]. This is supposed to eliminate accidental or coincidental observations, focusing primarily on a consistent effect of a more habitual nature. In contrast with the *Longholder* variable, a CEO is *Holder67*-overconfident in every year since the first time (s)he is classified as *Holder67*.

To examine the robustness of the relationship between CEO overconfidence and a lower likelihood of executing a toehold strategy, we also employ alternative measures of overconfidence. One alternative measure uses *external perception* as a proxy for actual overconfidence. By selecting newspaper articles and searching for the combination of the CEO name and certain keywords[25], CEOs are labelled overconfident if they are portrayed more often as overconfident than cautious in the business press. Malmendier & Tate (2008); Malmendier et al. (2011) use this approach to confirm the relation between overconfidence and acquisition behavior and early-life experiences, respectively. Furthermore, Hayward & Hambrick (1997) employ a measure of *self-importance* as an indicator of hubris to explain large take-over premiums. This *self-importance* measure is calculated as the salary of the CEO relative to the average pay of other executive officers.

We analyze the impact of CEO overconfidence on the likelihood of the occurrence and returns of toeholds in a general setting that allows for market inefficiencies, such as information asymmetry, and managerial frictions, such as agency costs and private benefits. Similar to Malmendier & Tate (2008), we assume that these frictions and the quality of merger opportunities do not vary systematically between overconfident and rational CEOs, i.e., that overconfident and rational CEOs sort randomly across firms over time and we account for violations of this assumption using firm and level controls.

[24] This approach neglects the vesting period as a barrier. We also considered the *Holder67* in an alternative form, where a CEO is labelled overconfident already after the first time the 67% threshold is crossed. No significant results were found.

[25] Examples are 'confident' or 'optimistic' (positive) and 'conservative' or 'frugal' (negative).

Moreover, we do not consider it likely that companies intentionally hire overconfident CEOs for their acquisition policy specifically, as one characteristic that is inseparably connected to overconfident CEOs is that their acquisition actions actually destroy shareholder value (Malmendier & Tate, 2008). In Table 2.4 we show that companies which consistently appoint overconfident CEO do not differ on average from other companies. Furthermore, from the 1193 firms, total, 327 firms switch once or more from CEO during our sample period. Only 8-12% of these switching firms choose an overconfident CEO consistently.

2.2.3 Control Variables

We now discuss the control variables that are used in this study. Board size can have a material impact on acquisition behavior, as too small (or too large) board sizes may lead to inefficient decision-making processes. The *CG* (corporate governance) variable is a dummy variable that is equal to 1 when the number of board members is between 4 and 12 (efficient board size according to Malmendier & Tate (2005a)). The amount to which the CEO already owns shares in the company under his/her supervision could be a source of distorted behavior as well (Malmendier & Tate, 2005b, 2008; Brown & Sarma, 2007). Variable *Owner* is a ratio defined as the CEO's shareholdings divided by the number of outstanding company shares. Variable *Size* controls for the acquirer's size and is obtained by taking the natural logarithm of the book value of the assets at year-end. *Tobin's Q* approximates the investment opportunities of the acquirer. Tobin's Q is measured as the ratio of the market value of assets and book value of assets. *The market value of assets* is measured by adding the market value of equity to the book value of total liabilities and the value of preferred shares, subsequently subtracting the value of convertible debt and deferred tax assets. The market value of equity is calculated by multiplying the price at the end of the fiscal period with the number of outstanding shares at the end of the fiscal period.

The variable *Cash Flow* is constructed by adding depreciation and amortization to the earnings before extraordinary items and is normalized by the book value of assets at the end of the previous year. The *Investments* variable is constructed by normalizing the capital expenditures by the book value of assets at the end of the previous year. The control variable *Cash* indicates the amount of cash and equivalents relative to the book value of assets. It serves as an indicator of the available internal resources. Control variable *Leverage* denotes the acquirer's leverage and is obtained by taking the outstanding debt as a fraction of the market value of equity, the latter being calculated as the product of the market price at year-end and the total number of shares outstanding. The variable *Value/MVA* controls for the value of the acquisition and is scaled by the market value of assets (MVA), to mitigate the impact of size distortions. In that context, the variable *Value/stake* looks at deal value scaled by the fraction of the target that was acquired.

Billett & Qian (2008) found lower returns for frequent acquirers, making it worthwhile to regard the impact of 'heavy' acquirers; this is done by control variable *Prev.acq.all* that looks at the total number of conducted acquisitions in the last three years. Furthermore, we use a control variable related to the learning effect[26] *Prev.acq.min*, which is similar to *Prev.acq.all*, however, now denotes the number of previous minority acquisitions. A geographical effect is controlled for by including a dummy for *Cross-Country* acquisi-

[26] Dai et al. (2019) show that toeholds are most likely to be utilized in difficult takeovers, those that offer low expected acquirer returns in the first place. If one corrects for the difficult context, toeholds provide a higher return on announcement, which even increases over time. This improvement can be attributed, to a certain extent, to learning. More specifically, acquirers in corporate takeovers 'learn-by-doing'; this learning works when the acquisition experience is toehold specific.

tions, while a sector-specific effect is controlled for by the dummy variable *Cross-Sector*, based on 2-digit SIC codes.

Tables 2.1, 2.2, 2.3, 2.4 show the characteristics of the acquiring firms at different levels, also split out over overconfident and non-overconfident CEOs. Overconfident CEOs manage companies that are not particularly different in characteristics. As industry leaders are believed to engage into many acquisitions, a small number of overconfident CEOs in those places could alter the data spread significantly. Since both median and mean of the company size are in a close range when the two groups are compared, this effect does not dominate these results.

2.2.4 Methodology

We examine whether overconfidence, primarily measured by one of the overconfidence measures {*Longholder, Holder67*}, is associated with a lower likelihood of acquiring a minority stake. This likelihood is denoted trough the dependent binary variable $Minority_i$, which takes the value 1 if a minority stake was taken in deal i and 0 in case of a majority stake. A minority stake is defined as a sought stake size of smaller than 50%, while the total acquired fraction of the target firm is also less than 50%. This results in the following regression equation, with $measure_i$ denoting one of the overconfidence measures {*Longholder, Holder67*} for all acquisitions i.

$$Minority_i = \beta_0 + \beta_1 \times measure_i + \varepsilon_i \tag{2.27}$$

Table 2.1: Summary statistics by CEO-firm-year

This table shows company summary statistics at CEO-firm-year level. The *CG* (corporate governance) variable is a dummy variable equal to 1, when the number of board members is between 4 and 12. *Owner* is a ratio defined as the CEO's shareholdings divided by the number of outstanding company shares. *Size* is calculated by taking the natural logarithm of the book value of the assets at year-end. *Tobin's Q* is measured as the ratio of the market value of assets and book value of assets. The variable *Cash Flow* is constructed by adding depreciation and amortization to the earnings before extraordinary items and is normalized by the book value of assets at the end of the previous year. The *Investments* variable is constructed by normalizing the capital expenditures by the book value of assets at the end of the previous year. The control variable *Cash* indicates the amount of cash and equivalents relative to the book value of assets. The variable *Leverage* is obtained by taking the outstanding debt as a fraction of the market value of equity. *Longholder* and *Holder67* are dummy variables and different measures for CEO overconfidence, taking the value of 1 when the CEO is classified as overconfident. SD denotes standard deviation.

Panel A: Full Sample

	Full Sample $N = 4649$		
Variables	Mean	Median	SD
Size ($M)	8.146	7.937	1.722
Tobin's Q	1.846	1.521	1.148
Cash flow ($M)	0.067	0.064	0.093
Investments ($M)	0.048	0.030	0.077
Cash ($M)	0.161	0.098	0.180
Leverage	0.133	0.098	0.138
CG	0.958	1.000	0.201
Owner	0.015	0.002	0.045

Panel B: sub-samples

	sub-sample: *Longholder* = 1 $N = 1240$			sub-sample: *Holder67* = 1 $N = 1818$		
Variables	Mean	Median	SD	Mean	Median	SD
Size ($M)	8.115	7.865	1.701	8.066	7.865	1.674
Tobin's Q	1.978	1.654	1.198	1.917	1.596	1.025
Cash flow ($M)	0.081	0.074	0.091	0.077	0.072	0.074
Investments ($M)	0.054	0.029	0.107	0.051	0.033	0.067
Cash ($M)	0.162	0.099	0.183	0.161	0.103	0.168
Leverage	0.123	0.089	0.131	0.123	0.090	0.132
CG	0.951	1.000	0.216	0.967	1.000	0.179
Owner	0.020	0.003	0.060	0.017	0.004	0.050

Table 2.2: Summary statistics by deal

This table shows summary statistics at deal level. *Minority* denotes a minority stake acquisition and is a dummy variable which takes the value 1 if a minority stake was taken in a deal and 0 in case of a majority stake. A minority stake is defined as a sought stake-size of smaller than 50%, while the total acquired fraction of the target firm is also less than 50%. *Cross-Country* is a dummy variable which takes the value of 1 if the target firm is from another country than the acquiring firm. *Cross-Industry* is a dummy variable which takes the value of 1 if the target firm is from another industry (based on 2-digit SIC codes) than the acquiring firm. *Value/MVA* and *Value/Stake* are the deal value as reported by ThomsonOne normalized by the Market Value of Assets (MVA) and the stake size (Stake) respectively. In Panel B and C the full sample is split by one of the overconfidence measures *Longholder* and *Holder67*, which are both dummy variables taking the value of 1 if a CEO is classified as overconfident. The difference in the means of the displayed variables is tested with a t-test. *Diff(0-1)* denotes the difference in means of the variables where the dummy is equal to 0 minus where the dummy is equal to 1. The p-values of the t-test are reported in the last columns of Panel B and C.

Panel A: Full Sample

	Full Sample			
Variables	*N*	Mean	Median	SD
Minority	9,694	0.051	0.000	0.221
Cross-Industry	9,694	0.462	0.000	0.499
Cross-Country	9,694	0.284	0.000	0.451
Value/MVA	4,308	0.060	0.016	0.290
Value/Stake	4,308	8.246	1.200	38.039

Panel B: Split by *Longholder*

	Longholder = 1				*Longholder* = 0		t-test	
Variables	*N*	Mean	Median	SD	*N*	Mean	Diff(0-1)	p-value
Minority	2,598	0.038	0.000	0.191	7096	0.056	0.018	0.000
Cross-Industry	2,598	0.438	0.000	0.496	7096	0.47	0.032	0.005
Cross-Country	2,598	0.273	0.000	0.445	7096	0.288	0.015	0.141
Value/MVA	1,157	0.052	0.017	0.114	3151	0.064	0.012	0.079
Value/Stake	1,157	9.580	1.125	47.350	3153	7.756	-1.824	0.230

Panel C: Split by *Holder67*

	Holder67 = 1				*Holder67* = 0		t-test	
Variables	*N*	Mean	Median	SD	*N*	Mean	Diff(0-1)	p-value
Minority	3,727	0.036	0.000	0.186	5967	0.061	0.025	0.000
Cross-Industry	3,727	0.469	0.000	0.499	5967	0.457	-0.012	0.239
Cross-Country	3,727	0.284	0.000	0.451	5967	0.283	-0.001	0.959
Value/MVA	1,704	0.050	0.016	0.108	2604	0.067	0.017	0.031
Value/Stake	1,704	6.408	1.120	22.920	2604	9.448	3.040	0.004

Table 2.3: Summary statistics by CEO

This table shows summary statistics at CEO level at the end of the sample period. *Prev.acq.All* is the total number of acquisitions a CEO engaged into, in the last three years. *Prev.acq.min*, is similar to Prev.acq.all, however now denotes the number of previous minority acquisitions. In Panel B and C the full sample is split by one of the overconfidence measures *Longholder* and *Holder67*, which are both dummy variables taking the value of 1 if a CEO is classified as overconfident. The difference in the means of the displayed variables is tested with a t-test. *Diff(0-1)* denotes the difference in means of the variables where the dummy is equal to 0 minus where the dummy is equal to 1. The p-values of the t-test are reported in the last columns of Panel B and C.

Panel A: Full Sample				
	Full Sample			
Variables	N	Mean	Median	SD
Prev. acq. All	1,633	3.224	2.000	4.642
Prev. acq. Minority	1,633	0.152	0.000	0.678

Panel B: Split by *Longholder*								
	Longholder = 1				*Longholder* = 0		t-test	
Variables	N	Mean	Median	SD	N	Mean	Diff(0-1)	p-value
Prev. acq. All	402	3.448	2.000	4.166	1,231	3.151	-0.2969	0.233
Prev. acq. Minority	402	0.107	0.000	0.485	1,231	0.167	0.0603	0.059

Panel C: Split by *Holder67*								
	Holder67 = 1				*Holder67* = 0		t-test	
Variables	N	Mean	Median	SD	N	Mean	Diff(0-1)	p-value
Prev. acq. All	640	3.208	2.000	4.161	993	3.2346	0.0266	0.906
Prev. acq. Minority	640	0.100	0.000	0.607	993	0.1863	0.0863	0.009

Table 2.4: Summary statistics by company

This table shows summary statistics at company level of company variables which are first averaged per company over our sample period 2004 - 2013. The *CG* (corporate governance) variable is a dummy variable equal to 1, when the number of board members is between 4 and 12. *Owner* is a ratio defined as the CEO's shareholdings divided by the number of outstanding company shares. *Size* is calculated by taking the natural logarithm of the book value of the assets at year-end. *Tobin's Q* is measured as the ratio of the market value of assets and book value of assets. The variable *Cash Flow* is constructed by adding depreciation and amortization to the earnings before extraordinary items and is normalized by the book value of assets at the end of the previous year. The *Investments* variable is constructed by normalizing the capital expenditures by the book value of assets at the end of the previous year. The control variable *Cash* indicates the amount of cash and equivalents relative to the book value of assets. The variable *Leverage* is obtained by taking the outstanding debt as a fraction of the market value of equity. *Longholder* and *Holder67* are dummy variables and different measures for CEO overconfidence, taking the value of 1 when the CEO is classified as overconfident. Furthermore for every company is determined whether it *Always* had an overconfident CEO (i.e. if the company switches from CEO in the sample period, it consistently appoints an overconfident CEO again); *Ever* had an overconfident CEO (i.e. the company switches randomly from overconfident to non-overconfident or vice versa during the sample period); or *Never* had an overconfident CEO (the company switches consistently to non-overconfident CEOs). Then the full sample is split in these subgroups (according to both overconfidence measures) and the means of the company variables are tested against each other. The p-values and means of subgroups are reported. Panel C displays the number of companies which switch from CEO in our sample period. For this number of companies it is determined whether they consistently appoint overconfident or non-onverconfident CEOs or pick between CEO types randomly.

Panel A: Comparisons by splits - *Longholder*

	Ever/Never versus Always Total number of firms = 1217			Ever/Always versus Never Total number of firms = 1217			Never versus Always Total number of firms = 1088		
Variables	Ever/Never mean	Always mean	*p*-value	Ever/Always mean	Never mean	*p*-value	Never mean	Always mean	*p*-value
Size ($M)	7.882	7.868	0.908	8.006	7.824	0.078	7.824	7.868	0.714
Tobin's Q	1.785	1.791	0.939	1.840	1.763	0.190	1.763	1.791	0.691
Cash flow ($M)	0.063	0.071	0.133	0.073	0.061	0.010	0.061	0.071	0.063
Investments ($M)	0.053	0.061	0.251	0.059	0.053	0.268	0.053	0.061	0.207
Cash ($M)	0.166	0.150	0.147	0.158	0.165	0.474	0.165	0.150	0.183
Leverage	0.139	0.131	0.402	0.130	0.140	0.187	0.140	0.131	0.317
CG	0.957	0.958	0.934	0.958	0.956	0.854	0.956	0.958	0.911
Owner	0.014	0.024	0.022	0.019	0.015	0.234	0.015	0.024	0.037
N	975	242		370	847		847	242	

Panel B: Comparisons by splits - *Holder67*

	Ever/Never versus Always Total number of firms = 1217			Ever/Always versus Never Total number of firms = 1217			Never versus Always Total number of firms = 1088		
Variables	Ever/Never mean	Always mean	*p*-value	Ever/Always mean	Never mean	*p*-value	Never mean	Always mean	*p*-value
Size ($M)	7.919	7.771	0.160	7.881	7.878	0.977	7.878	7.771	0.319
Tobin's Q	1.783	1.796	0.832	1.829	1.761	0.209	1.761	1.796	0.564
Cash flow ($M)	0.062	0.072	0.029	0.072	0.060	0.008	0.060	0.072	0.015
Investments ($M)	0.053	0.059	0.295	0.055	0.055	0.918	0.055	0.059	0.443
Cash ($M)	0.165	0.159	0.609	0.163	0.163	0.939	0.163	0.159	0.697
Leverage	0.141	0.128	0.137	0.124	0.145	0.006	0.145	0.128	0.052
CG	0.952	0.971	0.081	0.966	0.952	0.164	0.952	0.971	0.089
Owner	0.016	0.018	0.413	0.015	0.017	0.334	0.017	0.018	0.801
N	890	327		458	759		759	327	

Panel C: Companies which switch from CEO in sample

Longholder			*Holder67*		
Always non-overconfident	216	58%	Always non-overconfident	195	52%
Always overconfident	28	8%	Always overconfident	46	12%
Random	128	34%	Random	131	35%
Total switching companies	327	100%	Total switching companies	327	100%

This equation can be extended naturally by the inclusion of control variables, along with additional variables related to the acquisition value (deal variables) and fixed effects[27]. Including deal value variables leads unfortunately to a loss of almost half of the observations due to missing data.

2.2.5 Results

Table 2.5 provides an overview of the regression results conducted on the full sample for testing the first hypothesis. We observe that both measures of overconfidence have a significant negative effect on the likelihood of a minority stake acquisition. Furthermore, we observe that the *cross-country* variable has a significant and relatively large positive coefficient. This is a confirmation of the value of minority stakes when diversifying geographically (often more difficult acquisitions), which comes with increased levels of uncertainty. The 'experience' variables *Prev.acq.all* and *Prev.acq.min* show both strong significant effects. The number of all previous acquisitions shows a negative coefficient across all regressions, which indicates that a large number of conducted acquisitions in general decreases the likelihood of a minority stake acquisition, that is, if a CEO has done a lot of previous acquisitions, it is less likely for him to appeal to a toehold acquisition (either due to experience or to irrational stubbornness). However, the number of previous minority acquisitions displays a positive coefficient, pointing out a possible learning effect: If a CEO has done multiple minority stake acquisitions in the past, (s)he is more likely to do so again

[27] The industries for industry fixed effects are defined by following the classification of Malmendier & Tate (2008): Technical industry - primary SIC codes 1000-1799, 8711; Financial industry - primary SIC codes 6000-6799; Manufacturing industry - primary SIC codes 2000-3999; Transportation industry - primary SIC codes 4000-4999; Trade industry - primary SIC codes 5000-5999; and Service industry primary SIC codes 7000-8710, 8712-8720, 8722-8999.

Table 2.5: Overconfidence and the likelihood of a toehold strategy

This table displays the regression results of the dependent variable *Minority*, which is a dummy variable that takes the value of 1 if a minority stake was taken in a deal and 0 in case of a majority stake. A minority stake is defined as a sought stake-size of smaller than 50%, while the total acquired fraction of the target firm is also less than 50%. The *CG* (corporate governance) variable is a dummy variable equal to 1, when the number of board members is between 4 and 12. *Owner* is a ratio defined as the CEO's shareholdings divided by the number of outstanding company shares. *Size* is calculated by taking the natural logarithm of the book value of the assets at year-end. *Tobin's Q* is measured as the ratio of the market value of assets and book value of assets. The variable *Cash Flow* is constructed by adding depreciation and amortization to the earnings before extraordinary items and is normalized by the book value of assets at the end of the previous year. The *Investments* variable is constructed by normalizing the capital expenditures by the book value of assets at the end of the previous year. The control variable *Cash* indicates the amount of cash and equivalents relative to the book value of assets. The variable *Leverage* is obtained by taking the outstanding debt as a fraction of the market value of equity. *Cross-Country* is a dummy variable which takes the value of 1 if the target firm is from another country than the acquiring firm. *Cross-Industry* is a dummy variable which takes the value of 1 if the target firm is from another industry (based on 2-digit SIC codes) than the acquiring firm. *Value/MVA* and *Value/Stake* are the deal value as reported by ThomsonOne normalized by the Market Value of Assets (MVA) and the stake size (Stake) respectively. *Prev.acq.All* is the total number of acquisitions a CEO engaged into, in the last three years. *Prev.acq.min*, is similar to Prev.acq.all, however now denotes the number of previous minority acquisitions. Overconfidence is measured by *Longholder* and *Holder67*, which are both dummy variables taking the value of 1 if a CEO is classified as overconfident. Furthermore year, industry (acquirer) and year times industry fixed effects are included. Standard errors are clustered at CEO level, *t*-statistics are displayed in parentheses.

	Holder67 Overconfidence		*Longholder Overconfidence*	
Dep. Var.: Minority	(1)	(2)	(3)	(4)
Variables	Controls FE	Dealvars FE	Controls FE	Dealvars FE
Holder67	**-0.012*****	-0.009		
	(-2.733)	(-1.349)		
Longholder			**-0.009***	**-0.016****
			(-1.737)	(-2.159)
Size	0.005**	0.005	0.004**	0.005
	(2.388)	(1.573)	(2.280)	(1.503)
Tobin's Q	0.006**	0.009**	0.007**	0.009**
	(2.375)	(2.136)	(2.412)	(2.176)
Cash Flow	0.100*	-0.046	0.098*	-0.045
	(1.918)	(-0.895)	(1.877)	(-0.883)
Investments	0.157*	0.129	0.153*	0.126
	(1.866)	(1.358)	(1.820)	(1.336)
Cash	0.058**	0.106***	0.058**	0.105***
	(2.450)	(3.481)	(2.461)	(3.427)
Leverage	0.136***	0.172***	0.137***	0.175***
	(4.578)	(3.857)	(4.587)	(3.951)
Corporate Governance	-0.034	-0.035	-0.036*	-0.038
	(-1.597)	(-0.950)	(-1.696)	(-1.028)
Owner	0.019	0.173*	0.021	0.184*
	(0.467)	(1.767)	(0.517)	(1.811)
Prev. acq. All	-0.002***	-0.002***	-0.002***	-0.002***
	(-6.959)	(-3.215)	(-6.733)	(-3.168)
Prev. acq. Minority	0.047***	0.055***	0.046***	0.054***
	(7.590)	(5.471)	(7.347)	(5.391)

Continued on next page

Table 2.5 – *Continued from previous page*

	Holder67 Overconfidence		*Longholder Overconfidence*	
Dep. Var.: Minority	(1)	(2)	(3)	(4)
Variables	Controls FE	Dealvars FE	Controls FE	Dealvars FE
Cross-Industry	0.004	0.010	0.004	0.010
	(0.890)	(1.304)	(0.823)	(1.329)
Cross-Country	0.067***	0.077***	0.068***	0.077***
	(8.413)	(6.641)	(8.403)	(6.666)
Value/MVA		-0.142***		-0.144***
		(-5.542)		(-5.533)
Value/Stake		0.001***		0.001***
		(3.571)		(3.635)
Constant	-0.032	-0.036	-0.031	-0.032
	(-1.124)	(-0.793)	(-1.083)	(-0.695)
Observations	9,365	4,099	9,365	4,099
Adjusted R-squared	0.137	0.166	0.137	0.166
Year, Industry, Year x Industry FE	YES	YES	YES	YES

Note: CEO-clustered t-statistics in parentheses, *** p<0.01, ** p<0.05, * p<0.1

(Dai et al., 2019)[28]. The deal variable value/stake has a small positive effect, which means that the likelihood for a toehold is larger if the value per cent of the target is higher. The deal variable value/MVA however has a relatively large significant negative effect, which indicates that the likelihood of a toehold is smaller when the relative deal value for the acquiring firm is large.

Betton et al. (2009) develop a 'toehold threshold' equilibrium strategy: Acquire either no toehold at all (such that rejection costs are avoided) or acquire a toehold greater than a certain threshold. The threshold is the toehold size at which toehold benefits equal toehold induced rejection costs. The threshold value is idiosyncratic, however, Betton et al. (2009) find that the average toehold threshold value estimated from data is about 9%. We

[28] We also investigated whether the results hold when we only consider those CEOs who have conducted both type of acquisitions at least once during the sample period. The negative relation remains significant.

use this percentage as a cut-off point to exclude 'small' toeholds. We then compare the obtained results from the full sample also to a data sample including only stakes sizes greater than 9%, the regression results from this subsample are presented in Table C.1 in Appendix C.

Considering the results for the reduced sample with stake sizes $> 9\%$[29], there changes little to the direction or significance of the different variables[30]. This supports the significant negative relation that is found with the full sample. Our results also remain when we use as the dependent variable only those minority stake acquisitions, from which we certainly know that they were exercised (extended to a majority stake) at some point in time, thus confirming their use as a toehold strategy. The results of this analysis are in Table C.2 in Appendix C.

Robustness of the Overconfidence-Toehold Hypothesis

To examine the robustness of the relationship between overconfidence and the use of minority stakes in acquisitions, we test our hypothesis in a different setting. We construct an additional dataset consisting of a sample of 286 acquisitions in the period 2004-2013. However, now, (i) we require all acquiring companies to be firms from the UK and (ii) use *external perception* by media and *self-importance* as measures of overconfidence.

This country restriction is set to investigate if there are no acquirer country-specific

[29] We find the same results when considering cut-off points of 10% and 15%.

[30] Betton et al. (2009) also find empirically that toeholds are much more likely in hostile deals (which their model supports as well). One may suggest that a CEO needs a certain amount of confidence to initiate a hostile bid. However Dai et al. (2019) find that once one corrects for 'difficult deals' minority stakes result in higher bidder returns, which is inconsistent with overconfidence. For instance Malmendier & Tate (2008) find that overconfident CEO undertake value destroying acquisitions). Hence, our findings rather complement than contradict the findings of Betton et al. (2009) and Dai et al. (2019).

factors that could drive the relationship between overconfidence and the neglect of minority stakes. The UK is chosen because it is known for having a well-developed financial market, is known for an active M&A market and there is sufficient data available for deals in this country. Furthermore, it enables us to compare the results to our main dataset and previous research that mainly focuses on deals in the United States. Finally, a minimum market capitalization of the acquirer of 500 million pounds is set as a condition to make sure there is sufficient media coverage available about the CEO.

Following the measure of Malmendier & Tate (2008); Malmendier et al. (2011) we use outsider's perception as another proxy for overconfidence. We therefore collect articles from the British newspapers *The Guardian, Daily Telegraph and The Financial Times*. These newspapers are selected because they have a reputation of being 'quality press', and all three newspapers are described as having different political allegiances, which creates a more balanced view on outsiders perspective. Similar to Malmendier & Tate (2008), a CEO is classified as overconfident if he or she is mentioned more often as 'confident' or 'optimistic' than as 'reliable', 'cautious', 'frugal', 'steady', 'conservative' or 'practical' in all the collected articles. All references in articles are manually checked to make sure the articles refer to the CEO.

Furthermore, we calculate the *self-importance* measure of overconfidence as the salary of the CEO divided by the average salary of other executives (Hayward & Hambrick, 1997). Additionally, we calculate the ratio of the number of times a CEO is mentioned as overconfident over the number of times a CEO is mentioned as cautious in the newspapers and include the natural logarithm of this ratio *ln(Confident/Cautious)* as an additional continuous overconfidence measure. We also include the natural logarithm of the self-importance variable *ln(Self-importance)* as an additional overconfidence measure.

Table 2.6: Overconfidence and the likelihood of a toehold strategy - alternative measures
The dependent variable in the regressions is *Minority*, a binary variable taking the value of 1 if a minority stake is acquired and 0 otherwise. The dummy variable *External Perception* takes value 1 if a CEO is classified as overconfident, based on outsiders perception measured by media coverage. Articles that classify a CEO as cautious consist on or more of the following keywords: 'reliable', 'cautious', 'frugal', 'steady', 'conservative' and 'practical', referring to the CEO of interest. Articles that classify a CEO as overconfident consist one or more of the following keywords: 'confident' and 'optimistic', referring to the CEO of interest. Articles are obtained from The Guardian, Financial Times and The Daily Telegraph, and are manually checked to make sure the article is referring to the CEO. If a CEO is more often described as confident than cautious, the CEO is classified as overconfident. *Self-importance* is another overconfidence measure calculated as the ratio of the CEO salary to the average salary of other executives. *ln(Confident/Cautious)* is the natural log of the ratio calculated as the number of times a CEO is mentioned as overconfident relative to cautious. *ln(Self-importance)* is the natural log of the self-importance measure. *Size* is calculated by taking the natural logarithm of the book value of the assets at year-end. *Tobin's Q* is measured as the ratio of the market value of assets and book value of assets. The variable *Cash Flow* is constructed by adding depreciation and amortization to the earnings before extraordinary items and is normalized by the book value of assets at the end of the previous year. The *Investments* variable is constructed by normalizing the capital expenditures by the book value of assets at the end of the previous year. The control variable *Cash* indicates the amount of cash and equivalents relative to the book value of assets. The variable *Leverage* is obtained by taking the outstanding debt as a fraction of the market value of equity. *Cross-Country* is a dummy variable which takes the value of 1 if the target firm is from another country than the acquiring firm. *Cross-Industry* is a dummy variable which takes the value of 1 if the target firm is from another industry (based on 2-digit SIC codes) than the acquiring firm. *Value/MVA* and *Value/Stake* are the deal value as reported by ThomsonOne normalized by the Market Value of Assets (MVA) and the stake size (Stake) respectively. *Prev.acq.All* is the total number of acquisitions a CEO engaged into, in the last three years. *Prev.acq.min*, is similar to Prev.acq.all, however now denotes the number of previous minority acquisitions.

	External Perception		*Self-importance*		*ln(Confident/ Cautious)*	*ln(Self-importance)*
Dep. Var.: Minority	(1)	(2)	(3)	(4)	(5)	(6)
Variables	Controls FE	Dealvars FE	Controls FE	Dealvars FE	Dealvars FE	Dealvars FE
External Perception	**-0.132****	**-0.116***				
	(-1.983)	(-1.909)				
Self-importance			**-0.227****	**-0.167****		
			(-2.331)	(-2.073)		
ln(Confident/Cautious)					**-0.078****	
					(-2.518)	
ln(Self-importance)						**-0.374*****
						(-4.644)
Size	-0.001	-0.010	0.005	-0.039	-0.069**	-0.042
	(-0.030)	(-0.503)	(0.135)	(-1.235)	(-2.135)	(-1.386)
Tobin's Q	-0.005	-0.004	0.020	-0.049	-0.004	-0.047
	(-1.462)	(-1.651)	(0.425)	(-1.032)	(-0.591)	(-1.028)
Cash Flow	0.010	0.006	0.756***	0.764***	0.246	0.659***
	(1.025)	(0.662)	(3.414)	(3.976)	(0.643)	(3.845)
Investments	0.363	0.429	-0.488	-0.416	-0.983	-0.325
	(0.480)	(0.654)	(-0.592)	(-0.581)	(-0.741)	(-0.460)
Cash	0.246	0.215	0.072	0.063	0.266	0.357
	(0.606)	(0.630)	(0.146)	(0.186)	(0.503)	(1.031)
Leverage	0.053	0.078	0.202	0.484**	0.600**	0.435**
	(0.337)	(0.528)	(0.883)	(2.411)	(2.396)	(2.102)

Continued on next page

Table 2.6 – *Continued from previous page*

	External Perception		*Self-importance*		*ln(Confident/ Cautious)*	*ln(Self-importance)*
Dep. Var.: Minority	(1)	(2)	(3)	(4)	(5)	(6)
Variables	Controls FE	Dealvars FE	Controls FE	Dealvars FE	Dealvars FE	Dealvars FE
Owner	-0.453**	-0.418**	-0.244	-0.057	-0.447	-0.029
	(-2.028)	(-2.467)	(-0.827)	(-0.273)	(-1.568)	(-0.141)
Prev. acq. All	0.035	0.017	0.079*	0.075*	0.117**	0.059
	(1.129)	(0.688)	(1.688)	(1.887)	(2.455)	(1.547)
Prev. acq. Minority	-0.058	-0.078	-0.229	-0.192	-0.147	-0.142
	(-0.705)	(-1.214)	(-1.665)	(-1.639)	(-1.044)	(-1.219)
Cross-Industry	0.158**	0.173***	0.146	0.227***	0.187	0.210***
	(2.268)	(2.982)	(1.015)	(2.886)	(1.590)	(2.672)
Cross-Country	0.033	0.058	0.027	0.087	0.072	0.093
	(0.438)	(0.909)	(0.345)	(1.183)	(0.796)	(1.223)
Value/MVA		-0.465***		-0.492***		-0.471***
		(-7.256)		(-4.871)		(-4.632)
Value/Stake		0.001*		0.001***		0.001***
		(1.949)		(3.241)		(5.300)
Constant	0.171	0.443**	0.223	0.561	0.454	0.485
	(0.910)	(2.384)	(0.481)	(1.575)	(1.569)	(1.478)
Observations	286	285	144	144	164	143
Adjusted R-squared	0.058	0.258	0.114	0.339	0.183	0.371
Year-Industry FE	YES	YES	YES	YES	YES	YES

Note: CEO-clustered t-statistics in parentheses, *** p<0.01, ** p<0.05, * p<0.1

The regression results of the minority stake dummy on the *external perception* and *self-importance* measures and additional control variables are displayed in Table 2.6.

We observe that the negative relation between a minority stake acquisition and CEO overconfidence is again confirmed. For all measures, we find negative significant coefficients for the overconfidence measure, indicating the negative relation between the likelihood of a minority stake and overconfidence of a CEO. The results indicate that our hypothesis of a negative relation between CEO overconfidence and the likelihood of employing toehold strategies is robust when tested in a different setting with different overconfidence measures. We investigated how CEO overconfidence affects the likelihood of choosing a toehold strategy, when deciding between a toehold or majority acquisition. Whether an overconfident CEO is less likely to conduct a toehold strategy in general (when having the choice to do nothing as well) has to be investigated with more advanced statistical methods, thereby taking selection bias into account. We direct this to future research.

Overconfidence and Announcement Returns

As an additional analysis, we examined the market reaction measured by cumulative abnormal returns (CARs) of minority stake acquisitions versus majority stake acquisitions by overconfident CEOs. If the majority acquisition is conducted not out of overconfidence but because it is truly the better strategy to follow, this should be reflected in the abnormal returns. Many empirical studies find that acquirer's abnormal returns are often nihil (see e.g., Jensen & Ruback, 1983, and others). Since differences in acquirer returns are often observed in the case of public targets and not that much for private targets (Chang, 1998; Fuller et al., 2002; Draper & Paudyal, 2006; Faccio et al., 2006; Cooney et al., 2009), we will consider the sub-sample of public targets. Simple comparisons and t-tests are in Tables C.3 and C.4 in Appendix C. From these, we already observe some differences in CAR for both acquisition types.

More extensively, we regress the CARs over several time windows on *Majority*, which is a dummy that takes the value of 1 if a deal was a majority stake acquisition. Furthermore, we include overconfidence, and the interaction between overconfidence and *Majority* in this regression. Note how *Majority* serves as treatment effect in this setting. However, we have to take into account that this treatment is not randomly selected. Therefore, we employ a two-stage treatment selection model.

We estimate the coefficients with the maximum likelihood method. This results in the following specification:

$$
\begin{aligned}
CAR_{ik} &= \beta_0 + \beta_1 Majority_i + \beta_2 measure_i \\
&\quad + \beta_3 Majority_i \times measure_i + beta_4 \lambda \varepsilon_{ik} \\
Majority_i &= \gamma_0 + \gamma_1 measure_i + \boldsymbol{\theta'x} + \eta_i
\end{aligned} \tag{2.28}
$$

Where $\boldsymbol{x}$ is a vector of explanatory variables for the first stage of the treatment selection model and $\boldsymbol{\theta}$ is a vector of corresponding coefficients. We include *Size, Tobin's Q, Cash Flow, Investments, Cash, Leverage, Corporate Governance, Owner, Prev.acq.All, Prev.acq.-Minority, Cross-Industry, Cross-Country* as additional explanatory variables in the selection model. Finally, $\lambda \equiv \lambda(\hat{\gamma_0} + \hat{\gamma_1} measure_i + \hat{\boldsymbol{\theta'}} x)$ is the inverse Mills ratio evaluated at the fitted values of the choice equation, it corrects for the sample selection bias.

In the second stage, we regress the CAR of every acquiring company in acquisition i for every relevant window k on a dummy indicating a majority stake, an overconfidence measure (*Longholder, Holder67*) and the interaction effect between overconfidence and the majority stake dummy. We consider several distinct CAR event windows, which all include the announcement period and also take into account a run-up period and a post-announcement period.

The CARs are calculated as in Betton et al. (2009): Daily abnormal returns for each event period are estimated through the following regression equation

$$
r_{jt} = \alpha_j + \beta_j r_{mt} + \sum_{k=1}^{K} AR_{jk} d_{kt} + \varepsilon_{jt}, \quad t = \{\tau - 100, ..., \tau + 100\} \ \forall \tau \tag{2.29}
$$

where r_{jt} is the excess return to firm j at day t, r_{mt} is the value-weighted market return adjusted by the risk-free rate, and d_{kt} is a dummy variable that takes the value of one if day t is in the k-th event window and zero otherwise, finally τ is the acquisition date. Our CAR estimation method applies OLS with White's heteroskedastic-consistent covariance matrix. The CAR to firm j over event period k is calculated as $CAR_{jk} = \omega_k AR_{jk}$, where ω_k is the number of trading days in the event window.

The results of the regressions for the several event windows are presented in Figure C.1 in Appendix C. The effects of overconfidence, a majority acquisition, and the interaction effect of overconfidence and majority acquisition are given by the corresponding coefficients. The coefficients for the majority stake variable are overall negative and significant, indicating on average lower cumulative abnormal returns for majority acquisitions. This could indicate that the market recognizes irrational behaviour. There are no significant effects for the overconfidence measures and interaction effects, indicating that being a biased CEO does not necessarily affect the returns, while the signal of conducting a majority acquisition does.

2.3 Discussion

We modelled the choice between a toehold strategy versus a direct control acquisition and showed that CEO overconfidence affects the judgement of a CEO, which results in a lower likelihood of preferring the toehold strategy. Empirically, we find indications for the claims of our model by showing that an acquisition conducted by an overconfident CEO has a lower likelihood of being a toehold acquisition. Our findings relate to a growing strand of literature within corporate finance which relates behavioural biases to corporate decisions, and especially to studies which argue that moderate confidence can benefit the firm whereas overconfidence is harmful.

Goel & Thakor (2008) show that a risk-averse rational CEO under-invests in projects, thereby reducing firm value, whereas a moderately overconfident CEO mitigates the problem of underinvestment and thereby increases firm value. They state that an overconfident CEO makes investment decisions that (s)he would not make if (s)he was rational. This is also the main line of our model as we show that an overconfident CEO may prefer the direct acquisition, where (s)he would have preferred the toehold strategy if rational.

Moreover, the impact of overconfidence as behavioural bias differs from that of risk attitude. Goel & Thakor (2008) show that CEO overconfidence affects firm value in a different way than reduced risk aversion. They show that the effect of overconfidence is non-monotonically: Moderate overconfidence increases firm value by diminishing underinvestment, high overconfidence leads to overinvestment and decreases firm value. On the contrary, firm value decreases monotonically in CEO risk aversion.

Also Campbell et al. (2011) state that there is an interior optimum level of managerial confidence that maximizes firm value, but that overconfident CEOs do not maximize firm value. Furthermore, Gervais et al. (2011) argue that moderate overconfidence is beneficial for both the firm and the CEO in terms of compensation, if the firm is able to identify an overconfident CEO and set contracting optimally. According to these studies, along with ours, the better outcome for the shareholders is having a CEO who is moderately (over)confident but not too overconfident.

One may wonder how often CEOs are overconfident. From Goel & Thakor (2008), we infer that indeed CEOs are often overconfident: Under value-maximizing corporate governance, an overconfident manager, who sometimes makes value-destroying investments, has still a higher likelihood than a rational manager to be deliberately promoted to CEO. Therefore, they argue that overconfidence is a more prevalent attribute among

CEOs than in the general population. Ben-David et al. (2013) employ a laboratory approach, measuring overconfidence in a population of thousands of real-world senior financial executives, providing convincing evidence that executives are severely overconfident[31]. They find that firms with overconfident executives seem to follow more aggressive corporate policies, which is in line with our findings that overconfident CEOs have a higher likelihood of preferring the direct acquisition over the cautious toehold strategy.

Gervais et al. (2011) examine how CEOs are matched with firms based on both managerial overconfidence and firm attributes. From their model, they infer that the most overconfident executives will tend to end up in risky growth firms. Hirshleifer et al. (2012) find that firms with overconfident CEOs invest more in R&D, thereby achieving greater innovation. Furthermore, these firms have higher stock return volatility, consistent with overconfident CEOs undertaking riskier projects. They argue that their findings add to the puzzle of why firms are willing to deliberately hire overconfident managers. They term the bright sides and dark sides of CEO overconfidence and argue that the willingness to take audacious risks can be valuable to the firm.

In our empirical analysis, we assumed (as is common) that overconfident and rational CEOs sort randomly over firms. However, the above arguments and studies show that firms potentially hire overconfident CEOs on purpose. Hence, extending the empirical analysis to control for selection bias of CEOs would be of added value. Additionally, we have considered whether, given an acquisition, CEO overconfidence negatively affects the likelihood of a toehold strategy. However, a CEO also has the possibility to not acquire a stake at all. To investigate whether an overconfident CEO in general has a lower likelihood

[31] Ben-David et al. (2013) measure miscalibration, which is a form of overconfidence. They mention that in the psychology literature, overconfidence has several manifestations such as miscalibration, the above-average effect, and the illusion of control. Miscalibration is defined as excessive confidence about having accurate information.

of executing a toehold strategy relative to either a direct control acquisition, or no acquisition at all, we will have to take this possibility in account by using a two-stage model. We direct this to future research.

We employed four different measures of overconfidence in our analysis. Overconfidence as a behavioural trait remains however difficult to measure indirectly through proxies. The option-based measures rely on the expectations that an overconfident CEO may have of its firm's stock price. Therefore, implicitly, these measures require that the actions of the CEOs are reflected enough in the stock price, which is not just as much the case with every firm. Furthermore, overconfidence can change over time and even within the time frame of the dataset. Gervais & Odean (2001) show that overconfidence does not make traders wealthy, but the process of becoming wealthy can make traders overconfident. They argue that overconfidence will, on average, increase early in the career of a trader and then gradually decrease. It is plausible that such arguments translate to executives as well and overconfidence changes over time.

Moreover, determining between moderate overconfidence and high overconfidence remains a matter of judgement. Malmendier & Tate (2005a) use the Holder67 measure to identify overconfident CEOs, whereas Campbell et al. (2011) argue that 67% is the threshold for moderate confidence. In the measures that we have used, we can identify Holder67 as the 'stricter' measure compared to Longholder. Indeed, we find overall (also considering subsamples and certain toeholds) stronger significant results with the Holder67 measure. The self-importance variable is a continuous proxy for overconfidence and shows that the higher the level of self-importance, the lower the likelihood of a toehold strategy. These findings support the notion that the level of overconfidence matters, where high overconfidence affects judgement critically.

Regarding the theoretic model, we considered the toehold option in isolation. Le & Schultz (2007) describes the advantages of a toehold in single and multiple bidder acquisitions. The advantages in the single bidder context can be reflected in the toehold exercise price, which can be different from the direct acquisition premium. In particular Betton & Eckbo (2000) states that "greater bidder toeholds reduce the probability of competition and target resistance and are associated with both lower bid premiums and lower pre-bid target stock price run-ups.". A well-known result from real options theory is that competition erodes option value (Dixit & Pindyck, 1994; Smit & Trigeorgis, 2004). Hence, this means that competition lowers the toehold real option exercise threshold. Therefore, we expect an even stronger negative effect of overconfidence in a competitive setting, as CEO overconfidence can 'easier' cause a switch in preferences from toehold strategy to direct acquisition strategy.

Finally, we have modelled the toehold strategy as a real option with infinite maturity. However, the acquisition strategy that the CEO of an acquiring firm has in mind, can be of a limited time span: The acquirer chooses to either acquire a controlling stake now or to acquire a part now and the remaining stake within T years (instead of 'ever in the future'). When considering two nearly identical American-style options with as only difference the time to expiry $\tau_1 > \tau_2$, the option with longer time to expiry will have a higher value, since it has the additional right to exercise between the two expiration dates, and therefore, this additional right should have additional value (e.g., Kwok, 2008).

We can not however extend this line of reasoning one-on-one to the toehold option. The 'strikes' or exercise prices of a finite and infinite option would be different, depending on the optimal exercise threshold in the finite case versus the infinite case. Since the value of the toehold option is determined by the stochastically discounted pay-off, we can deduct that if the finite and infinite option have threshold values close to each other, their option values will also be alike. However, if the threshold values are far apart, this would mean that the threshold of the finite real option may only be sub-optimal, as it would be very different if the horizon would be infinite. As the toehold real option with infinite horizon offers more flexibility, it is likely that its value will be (slightly) higher than of a finite real option[32].

Moreover, a lower toehold option value (whether following from infinite or finite horizon), reinforces the CEO-overconfidence effect, as it is then easier to underestimate the toehold value relative to the direct acquisition value. Overconfidence of a CEO can then easier cause the preference for a strategy to alter from toehold strategy to direct acquisition. Therefore, valuing the toehold option as a complete strategy with finite maturity and thereby also investigating how the toehold option value varies with different maturities, would be of added value. This would have the potential to identify another factor which affects the interaction between CEO-overconfidence and the choice of an acquisition strategy. Obtaining closed-form solutions for finite American-style dividend-paying call-type real options remains difficult and is only possible under specific assumptions. We direct this thought to future research.

[32] The derivative of the toehold real option with respect to the threshold is

$$\frac{\partial O}{\partial R^*} = \left\{(K+Q)\alpha - \frac{\pi\beta}{R^*}\right\}\left(\frac{R}{R^*}\right)^{\beta} < 0, \tag{2.30}$$

where π is the option pay-off such that $O = \pi(R^*)\left(\frac{R}{R^*}\right)^{\beta}$. Hence, a higher threshold R^* leads to a lower option value, however, since $R^* = X^*/Y^*$, the threshold does not have to be necessarily higher in the infinite horizon setting compared to the finite horizon setting.

2.4 Conclusion

Acquisitions tend to provide poor bidder announcement returns while sellers receive the better half. A toehold strategy may transfer some of the seller advantages to the bidder. Yet these strategies are only rarely executed. This study attempts to answer the question: Do overconfident CEOs ignore the toehold option? We show that the answer is likely to be 'yes' and provide a new explanation for the neglect of toehold strategies.

We develop a real option model, where a toehold can be considered as a call option on the control acquisition. When overconfident CEOs overestimate their own realizable synergies, they have a higher likelihood of preferring the immediate control acquisitions over the toehold real option. As a result, they tend to neglect toehold strategies and prefer the direct control acquisition instead.

We empirically investigate our claims of the impact of CEO overconfidence on the use of toeholds in acquisition strategies. Absent other market frictions, we find that, given an acquisition, overconfident CEOs are more likely to execute control acquisitions instead of minority stake acquisitions.

Overconfidence is conceptualized in our analysis through different measures. We use CEOs' private investment decisions to capture their revealed beliefs and measure overconfidence. For robustness and to show that sub-optimal decision-making in the personal portfolio is not a result of errors but of behavioral biases, we use alternative measures of overconfidence, which are based on the external perception of CEOs by quality newspapers and self-importance through salary differences.

We obtain the same findings with all overconfidence measures. The main empirical results show economically and statistically strongly significant evidence for a lower likelihood of toeholds strategies compared to majority acquisitions among overconfident CEOs. Additionally, we find that cumulative abnormal returns are on average higher for minority stake acquisitions than for control acquisitions. The evidence that minority stakes perform better than full acquisitions is inconsistent with the neglect of toehold strategies.

The implication of our study for contracting and deal execution practices is that CEOs should focus attention on toehold acquisition strategies as a potential way to improve acquisition performance. Acknowledging the existence of overconfidence in acquisition strategies can offer executives insights and new organisational processes that could be helpful in efforts to de-bias acquisition strategies.

A Derivation of Option Value and Exercise Threshold

Denote by $O(X,Y)$ the option value of the toehold. Using Itō's lemma we write for the dynamics:

$$dO = O_X dX + O_Y dY + \left[\frac{1}{2}\sigma_X^2 X^2 O_{XX} + \frac{1}{2}\sigma_Y^2 Y^2 O_{YY} + \rho\sigma_X\sigma_Y O_{XY}\right] dt.$$

In equilibrium it should hold that the expected return on the option is equal to the risk-free rate r. Hence, if combined with above dynamics we arrive at the following PDE:

$$(\mu_X - q_X)XO_X + \mu_Y Y O_Y + \frac{1}{2}\sigma_X^2 X^2 O_{XX} + \rho\sigma_X\sigma_Y O_{XY} = rO,$$

which should be solved subject to the following boundary conditions:

$$\begin{aligned}
O(X^*,Y^*) &= (V^C(X^*,Y^*) - V^B(X^*) - (1+\psi)(1-\omega)V^T(Y^*)) \\
O_X(X^*) &= (K+Q)\alpha \\
O_Y(Y^*) &= (K+Q)[(1-\theta)-(\gamma-\alpha)] - Q(1+\psi)(1-\omega) \\
\lim_{(X/Y)\to 0} \frac{O(X,Y)}{X} &= 0,
\end{aligned}$$

where

$$
\begin{aligned}
V^B(X) &= KX \\
V^T(Y) &= QY \\
\theta &= \frac{K}{K+Q} \\
S(X,Y) &= (\theta+\alpha)X + [(1-\theta) - (\gamma-\alpha)]Y \\
V^C(X,Y) &= S(X,Y)(K+Q) \\
V^C(X,Y) &= V^B(X) + V^T(Y) + (K+Q)(\alpha(X+Y) - \gamma Y).
\end{aligned}
$$

It is fairly straightforward to see that the value function $O(X,Y)$ is linearly homogeneous in (X,Y), as $O(aX,aY) = aO(X,Y)$. Hence, if we let $R = X/Y$, we can describe the option as follow:

$$O(X,Y) = YO(\frac{X}{Y},1) = YO(R)$$

We can show that from the chain-rule it follows that (similar to Morellec & Zhdanov, 2005):

$$
\begin{aligned}
O_X(X,Y) &= O_R(R) \\
O_Y(X,Y) &= O(R) - RO_R(R) \\
O_{XX}(X,Y) &= O_{RR}(R)/Y \\
O_{YY}(X,Y) &= R^2 O_{RR}(R)/Y \\
O_{XY}(X,Y) &= -RO_{RR}(R)/Y
\end{aligned}
$$

Substituting these in the equilibrium and boundary conditions leads to:

$$\frac{1}{2}\sigma_R^2 R^2 O_R R + \mu_R R O_R = (r - \mu_Y) O,$$

with boundary conditions:

$$\begin{aligned} O(R^*) &= (K+Q)\Big(\alpha R^* + (\alpha - \gamma)\Big) - \psi V^T(1) \\ &\quad + \omega(1+\psi)V^T(1) \\ O_R(R^*) &= (K+Q)\alpha \\ \lim_{R\to 0} O(R)/R &= 0 \end{aligned}$$

The general solution of such a problem is well-known:

$$O(R) = AR^\beta + BR^\delta$$

With A and B positive constants and with β and δ respectively the positive and negative roots of the quadratic equation:

$$\begin{aligned} &\frac{1}{2}(\sigma_X^2 + \sigma_Y^2 - 2\rho\sigma_X\sigma_Y)\beta(\beta-1) \\ &\qquad + [(\mu_X - q_X) - \mu_Y]\beta - (r - \mu_Y) = 0 \\ =&\frac{1}{2}\sigma_R^2\beta(\beta-1) + \mu_R\beta - (r-\mu_Y) = 0 \end{aligned} \tag{31}$$

From the last boundary condition it follows that $B = 0$. Then we can write:

$$\begin{aligned} A{R^*}^{\beta} &= V^C(R^*) - V^B(R^*) - (1+\psi)(1-\omega)V^T(1) \\ &= V^T + (K+Q)(\alpha R^* - (\gamma - \alpha)) - (1+\psi)V^T + \omega(1+\psi)V^T \\ \beta A {R^*}^{\beta - 1} &= (K+Q)\alpha \\ A &= \left\{V^C(R^*) - V^B(R^*) - (1+\psi)(1-\omega)V^T\right\}(R^*)^{-\beta} \\ A &= \frac{1}{\beta}\left\{(K+Q)\alpha\right\} {R^*}^{1-\beta} \end{aligned}$$

from which we obtain:

$$\begin{aligned} O(R) = &\left\{V^C(R^*) - V^B(R^*) - (1+\psi)(1-\omega)V^T\right\}\left(\frac{R}{R^*}\right)^{\beta} \\ = &\Big\{V^T + (K+Q)(\alpha R^* - (\gamma-\alpha)) - (1+\psi)V^T \\ &+ \omega(1+\psi)V^T\Big\}\left(\frac{R}{R^*}\right)^{\beta}, \end{aligned}$$

and we can derive, through the fact that $A = A$, that:

$$R^* = \frac{\beta}{\beta - 1}\frac{(K+Q)(\gamma-\alpha) - [1-(1+\psi)(1-\omega)]Q}{(K+Q)\alpha}$$

B The derivative with respect to option parameters

From the quadratic equation (31) in Appendix A we solve for β to find:

$$\beta = \frac{\left(\frac{\sigma_R^2}{2} - \mu_R\right) + \sqrt{\left(\mu_R - \frac{\sigma_R^2}{2}\right)^2 + 2\sigma_R^2(r - \mu_Y)}}{\sigma_R^2}$$

From the equation

$$\begin{aligned} Q(\beta, \mu_R) =& \frac{1}{2}(\sigma_X^2 + \sigma_Y^2 - 2\rho\sigma_X\sigma_Y)\beta(\beta - 1) \\ & + [(\mu_X - q_X) - \mu_Y]\beta - (r - \mu_Y) = 0 \\ =& \frac{1}{2}\sigma_R^2\beta(\beta - 1) + \mu_R\beta - (r - \mu_Y) = 0, \end{aligned}$$

we have by the implicit differentiation theorem[33]:

$$\frac{\partial \beta}{\partial \mu_R} = -\frac{\frac{\partial Q}{\partial \mu_R}}{\frac{\partial Q}{\partial \beta}} = -\frac{\beta}{\sigma_R^2\beta - \frac{1}{2}\sigma_R^2 + \mu_R} = -\frac{>0}{>0} \Longleftrightarrow \frac{\partial \beta}{\partial \mu_R} < 0.$$

Since by definition we have $\frac{\partial q_X}{\alpha} > 0$ it follows that $\frac{\partial \mu_R}{\partial \alpha} < 0$. Hence, as $\frac{\partial \beta}{\partial \alpha} = \frac{\partial \beta}{\partial \mu_R} \times \frac{\partial \mu_R}{\partial \alpha}$ it ultimately follows that $\frac{\partial \beta}{\partial \alpha} > 0$. In the same way we can derive the derivatives of β with respect to μ_Y and σ_Y

[33] For $Q(x, y) = 0$ the derivative is given by:

$$\frac{dy}{dx} = -\frac{\partial Q/\partial x}{\partial Q/\partial y} = -\frac{Q_x}{Q_y}$$

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C Additional Figures and Tables

Table C.1: Overconfidence and the likelihood of a toehold strategy - minimum size toeholds
This table displays the regression results for the sub-sample of stake sizes larger than 9%. The dependent variable is *Minority*, which is a dummy variable that takes the value of 1 if a minority stake was taken in a deal and 0 in case of a majority stake. A minority stake is defined as a sought stake-size of smaller than 50%, while the total acquired fraction of the target firm is also less than 50%. The *CG* (corporate governance) variable is a dummy variable equal to 1, when the number of board members is between 4 and 12. *Owner* is a ratio defined as the CEO's shareholdings divided by the number of outstanding company shares. *Size* is calculated by taking the natural logarithm of the book value of the assets at year-end. *Tobin's Q* is measured as the ratio of the market value of assets and book value of assets. The variable *Cash Flow* is constructed by adding depreciation and amortization to the earnings before extraordinary items and is normalized by the book value of assets at the end of the previous year. The *Investments* variable is constructed by normalizing the capital expenditures by the book value of assets at the end of the previous year. The control variable *Cash* indicates the amount of cash and equivalents relative to the book value of assets. The variable *Leverage* is obtained by taking the outstanding debt as a fraction of the market value of equity. *Cross-Country* is a dummy variable which takes the value of 1 if the target firm is from another country than the acquiring firm. *Cross-Industry* is a dummy variable which takes the value of 1 if the target firm is from another industry (based on 2-digit SIC codes) than the acquiring firm. *Value/MVA* and *Value/Stake* are the deal value as reported by ThomsonOne normalized by the Market Value of Assets (MVA) and the stake size (Stake) respectively. *Prev.acq.All* is the total number of acquisitions a CEO engaged into, in the last three years. *Prev.acq.min*, is similar to Prev.acq.all, however now denotes the number of previous minority acquisitions. Overconfidence is measured by *Longholder* and *Holder67*, which are both dummy variables taking the value of 1 if a CEO is classified as overconfident. Furthermore year, industry (acquirer) and year times industry fixed effects are included. Standard errors are clustered at CEO level, t-statistics are displayed in parentheses.

	Holder67 Overconfidence		*Longholder Overconfidence*	
Dep. Var.: Minority	(1)	(2)	(3)	(4)
Variables	Controls FE	Dealvars FE	Controls FE	Dealvars FE
Holder67	**-0.010*** **	-0.008		
	(-2.734)	(-1.322)		
Longholder			**-0.008** **	**-0.014** **
			(-2.105)	(-2.156)
Size	0.003**	0.006*	0.003**	0.005*
	(2.185)	(1.858)	(2.061)	(1.796)
Tobin's Q	0.004	0.000	0.004	0.000
	(1.411)	(0.094)	(1.454)	(0.124)
Cash Flow	0.122**	0.015	0.121**	0.015
	(2.474)	(0.334)	(2.448)	(0.353)
Investments	0.140*	0.136	0.136*	0.134
	(1.719)	(1.479)	(1.680)	(1.462)
Cash	0.033	0.078***	0.033	0.077***
	(1.538)	(2.926)	(1.533)	(2.883)
Leverage	0.127***	0.147***	0.127***	0.150***
	(4.509)	(3.483)	(4.520)	(3.563)
Corporate Governance	-0.020	-0.021	-0.022	-0.023
	(-1.362)	(-0.769)	(-1.485)	(-0.856)
Owner	0.008	0.140*	0.011	0.148*
	(0.248)	(1.703)	(0.339)	(1.752)

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Table C.1 – *Continued from previous page*

	Holder67 Overconfidence		*Longholder Overconfidence*	
Dep. Var.: Minority	(1)	(2)	(3)	(4)
Variables	Controls FE	Dealvars FE	Controls FE	Dealvars FE
Prev. acq. All	-0.001***	-0.002**	-0.001***	-0.002**
	(-6.171)	(-2.397)	(-5.908)	(-2.373)
Prev. acq. Minority	0.035***	0.043***	0.035***	0.043***
	(6.400)	(4.745)	(6.234)	(4.673)
Cross-Industry	0.004	0.008	0.003	0.008
	(0.835)	(1.195)	(0.769)	(1.225)
Cross-Country	0.053***	0.063***	0.053***	0.063***
	(8.209)	(6.229)	(8.189)	(6.256)
Value/MVA		-0.087***		-0.088***
		(-4.248)		(-4.276)
Value/Stake		0.000		0.000
		(1.070)		(1.147)
Constant	-0.030	-0.041	-0.029	-0.038
	(-1.358)	(-1.123)	(-1.301)	(-1.022)
Observations	9,265	4,044	9,265	4,044
Adjusted R-squared	0.099	0.118	0.098	0.118
Year, Industry, Year x Industry FE	YES	YES	YES	YES

Note: CEO-clustered t-statistics in parentheses, *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table C.2: Overconfidence and the likelihood of a toehold strategy - certain toeholds

This table displays the regression results of the dependent variable *Toehold*, which is a dummy variable that takes the value of 1 if a minority stake was taken in a deal and this minority stake is verified to be extended to a controlling stake later; it takes value 0 in case of a majority stake. A minority stake is defined as a sought stake-size of smaller than 50%, while the total acquired fraction of the target firm is also less than 50%. The *CG* (corporate governance) variable is a dummy variable equal to 1, when the number of board members is between 4 and 12. *Owner* is a ratio defined as the CEO's shareholdings divided by the number of outstanding company shares. *Size* is calculated by taking the natural logarithm of the book value of the assets at year-end. *Tobin's Q* is measured as the ratio of the market value of assets and book value of assets. The variable *Cash Flow* is constructed by adding depreciation and amortization to the earnings before extraordinary items and is normalized by the book value of assets at the end of the previous year. The *Investments* variable is constructed by normalizing the capital expenditures by the book value of assets at the end of the previous year. The control variable *Cash* indicates the amount of cash and equivalents relative to the book value of assets. The variable *Leverage* is obtained by taking the outstanding debt as a fraction of the market value of equity. *Cross-Country* is a dummy variable which takes the value of 1 if the target firm is from another country than the acquiring firm. *Cross-Industry* is a dummy variable which takes the value of 1 if the target firm is from another industry (based on 2-digit SIC codes) than the acquiring firm. *Value/MVA* and *Value/Stake* are the deal value as reported by ThomsonOne normalized by the Market Value of Assets (MVA) and the stake size (Stake) respectively. *Prev.acq.All* is the total number of acquisitions a CEO engaged into, in the last three years. *Prev.acq.min*, is similar to Prev.acq.all, however now denotes the number of previous minority acquisitions. Overconfidence is measured by *Longholder* and *Holder67*, which are both dummy variables taking the value of 1 if a CEO is classified as overconfident. Furthermore year, industry (acquirer) and year times industry fixed effects are included. Standard errors are clustered at CEO level, t-statistics are displayed in parentheses.

	Holder67 Overconfidence		*Longholder Overconfidence*	
Dep. Var.: Minority	(1)	(2)	(3)	(4)
Variables	Controls FE	Dealvars FE	Controls FE	Dealvars FE
Holder67	**-0.009*****	**-0.012*****		
	(-4.166)	(-3.225)		
Longholder			**-0.004***	**-0.006***
			(-1.701)	(-1.761)
Size	-0.002*	-0.001	-0.003**	-0.000
	(-1.938)	(-0.219)	(-2.030)	(-0.189)
Tobin's Q	-0.001	-0.002	-0.001	-0.002
	(-0.514)	(-1.117)	(-0.450)	(-1.136)
Cash Flow	0.144***	0.097**	0.141***	0.094**
	(3.289)	(2.563)	(3.237)	(2.554)
Investments	0.172**	0.133*	0.169**	0.128*
	(2.172)	(1.709)	(2.136)	(1.654)
Cash	0.027	0.049*	0.027	0.049*
	(1.514)	(1.832)	(1.548)	(1.836)
Leverage	0.055**	0.059	0.056**	0.061*
	(2.548)	(1.615)	(2.566)	(1.674)
Corporate Governance	-0.017	-0.012	-0.018	-0.013
	(-1.531)	(-0.702)	(-1.634)	(-0.787)
Owner	-0.010	0.032	-0.012	0.031
	(-0.396)	(0.528)	(-0.491)	(0.526)
Prev. acq. All	-0.000***	-0.001**	-0.000***	-0.001**
	(-3.949)	(-2.025)	(-4.016)	(-2.390)
Prev. acq. Minority	0.010**	0.014*	0.010**	0.014*

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Table C.2 – *Continued from previous page*

	Holder67 Overconfidence		*Longholder Overconfidence*	
Dep. Var.: Minority	(1)	(2)	(3)	(4)
Variables	Controls FE	Dealvars FE	Controls FE	Dealvars FE
	(2.348)	(1.818)	(2.246)	(1.781)
Cross-Industry	-0.002	-0.002	-0.002	-0.002
	(-0.638)	(-0.472)	(-0.733)	(-0.440)
Cross-Country	0.008**	0.013**	0.008**	0.013**
	(2.436)	(2.500)	(2.447)	(2.490)
Value/MVA		-0.024**		-0.024**
		(-2.486)		(-2.497)
Value/Stake		-0.000		-0.000
		(-0.566)		(-0.472)
Constant	0.021	0.004	0.021	0.002
	(1.436)	(0.174)	(1.431)	(0.083)
Observations	9,040	3,914	9,040	3,914
Adjusted R-squared	0.057	0.057	0.055	0.054
Year, Industry, Year x Industry FE	YES	YES	YES	YES

Note: CEO-clustered t-statistics in parentheses, *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table C.3: CARs comparison - majority stakes

This table shows the average CARs for several windows for the majority stake acquisition type. The sample is split according to one of the overconfidence measures *Longholder* or *Holder67*. The means of the subgroups are tested against each other and the p-values are reported.

Panel A: Public targets						
	Longholder = 0 N = 517	*Longholder* = 1 N = 191		*Holder67* = 0 N = 430	*Holder67* = 1 N = 278	
CAR windows	mean	mean	p-value	mean	mean	p-value
$[t-1, t+1]$	-0.003	-0.005	0.595	-0.004	-0.003	0.750
$[t-3, t+3]$	-0.003	-0.005	0.721	-0.004	-0.004	0.967
$[t-5, t+5]$	-0.004	-0.001	0.652	-0.002	-0.004	0.752
$[t-1, t+3]$	-0.004	-0.005	0.814	-0.005	-0.004	0.807
$[t-1, t+5]$	-0.005	-0.001	0.476	-0.004	-0.003	0.712
$[t-1, t+10]$	-0.004	0.002	0.363	-0.002	-0.002	0.876
$[t-1, t+20]$	-0.004	-0.008	0.603	-0.002	-0.009	0.296
$[t-3, t+5]$	-0.004	-0.001	0.604	-0.003	-0.003	0.863
$[t-3, t+10]$	-0.003	0.002	0.426	-0.001	-0.001	0.992
$[t-3, t+20]$	-0.003	-0.007	0.551	-0.001	-0.009	0.262
$[t-5, t+10]$	-0.002	0.003	0.423	0.000	-0.003	0.661
$[t-5, t+20]$	-0.003	-0.007	0.599	0.000	-0.010	0.162

Panel B: Full sample						
	Longholder = 0 N = 6596	*Longholder* = 1 N = 2482		*Holder67* = 0 N = 5491	*Holder67* = 1 N = 3587	
CAR windows	mean	mean	p-value	mean	mean	p-value
$[t-1, t+1]$	0.003	0.004	0.658	0.003	0.004	0.163
$[t-3, t+3]$	0.004	0.005	0.224	0.004	0.005	0.515
$[t-5, t+5]$	0.004	0.005	0.326	0.004	0.004	0.972
$[t-1, t+3]$	0.004	0.005	0.457	0.003	0.005	0.182
$[t-1, t+5]$	0.004	0.005	0.526	0.003	0.005	0.119
$[t-1, t+10]$	0.004	0.006	0.150	0.004	0.005	0.318
$[t-1, t+20]$	0.002	0.005	0.088	0.001	0.005	0.047
$[t-3, t+5]$	0.004	0.005	0.277	0.004	0.005	0.358
$[t-3, t+10]$	0.003	0.006	0.073	0.004	0.005	0.627
$[t-3, t+20]$	0.002	0.006	0.045	0.002	0.005	0.122
$[t-5, t+10]$	0.003	0.006	0.090	0.004	0.004	0.788
$[t-5, t+20]$	0.002	0.006	0.056	0.002	0.004	0.383

Table C.4: CARs comparison - non-overconfident CEOs

This table shows the average CARs for several windows for both the majority stake and toehold strategy acquisition type. Only deals of a non-overconfident CEO are considered. The CARs of the acquisition types are compared. The means of the subgroups are tested against each other and the p-values are reported.

Panel A: Public targets

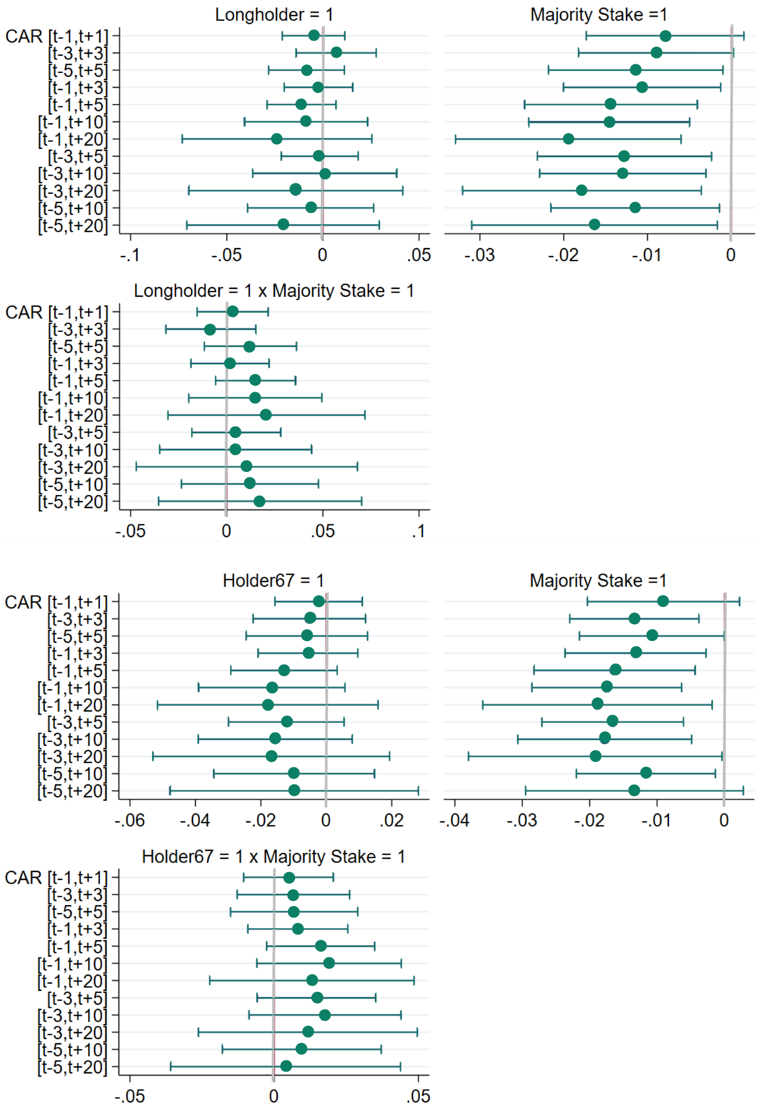
	Longholder = 0				*Holder67* = 0			
	Minority $N = 124$	Majority $N = 517$			Minority $N = 107$	Majority $N = 430$		
	mean	mean	diff (Min - Maj)	p-value	mean	mean	diff (Min - Maj)	p-value
$[t-1, t+1]$	0.005	-0.003	0.008	0.061	0.005	-0.004	0.009	0.063
$[t-3, t+3]$	0.006	-0.003	0.009	0.089	0.009	-0.004	0.013	0.030
$[t-5, t+5]$	0.008	-0.004	0.011	0.049	0.008	-0.002	0.010	0.102
$[t-1, t+3]$	0.006	-0.004	0.011	0.024	0.008	-0.005	0.013	0.022
$[t-1, t+5]$	0.010	-0.005	0.014	0.005	0.012	-0.004	0.016	0.007
$[t-1, t+10]$	0.011	-0.004	0.015	0.010	0.015	-0.002	0.017	0.007
$[t-1, t+20]$	0.016	-0.004	0.020	0.006	0.016	-0.002	0.019	0.055
$[t-3, t+5]$	0.009	-0.004	0.013	0.032	0.013	-0.003	0.016	0.010
$[t-3, t+10]$	0.010	-0.003	0.013	0.039	0.016	-0.001	0.018	0.019
$[t-3, t+20]$	0.015	-0.003	0.018	0.017	0.018	-0.001	0.019	0.046
$[t-5, t+10]$	0.009	-0.002	0.012	0.064	0.011	0.000	0.011	0.105
$[t-5, t+20]$	0.014	-0.003	0.016	0.036	0.013	0.000	0.013	0.200

Panel B: Full sample

	Longholder = 0				*Holder67* = 0			
	Minority $N = 340$	Majority $N = 6596$			Minority $N = 307$	Majority $N = 5491$		
	mean	mean	diff (Min - Maj)	p-value	mean	mean	diff (Min - Maj)	p-value
$[t-1, t+1]$	0.003	0.003	-0.001	0.705	0.004	0.003	0.001	0.710
$[t-3, t+3]$	0.005	0.004	0.002	0.581	0.008	0.004	0.004	0.200
$[t-5, t+5]$	0.005	0.004	0.001	0.727	0.006	0.004	0.002	0.540
$[t-1, t+3]$	0.005	0.004	0.001	0.607	0.007	0.003	0.003	0.191
$[t-1, t+5]$	0.006	0.004	0.002	0.493	0.006	0.003	0.003	0.304
$[t-1, t+10]$	0.009	0.004	0.006	0.097	0.013	0.004	0.009	0.013
$[t-1, t+20]$	0.014	0.002	0.013	0.028	0.017	0.001	0.016	0.015
$[t-3, t+5]$	0.006	0.004	0.002	0.488	0.008	0.004	0.004	0.258
$[t-3, t+10]$	0.009	0.003	0.006	0.155	0.014	0.004	0.010	0.037
$[t-3, t+20]$	0.015	0.002	0.013	0.054	0.019	0.002	0.017	0.029
$[t-5, t+10]$	0.008	0.003	0.005	0.241	0.013	0.004	0.009	0.085
$[t-5, t+20]$	0.014	0.002	0.012	0.074	0.017	0.002	0.015	0.050

Figure C.1: Acquisition type and announcement CARs

This figure displays the coefficients of the second stage of a treatment selection model for the sample of public targets. In this second stage the CARs over several windows are regressed on one of the overconfidence measures *Longholder* or *Holder67*, which are dummy variables taking the value of 1 if the CEO is classified as overconfident; *Majority Stake*, a dummy taking the value of 1 if the acquisition was a majority stake acquisition; and their interaction effects. In the first stage the selection of the treatment (*Majority Stake*) is captured by including the following selection variables: *Size, Tobin's Q, Cash Flow, Investments, Cash, Leverage, Corporate Governance, Owner, Prev.acq.All, Prev.acq.Minority, Cross-Industry, Cross-Country*. The definitions of these variables are provided in the caption of Table 2.5. The circles represent the estimated coefficients and the spiked lines represent 95% confidence intervals. The coefficients are estimated by the method of maximum likelihood.



Let us never negotiate out of fear,

but let us never fear to negotiate.

John Fitzgerald Kennedy

3

To Auction Directly or Sequentially?[†]

WHETHER IT IS A PIECE OF ART, a car, or even a house, all kinds of objects are sold via auctions. Nowadays, even holidays or day trips are auctioned off online to the highest bidder within a certain time limit. It is evident that auctions are a popular selling mechanism. On the other hand, one may sell an object through a negotiation with a potential seller. The choice between these two selling mechanisms is often crucial and, therefore, has been widely studied.

[†]This chapter is based on Matawlie (2020)

Bulow & Klemperer (1996) state that competition among bidders drives prices up, such that an auction should be the preferred selling mechanism for sellers. Bulow & Klemperer (2009) indeed show that auctions generate higher revenues from a seller's point of view compared to sequential negotiations (where buyers make offers sequentially). On the other hand, Roberts & Sweeting (2013), find that the seller can obtain higher expected revenues from the sequential negotiation than from the simultaneous auction, even when buyers' signals about their values are noisy. It is, therefore, as yet unclear whether sellers should prefer auctions or negotiations.

Whereas the relative performance of auctions versus (sequential) negotiations for sellers has been widely examined, auctions have, to our best knowledge, not been compared to negotiations which are only followed by an auction if the negotiation fails. Motivated by the observation that many auctions in corporate transactions are preceded by one-to-one negotiations, and by anecdotal evidence from the real estate market that auctions are organized after negotiations with one or two private parties have failed, we explore another selling mechanism: the sequential mechanism. In a sequential mechanism, a seller of an object can choose to negotiate first privately with an interested buyer, and if the negotiation fails due to price inadequacy, the seller organizes an auction afterwards. Alternatively, the seller could opt to sell the object directly via an auction.

We first model the choice between both selling mechanisms, sequential mechanism and direct auction, through a rational framework where organizing an auction is costly in the form of search costs. Search costs represent all direct and indirect costs associated with organizing an auction. We find that from a rational point of view, a seller should always prefer the direct auction as this results in higher expected payoffs. This is intuitively understandable, as a failed negotiation sends out a signal which leads to lower revenues in the subsequent auction. All in all, this results in lower total expected payoffs from the complete sequential mechanism than from the direct auction. We denote the difference in expected payoffs between the direct auction and sequential mechanism as the 'negotiation penalty' at mechanism level. We find that this mechanism negotiation penalty decreases in search costs. On the other hand, the difference in expected payoffs between the direct and sequential auction increases in search costs.

These findings do however, not explain the observation that many sellers still choose to negotiate first. Whereas our rational model is in line with classical economic theory which states that sellers should prefer auctions, as this maximizes expected value, a whole strand of literature shows that agents do not always act as expected value maximizers; neither do they always act as expected utility maximizers (Barberis, 2013). Choosing between a direct auction and a negotiation with a possible subsequent auction in case of failure of the negotiation, is similar to choosing between a prospect with a certain outcome (the auction) and a lottery of outcomes (negotiation with a probability of success, and otherwise proceeding to an auction). Whereas a whole strand of literature shows that there are several channels that affect the *performance* of auctions and negotiations[1], behavioural channels that may explain *the choice* between selling mechanisms have not been explored much.

Choice-making often deviates from rational theory and is therefore also modelled through behavioural theory. Motivated by the analogy of choosing between prospects when choosing between selling mechanisms, we approach this choice between a direct auction and two-stage selling mechanism (negotiation-auction) from a behavioural point of view by incorporating *Prospect Theory* (PT) in our auction theory model. Prospect the-

[1] See for instance Thaler (1988) (winner's curse), Betton & Eckbo (2000) (toeholds), Povel & Singh (2006) (asymmetry), Hörner & Sahuguet (2007) (costly signaling), Aktas et al. (2010) (pressure of competition). Gentry & Stroup (2019) (information frictions)

ory (Kahneman & Tversky, 1979; Tversky & Kahneman, 1992) is a prominent behavioural theory which is also able to capture behavioural traits that utility theory fails to explain.

To the best of our knowledge, choice making between a direct auction and a sequential selling mechanism has not yet been analyzed through a behavioural lens by integrating prospect theory and auction theory. We examine which selling mechanism the seller would prefer according to prospect theory and how search costs would influence this decision. In contrast with rational theory, we find that a PT agent is able to prefer the sequential mechanism. Furthermore, we find that search costs do not affect this choice in the same way as in the rational framework: The PT preference parameters determine whether search costs affect the negotiation penalty between selling mechanisms in a positive or negative way.

For an empirical investigation of our model's predictions, we use a dataset of corporate takeovers through any of these selling mechanisms: direct auction, negotiation, or sequential auction. We find that the negotiation penalty exists in the form of lower premiums for the sequential auction compared to the direct auction. This negotiation penalty does not exist between the negotiation and direct auction. Both these findings are in accordance with our rational model.

Furthermore, we find that the likelihood of choosing the sequential mechanism seems to decrease in search costs, which can be explained by our PT model. This may be counterintuitive at first. After all, one may think that with high search costs, a seller should try the negotiation therewith avoiding the costs of the auction. However, the perspective of failing the negotiation and then facing lower payoffs in the subsequent auction, makes the choice for the direct auction more attractive. This shows us that whereas outcomes (payoffs) of the selling procedures are explainable by rational theory, choice between selling mechanisms is not.

Our research is closely related to the ongoing discussion in the literature on whether sellers should prefer auctions or negotiations (e.g. Bulow & Klemperer, 2009; Roberts & Sweeting, 2013; Davis et al., 2013). Many channels may influence the choice between selling mechanisms, however the behavioural channel has not much been explored. We contribute to this discussion and the literature by comparing the direct auction with a sequential selling procedure. We model the choice between selling procedures both from a rational and behavioural angle and we compare the predictions. We show that in our models the choice for a sequential selling mechanism can be explained with prospect theory but not with expected value maximization. We furthermore contribute to the literature on behavioural theory, in particular prospect theory and its applications.

This chapter is organized as follows, Section 3.1 discusses literature on auctions and negotiations. Section 3.2 outlines the models and their predictions and Section 3.3 discusses model results. Section 3.4 presents an empirical illustration of the model. Then follows a conclusion in Section 3.5.

3.1 Literature

Since the seminal work of Vickrey (1961), auction theory has been studied from several perspectives (see Klemperer (1999) for an early overview and see e.g. Krishna (2009) for a modern-day overview of fundamental concepts). Paul Milgrom and Robert Wilson received the 2020 Nobel prize in economic sciences for their improvements to auction theory and inventions of new auction formats (see e.g., Milgrom & Weber, 1982; Milgrom, 1989, 2000; Milgrom & Milgrom, 2004; Wilson, 1979, 1985, 1992). This only more demonstrates how relevant and topical auction theory related questions are.

Auctions have been a popular subject from practical, empirical, and theoretical angles. After all, auctions are a widely used selling mechanism: From governmental transactions to corporate takeovers, to the sale of real estate, consumer objects and art, all of these are possible to conduct through auctions, either physical or virtual[2].

Besides auctions, objects can also be sold through one-on-one negotiations (or variants of these). The comparison of auctions and negotiations as selling mechanisms has been widely studied. Classical economic theory, formalized by Bulow & Klemperer (1996) states that competition among bidders drives prices up, so that an auction should be the preferred selling mechanism for sellers. They show that a standard English auction (ascending price, open bid) with one extra bidder generates higher revenues than every form of negotiation without that extra bidder.

Bulow & Klemperer (2009) show why sellers usually prefer auctions by comparing a simple simultaneous auction to sequential negotiations (a sequential process in which potential buyers decide in turn whether to enter the bidding) under the condition that participation in each of the mechanisms is costly. They find that auctions generate higher expected revenues from a seller's point of view, however negotiations are more efficient from a general welfare point of view[3]. Furthermore, they show that "*sellers will generally prefer auctions and buyers will generally prefer sequential mechanisms*". This is also illustrated through a poll conducted among private equity firms, in which 90% of the private equity firms indicated that they would prefer to avoid auctions when they act as bidders,

[2] For example Varian (2007) study advertisement auctions used by Google and Yahoo. Bajari & Hortaçsu (2003) study the winner's curse in eBay auctions. The winner's curse in auctions was first studied by Thaler (1988).

[3] A similar finding is obtained in the context of corporate takeovers by Pagnozzi & Rosato (2016), who focus on the mechanism that maximizes consumers' surplus; in their model it turns out that the mechanism that is preferred by the *buyer* maximizes consumers' surplus. Gretschko & Wambach (2016) compare auctions versus negotiations in public procurement and find that an intransparent negotiation always yields higher social surplus than a transparent auction.

but 80% of the same companies pointed out that as sellers, they would prefer auctions (Stephenson et al., 2006).

Davis et al. (2013) find in an experimental setting, despite the theoretic predictions of Bulow & Klemperer (2009), that average seller revenues tend to be higher under a sequential negotiation mechanism. Roberts & Sweeting (2013) also compare auctions with sequential mechanisms, however, they allow potential buyers to receive a noisy signal about their valuation before entering any of the mechanisms. They show that the seller can obtain higher expected revenues from the sequential negotiation compared to the simultaneous auction, even when buyers' signals about their values are quite noisy[4]. Judging by the literature, there is as yet no clear conclusion about which selling mechanism sellers should prefer.

A related strand of literature analyzes channels that affect the performance of auctions and negotiations, such as the winner's curse (Thaler, 1988), effect of toeholds in bidding (Betton & Eckbo, 2000), asymmetry among bidders (Povel & Singh, 2006), costly signaling in auctions (Hörner & Sahuguet, 2007) and latent pressure of competition (i.e. an auction) in negotiations (Aktas et al., 2010). Gentry & Stroup (2019) analyzed channels through which information frictions affect takeover markets. They tried to identify situations in which auctions or negotiations produce higher prices for target shareholders and found that auctions tend to produce higher prices in takeover markets with high pre-entry uncertainty, while the reverse is true for negotiations.

[4]Other studies on the theoretical comparison of auctions and negotiations include among others Bajari & Tadelis (2001) (procurement contracts, buyer point of view), Fluck et al. (2007) (privatization), McAdams & Schwarz (2007) (credibility in sale mechanisms), or Manelli & Vincent (1995) (procurement mechanisms). Empirical studies on comparison of these sale mechanisms have been conducted by Bajari et al. (2009) (procurement), Boone & Mulherin (2007) (corporate firm sales), Mayer (1998); Chow et al. (2015) (real estate sales), Kjerstad (2005) (medical and surgical articles), Lusht (1996) (real estate: they find that auctions produce 8% higher prices than negotiations for real estate sales in Melbourne.).

In light of the behavioural channel, auction theory has furthermore been extended from the risk-neutral perspective to an expected utility perspective (e.g Maskin & Riley, 1984; Cox et al., 1988). Prospect theory (PT), on the other hand, is a prominent alternative behavioural theory which formulates a model for decisions under risk and uncertainty (Tversky & Kahneman, 1992). With their initial paper, Kahneman & Tversky (1979) demonstrated how people systematically violate the predictions of expected utility. With prospect theory, they presented a model which captures the experimental evidence on risk taking, including the documented violations of expected utility. Prospect theory encompasses the elements loss aversion, diminishing sensitivity, probability weighting, risk aversion (seeking) over gains (losses), and reference point dependence, all of which have shown to be behavioural traits affecting decision-making. For a guide to prospect theory and its characteristics, see Wakker (2010). Prospect theory has known applications in different fields, for an overview of research on applications of prospect theory in several fields, see Barberis (2013).

In this study, we analyze the decision between an auction and a two-stage selling mechanism. In the two-stage or sequential mechanism, a seller starts off with a private negotiation and proceeds to an auction when the negotiation fails. The choice between these two selling mechanisms strongly resembles the choice between two prospects. Due to this analogy and to explore the behavioural channel more, we analyze the decision between these two selling mechanisms with an integrated prospect theory and auction theory framework.

3.2 Model and Predictions

This section develops a simple model, with one seller of a single object and a maximum of two bidders who compete in the auction. The seller may choose to sell the object via an auction where bidders compete against each other by offering higher prices and the seller receives the highest bid[5]. Soliciting bids in an auction is not free as it requires time, investment, and effort. We indicate these costs as *search costs*, which in total include direct costs, such as costs for organizing the selling process, as well as indirect costs, such as opportunity costs resulting from distractions from daily operations and the effort to find bidders. To account for these costs, we assume that the seller pays a fixed cost c for organizing an auction.

On the other hand, the seller may opt for a two-stage mechanism. In such a mechanism, we assume that the seller starts off with a one-on-one private negotiation with one bidder and may proceed to an auction eventually when the negotiation fails[6]. We assume that there are no significant costs involved in a private negotiation. Hence, the seller may believe that trying the negotiation is a free extra option. However, how does a failed negotiation affect the bidding behaviour of bidders in the subsequent auction and how does the expected payoff of a two-stage mechanism compare to a direct auction? We model these settings for the case of two bidders. We will refer to the direct auction as the simultaneous auction (SIMA) and to the two-stage mechanism as the sequential mechanism

[5] We consider a closed-form first price auction in our model. Note however that the first-price closed form auction is strategically equivalent to the open descending price auction (Krishna, 2009).

[6] This mechanism may seem similar to the two-stage mechanism of Betton et al. (2009) for corporate acquisitions. However, in our mechanism the seller initiates the process instead of the buyer. Moreover, the model of Betton et al. (2009) describes a bidding contest for a firm and therefore includes context-specific variables, whereas our model considers the sale of a general object and not a firm in particular.

(SEQ) with a first-stage negotiation (NEG) and a possible sequential auction (SEQA).

3.2.1 Model Setup

Consider two bidders, B_1 and B_2 in the possible selling procedures SIMA and SEQ described above. Both bidders have private and independent values for the target. Without loss of generality, we normalize the seller's value of the object to 0 and the buyers' valuations between 0 and 1 (Bulow & Klemperer, 1996). Although the seller does not observe the bidders' valuations (v_1, v_2), (s)he knows the distribution of values, $v_i \overset{iid}{\sim} U(0,1)$.

For the SIMA, it is fairly straightforward to derive the equilibrium strategies. Since the bidders are symmetric in this setting (they have the same range and distribution of private values), the equilibrium strategies are also symmetric (for details see Krishna, 2009). Let $b_i^s(v_i)$ be the bidding function for *symmetric* bidders. The bidding function is found by maximizing the expected payoff of a bidder and solving the resulting differential equation, this gives :

$$b_i^s(v_i) = \frac{1}{G(v_i)} \int_0^{v_i} yg(y)dy, \tag{3.1}$$

This result holds for general n and any i.i.d distribution F of private values. Furthermore, $G(\cdot)$ denotes the CDF of $Y_1^{(n-1)}$, the highest order statistic of $n-1$ private values. For $n = 2$ bidders with $v_i \overset{iid}{\sim} U(0,1)$, this gives

$$b_i^s(v_i) = \frac{1}{2} v_i. \tag{3.2}$$

The net benefit for bidder i is equal to $(v_i - b_i^s(v_i)) = v_i/2$. For the expected payoff in the SIMA for the seller we have

$$\mathbb{E}[\text{SIMA}] = b_i^s\Big(\mathbb{E}\big[\max\{v_1, v_2\}\big]\Big) - c = \frac{1}{3} - c \tag{3.3}$$

In the sequential mechanism SEQ, the selling party first negotiates (NEG) with one bidder B_1. If the private value of this bidder v_1 is larger than some threshold $z \in (0,1)$, B_1 bids a price p^*, which the seller accepts[7]. Otherwise, if $v_1 < z$, B_1 bids p_0 which the seller rejects. If the negotiation fails, the seller proceeds to an sequential auction, where the first bidder B_1 participates again. The seller has to pay an extra amount of c to attract the second bidder and organize the auction, here c represents the aggregated search costs.

In the sequential auction following the failed negotiation, the second bidder B_2 has a uniformly distributed private value $v_2 \in [0,1]$. Being in a SEQA means that the NEG has failed, therefore, B_2 infers that B_1's private value is uniformly distributed as $v_1 \in [0,z]$[8]. We can derive the equilibrium bidding strategies of these *asymmetric* bidders as follows: Let $b_1^a(v_1)$ and $b_2^a(v_2)$ be the asymmetric bidding functions of respectively B_1 and B_2, with inverse bidding functions ϕ_1 and ϕ_2. Furthermore, we have $b_1^a(0) = b_2^a(0) = 0$ and $b_1^a(z) = b_2^a(1) = \bar{b}$, which denotes the common highest bid[9]. The expected payoff for bidder $i \neq j$, with value v_i bidding an amount $b < \bar{b}$ is given by:

$$\Pi(v_i, b) = F_j\big(\phi_j(b)\big)(v_i - b), \tag{3.4}$$

[7] This can also be viewed as that the seller proposes a price p^* which the bidder B_1 is willing to pay when $v_1 \geq z$.

[8] The conditional probability $\Pr(U \leq u | U \leq z) = \frac{\Pr(U \leq u, U \leq z)}{\Pr(U \leq z)} = \frac{u}{z}$, which indicates an $(0,z)$-uniformly distributed variable.

[9] If for instance $b_2^a(1) > b_1^a(z)$, then B_2 with private value equal to 1 could increase the payoff by bidding slightly less than $b_2^a(1)$ and vice versa. For details see Krishna (2009).

where F_j is the cumulative distribution function of private values for bidder j. Taking the first-order condition with respect to b allows to rewrite:

$$\phi_j'(b) = \frac{F_j\left(\phi_j(b)\right)}{f_j\left(\phi_j(b)\right)} \frac{1}{(\phi(b) - b)} \tag{3.5}$$

with $f_j = F_j'$ being the PDF of v_j. Next, solving the differential equations for ϕ_1 and ϕ_2, with boundary conditions $\phi_1(\bar{b}) = z$ and $\phi_2(\bar{b}) = 1$, ultimately allows us to take the inverses of ϕ_i to obtain the bidding functions, which are in our setting:

$$b_1^a(v_1) = \frac{1}{k_1 v_1}\left(1 - \sqrt{1 - k_1 v_1^2}\right) \quad v_1 \in [0, z] \tag{3.6}$$

$$b_2^a(v_2) = \frac{1}{k_2 v_2}\left(1 - \sqrt{1 - k_2 v_2^2}\right) \quad v_2 \in [0, 1] \tag{3.7}$$

$$k_1 = \frac{1}{z^2} - 1 \tag{3.8}$$

$$k_2 = 1 - \frac{1}{z^2} \tag{3.9}$$

$$b_1^a(z) = b_2^a(1) = \bar{b} = \frac{z}{z+1} \tag{3.10}$$

The first bidder B_1 can, however, choose to deviate from this strategy by pretending that (s)he is a low-type ($v_1 < z$) bidder in the negotiation stage. The second bidder B_2 will assume in the auction stage that B_1 is a low-type bidder and therefore has private value $v_1 \in [0, z]$. Hence, B_2 will bid accordingly $b_2^a(v_2)$ as in Equation (3.7).

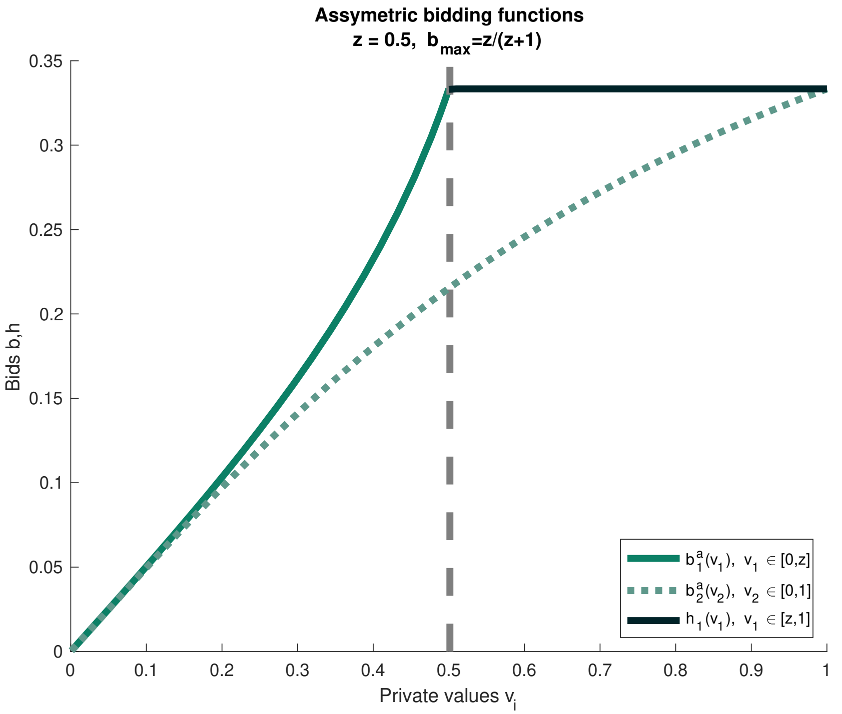
The bidding function $h_1(v_1)$ for the deviating high-type bidder B_1 is obtained by optimizing the expected payoff in the case of deviating:

$$h_1(v_1) = \arg\max_{h_1(v_1)} \left\{ F\left(b_2^{a^{-1}}(h_1)\right)(v_1 - h_1) \right\}, \tag{3.11}$$

where F is the cumulative distribution function of the standard uniform distribution and $b_2^{a^{-1}}$ is the inverse function of b_2^a. By solving Equation (3.11) with h_1 between 0 and the highest possible bid $\bar{b} = \frac{z}{z+1}$ (Equation (3.10)), we find that it is rather optimal for the deviating bidder to just bid the maximum bid $\bar{b} = b_1(z) = b_2(1)$. Hence,

$$h_1(v_1) = \bar{b} = \frac{z}{z+1} \quad \text{for } v_1 \in [z, 1] \tag{3.12}$$

Figure 3.1: Bidding functions for $z = 0.5$
This figure shows the asymmetric bidding functions for both bidders $b_1^a(v_1)$ and $b_2^a(v_2)$ along with the bidding function for the high-type deviating bidder $h_1(v_1)$ for an arbitrary value of $z = 0.5$.



An example of bidding functions for arbitrary $z = 0.5$ is displayed in Figure 3.1 (and for $z = 0.2$ in Figure E.1 in E). From these figures, we observe how b_1 is steeper, which indicates that B_1 bids more aggressively since the bids are over a smaller range than from

B_2. We furthermore see that both bidding functions are increasing with private values and the maximum bid is obtained for the maximum private values z and 1 of B_1 and B_2 respectively, such that $b_1(z) = b_2(1) = \bar{b} = \frac{z}{z+1}$.

Using the equilibrium bidding functions and distributions for the private values (v_1, v_2) we can derive the expected payoff for the seller from the sequential mechanism. The expected value from the negotiation (NEG) is simply p^*. The expected value of the sequential auction (SEQA) (see Appendix A for details) is[10]:

$$\mathbb{E}[\text{SEQA}] = z^2 \left(\frac{\log\left(\frac{z\left(-\sqrt{z^2-1}+z+1\right)}{z+1}\right)}{(z^2-1)^{3/2}} - \frac{\log\left(\frac{z\left(\sqrt{z^2-1}+z+1\right)}{z+1}\right)}{(z^2-1)^{3/2}} + \frac{2\tan^{-1}\left(\frac{\sqrt{z^2-1}}{z+1}\right)}{(z^2-1)^{3/2}} \right) + \frac{z}{z+1} \tag{3.13}$$

The negotiation succeeds when the private value of the first bidder exceeds threshold z. Since the private values are standard uniformly distributed, the probability of NEG succeeding boils down to $\Pr(v_1 \geq z) = 1 - z$. Hence, with probability z, the seller will need to proceed to the SEQA. Therefore, the expected value of the complete sequential mechanism (SEQ) is:

$$\begin{aligned} \mathbb{E}[\text{SEQ}] &= \Pr(v_1 \geq z)p^* + \Pr(v_1 \leq z)\left(\mathbb{E}[\text{SEQA}] - c\right) \\ &= (1-z)p^* \qquad + z\left(\mathbb{E}[\text{SEQA}] - c\right) \end{aligned} \tag{3.14}$$

[10] We checked the expected value of SEQA by simulating 1.000.000 private values $v_1 \sim U(0, z)$ and $v_2 \sim U(0, 1)$, then calculating SEQA at every simulation and taking the average SEQA over all simulations. We did this for a range of different z. Plotting the SEQA averages as function of z matches expression (3.13).

3.2.2 Equilibrium

Suppose the seller is in the negotiation stage of the sequential mechanism. The seller has no information about the private value v_1 of B_1. The seller knows, however, that the expected value of the simultaneous auction (SIMA) is $\mathbb{E}[\text{SIMA}] = 1/3 - c$. Therefore, the seller would like to receive at least the expected value of SIMA, otherwise it would make no sense to choose the sequential mechanism over SIMA[11]. Therefore, it should hold that $p^* \geq \frac{1}{3} - c$. Of course, in order to maximize the own payoff, B_1 would bid the lowest bid possible which is accepted by the seller. Hence, B_1 bids $p^* = \frac{1}{3} - c$, such that bidder B_1's payoff is $v_1 - (1/3 - c)$.

Furthermore, for a private value equal to the threshold value: $v_1 = z$, the bidder B_1 should be indifferent between finishing the sale in the negotiation or going to the auction. Hence, the payoffs of NEG and SEQA for B_1 should match when $v_1 = z$, that is:

$$
\begin{aligned}
z - p^* &= \Pr\big(b_2^a(v_2) < b_1^a(z)\big)\big(z - b_1^a(z)\big) \\
z - p^* &= \Pr\Big(v_2 < \phi_2\big(b_1^a(z)\big)\Big)\big(z - b_1^a(z)\big) \\
z - p^* &= \phi_2\big(b_1^a(z)\big)\big(z - b_1^a(z)\big) \\
z - p^* &= \phi_2(\bar{b})(z - \bar{b}) = 1 \cdot (z - \bar{b}) = z - \frac{z}{z+1}
\end{aligned}
$$

$$p^* = \frac{z}{z+1} = \frac{1}{3} - c \tag{3.15}$$

$$z = \frac{1-3c}{3c+2} \qquad 0 \leq c \leq \frac{1}{3} \tag{3.16}$$

[11] We consider the case where the bargaining power is not completely with the seller, that is, the seller does not actually set the price. When the seller has all bargaining power, the seller sets the demanded price p^* such that the expected payoff of the sequential mechanism is maximized. Then this results in a higher expected payoff for the sequential mechanism compared to the simultaneous mechanism.

where the search costs are at the most $1/3$, otherwise the expected value of SIMA can become negative. We can verify that indeed for $z = \frac{1-3c}{3c+2}$ it holds for every $v_1 < z$ that

$$v_1 - p < \phi_2\big(b_1^a(v_1)\big)\left(v_1 - b_1^a(v_1)\right) \quad \text{for } v_1 < z \tag{3.17}$$

Notice how the probability that the negotiation succeeds $(1-z)$ is affected by search costs, for $c = 0$, we have $(1 - z) = 1/2$. This probability increases in c to $(1 - z) = 1$ for $c = 1/3$. This is in line with the intuition that in the sequential mechanism, the seller would settle easier in the negotiation when the costs of the auction up ahead are high in case the negotiation fails. Furthermore, since $p^* = \bar{b}$ and the best strategy for a deviating bidder B_1 is to bid $h_1(v_1) = \bar{b}$ for $v_1 > z$, the first bidder has no incentive to deviate from the equilibrium strategy $b_1^a(v_1)$ as outlined above.

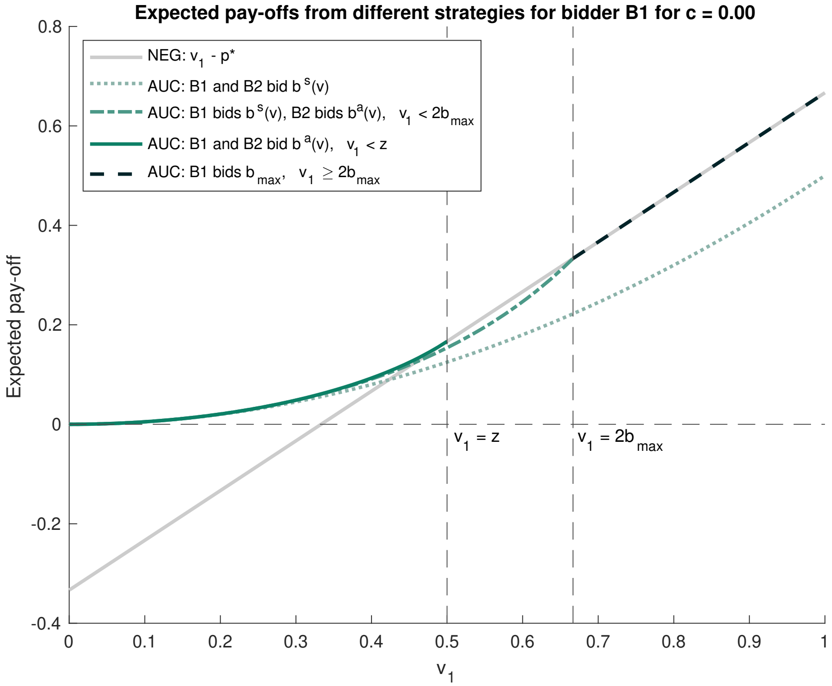
Does B_1 have an incentive to deviate from the general equilibrium strategy described above at all? We have stated that the best strategy to follow for B_1 is to bid p^* in the negotiation if $v_1 \geq z$ and to proceed to the auction and bid $b_1^a(v_1)$ if $v_1 < z$. In Figure3.2 we have plotted for $c = 0$ the expected payoffs for bidder B_1 for different strategies and different selling mechanisms (additional Figures E.2 for $c = 1/12$ and E.3 $c = 1/6$ are in Appendix E). From these figures we observe how for the majority of private values, the expected payoffs for the *bidder* from the negotiation and sequential auction (solid lines) are higher than from the direct auction (dotted line). This confirms that bidders in general prefer negotiations over auctions.

The expected payoff for the bidder in every strategy is

$$\text{Pr(other bidder's bid is lower)} \times [\text{private value - own bid}].$$

Figure 3.2: Bidding strategies for B_1 with $c = 0, z = 1/2$
This figure shows the expected payoffs for bidder B_1 resulting from different strategies that are possible to follow for B_1 in the case of $c = 0 \implies z = 1/2$. The expected payoff for the negotiation is the private value minus the equilibrium bid $v_1 - p^*$. The expected payoffs for B_1 from the auction is $\Pr(b_1 > b_2)[v_1 - b_1]$, where b_1 and b_2 denote the bids from bidders B_1 and B_2 respectively, dependent on which strategy the bidders follow. The expected payoffs in the same orders as in the legend in the figure below are therefore:

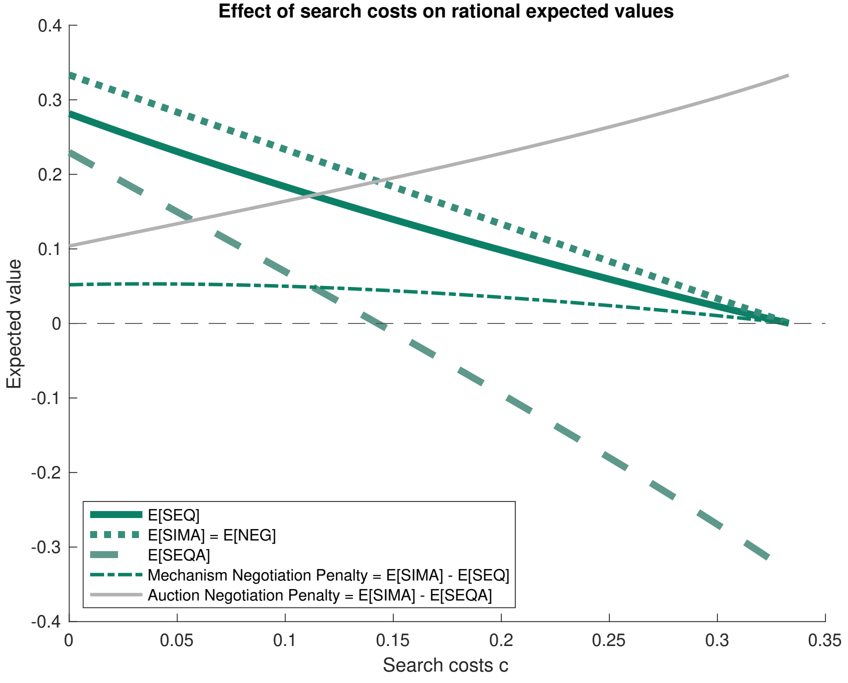
$$\mathbb{E}[AUC] \text{ for } B_1 = \begin{cases} v_1[v_1 - \frac{1}{2}v_1] \\ \phi_2(\frac{1}{2}v_1)[v_1 - \frac{1}{2}v_1] \\ \phi_2(b^a(v_1))[v_1 - b^a(v_1)] \\ 1[v_1 - \bar{b}] \end{cases}$$



In the direct auction, both B_1 and B_2 bid according to $b_i^s(v_i) = 1/2v_i$. Since the bidding strategies are symmetric, the probability of a winning bid for B_1 is $\Pr(v_2 < v_1) = v_1$; the expected payoff from the direct auction is therefore $1/2v_1^2$. In the sequential auction, both bidders bid according to $b_i^a(v_i)$. The probability of a winning bid for B_1 is $\phi_2(b_1^a(v_1))$ as showed in Equation (3.15) and the expected payoff from the sequential auction is therefore $\phi_2\left(b_1^a(v_1)\right)\left[v_1 - b_1^a(v_1)\right]$. If B_1 decides to proceed to the auction regardless of v_1 smaller or larger than z and decides to bid in the auction according to $b_1^s(v_1)$ instead of $b_1^a(v_1)$, the expected payoff is $\phi_2\left(\frac{1}{2}v_1\right)\left[v_1 - \frac{1}{2}v_1\right]$ since B_2 will belief that ending up in the auction implies $v_1 < z$; B_1 will bid b_1^s only for $v_1 < 2\bar{b}$, for higher private values B_1 will win with certainty by bidding $\bar{b}$ as this is the maximum bid of B_2. The Figures 3.2, E.2, and E.3 confirm that the highest expected payoff[12] for B_1 is indeed obtained by bidding b_1^a in the SEQA if $v_1 < z$ and bidding p^* in the NEG if $v_1 > z$.

Figure 3.3: Expected values as function of search costs

This figure shows the rational expected values of the simultaneous (direct) auction (SIMA), the sequential mechanism (SEQ) and the auction stage of the sequential mechanism (SEQA) as a function of the search costs c. Furthermore, the negotiation penalty is displayed at both mechanism level and auction level. The expected value of the negotiation stage of the sequential mechanism (NEG) is equal to the expected value of SIMA.



[12] Although the difference is small, bidding b_1^a gives a strictly higher expected payoff than bidding b_1^s for B_1 in the SEQA.

The expected values of SIMA, SEQ, and SEQA for the *seller* as function of the search costs c are displayed in Figure 3.3. We observe that the expected value of SIMA is higher than that of SEQ for every value of c. We address the difference in expected values as the 'negotiation penalty'. The negotiation penalty exists both at mechanism level (SIMA - SEQ) and auction level (SIMA - SEQA). We observe that the negotiation penalty decreases in search costs at the mechanism level and increases in search costs at the auction level. Hence, whereas high search costs increase the probability of a NEG succeeding in the sequential mechanism, the seller would have been better off choosing the SIMA from the start. This confirms the findings of Bulow & Klemperer (1996) that an auction maximizes payoffs for the seller in a rational framework.

It is therefore, from a rational point of view, still not clear why a seller would prefer the sequential mechanism over the simultaneous auction, since the SIMA is superior in terms of expected value. However, up to now, we have approached this choice problem between SIMA and SEQ from a rational risk-neutral perspective. In the next section, we analyze how utilities and weighted probabilities affect the decision between both mechanisms.

3.2.3 Integrating Prospect Theory and Auction Theory

In this section, we incorporate prospect theory [13] (PT) into our auction theory framework. To the best of our knowledge, PT has not been used before to analyze decisions between these two types of selling mechanisms: Direct auction versus sequential mechanism.

[13] Formally named 'cumulative prospect theory' (Tversky & Kahneman, 1992), it was an adapted and improved version of the original prospect theory (Kahneman & Tversky, 1979). We therefore simply refer to prospect theory (PT) instead of cumulative prospect theory, as is common in the literature (e.g. Wakker, 2010).

Prospect Theory

PT states that people make decisions based on the PT-value, an adapted expected value, where outcomes are evaluated through a utility function (value function) relative to a reference point and probabilities are weighted with a probability weighting function (PWF). Some typical characteristics are that the utility function is convex over losses and concave over gains. Furthermore, the utility function is kinked at the reference point and is steeper for losses. Loss aversion encompasses the behavioural trait that people are more sensitive to losses than to gains. Moreover, another important aspect of PT is probability weighting, conducted via the probability weighting function, which assigns decision weights to the objective probabilities, often in such a way that the tails of the distribution are overweighted. PT states that people use such transformed probabilities rather than objective probabilities for their decisions.

We now briefly review the concepts of prospect theory (PT). Consider several outcomes (gains/losses) x_i with corresponding probabilities p_i, that is, consider the prospect:

$$\mathcal{X} = (p_1, x_1; ...; p_n, x_n), \tag{3.18}$$

where we have

$$x_1 \geq ... \geq x_k \geq RP \geq x_{k+1} \geq ... \geq x_n, \tag{3.19}$$

with RP denoting the reference point, and $\sum_{i=1}^{n} p_i = 1$. The reference point plays no role in the regular expected value and expected utility. The regular expected value of the prospect in Equation (3.18) is simply computed as $\mathbb{E}(\mathcal{X}) = \sum_{i=1}^{n} p_i x_i$. An agent in the expected utility framework with utility function $U(\cdot)$ bases decisions on the expected utility, which is computed as

$$EU(\mathcal{X}) = \sum_{i=1}^{n} p_i U(W + x_i), \tag{3.20}$$

where W is the current level of wealth. A prospect theory agent evaluates the outcomes with corresponding probabilities in Equation (3.18) by computing the following PT-value:

$$PT(\mathcal{X}) = \sum_{i=1}^{n} \pi_i U(x_i; RP). \tag{3.21}$$

Here $U(\;\cdot\;; RP)$ denotes the utility function with reference point RP:

$$U(y; RP) = \begin{cases} u(y - RP) & \text{if } y \geq RP \\ -\lambda u(-(y - RP)) & \text{if } y < RP \end{cases} \tag{3.22}$$

with u being the function that assigns utility to outcomes. The reference point RP is nontrivial and has (empirical) meaning, it determines the point above (below) which outcomes are considered gains (losses). The reference point can represent, for instance, the status quo (current wealth) or even an minimum required gain the agent hopes to achieve, then every outcome below this point will, despite being a positive outcome, 'feel' as a loss. We choose as reference point the current wealth and therefore denote it 0, as is common. Furthermore, λ denotes the loss aversion parameter, which is the factor with which losses 'hurt' more than a gain of the same magnitude is 'enjoyed'. Finally

$$\pi_i = \begin{cases} w^+(p_i + \ldots + p_1) - w^+(p_{i+1} + \ldots + p_1) & \text{for } i \leq k, \\ w^-(p_i + \ldots + p_n) - w^-(p_{i+1} + \ldots + p_n) & \text{for } i \geq k+1. \end{cases} \tag{3.23}$$

The formula in Equation (3.21) can be generalized for a gamble $\mathcal{Y}$ with continuous outcomes y which follow continuous cumulative distribution function $F(y)$ and probability distribution function $f(y) = F'(y)$ with reference point at $RP = 0$ as (Wakker, 2010):

$$PT(\mathcal{Y}) = \int_{\mathbb{R}^-} U(y)w^{-\prime}(F(y))f(y)dy + \int_{\mathbb{R}^+} U(y)w^{+\prime}(1-F(y))f(y)dy. \quad (3.24)$$

$$= \int_{-\infty}^{0} U(y)\frac{d}{dy}\Big(w^{-}(F(y))\Big)dy + \int_{0}^{\infty} U(y)\frac{d}{dy}\Big(-w^{+}(1-F(y))\Big)dy. \quad (3.25)$$

PT in the Negotiation-Auction Framework

Incorporating PT in our auction theory model of direct auction and the sequential selling mechanism comes down to applying the utility function and probability weighting functions continuously for the evaluation of SIMA, Equation (3.3) and SEQA, Equation (3.13) and discretely to the probabilities for the evaluation of SEQ, Equation (3.14)[14].

We assume that the decision-maker (who is the seller choosing between mechanisms), evaluates choices according to prospect theory. We assume here that the bidders are (risk-neutral) expected value maximizers and direct the general case where both sellers and bidders are PT agents to future research. For the PT-value of the simultaneous mechanism

[14]One could argue that the expected values of SEQA and SIMA are not calculated by the decision-maker self, but for instance by some analysts. PT could then be applied by just filling in the rationally calculated expected values of SIMA and SEQA in the utility function of the decision maker and weighting the probabilities in $\mathbb{E}[SEQ]$ accordingly. We assume however that the decision-maker evaluates both strategies completely on his/her own, including the expected values and hence applies PT within continuous expectations.

(SIMA), we have

$$PT[\text{SIMA}] = \int_0^{2c} U\left(\frac{1}{2}x - c\right) \frac{d}{dx}\Big(w^-(H(x))\Big) dx + \int_{2c}^{1} U\left(\frac{1}{2}x - c\right) \frac{d}{dx}\Big(-w^+(1 - H(x))\Big) dx, \tag{3.26}$$

where $x = \max\{v_1, v_2\}$ denotes the private value of the highest bidder and $H(x) = F(x)^2$ is the cumulative distribution function (CDF) of the largest order statistic of two standard uniformly distributed variables. The complete integration is over the range $(0, 1)$ since the private values are standard uniformly distributed. Outcomes (which may be gains or losses) in this case are the highest bids resulting from the symmetric bidding function $b^s(x) = x/2$ minus search costs c. As we use a reference point of $RP = 0$, the cut-off point $2c$ in the integral differentiates between positive and negative outcomes: $b^s(x) - c = x/2 - c > 0 \iff x > 2c$.

For the PT-value of the sequential mechanism (SEQ), we have[15]:

$$PT[\text{SEQ}] = \pi_1(z)\,(PT[\text{SEQA}]) + \pi_2(z)U(p^*). \tag{3.27}$$

[15] We assume that the decision-maker first evaluates the value of SEQA and then uses that to evaluate the complete mechanism SEQ. That is, we first calculate the PT-value of SEQA and use the certainty equivalent of this value in the calculation of the PT-value of SEQ. Since the certainty equivalent is obtained by taking $CE = U^{-1}(PT[\text{SEQA}])$ and it is thereafter plugged into the utility function as $U(CE)$ again, we can rather work directly with the value $PT[\text{SEQA}]$ in Equation (3.27).

The weighted probabilities $\pi_1(z)$ and $\pi_2(z)$ in (3.27) are defined as:

$$\pi_1(z) = \begin{cases} w^+(1) - w^+(1-z) = 1 - w^+(1-z) & \text{if } 0 \leq U^{-1}\big(PT[\text{SEQA}]\big) < p^* \\ w^+(z) & \text{if } U^{-1}\big(PT[\text{SEQA}]\big) \geq p^* \\ w^-(z) & \text{if } PT[\text{SEQA}] < 0 \end{cases} \tag{3.28}$$

$$\pi_2(z) = \begin{cases} w^+(1-z) & \text{if } U^{-1}\big(PT[\text{SEQA}]\big) < p^* \\ w^+(1) - w^+(z) = 1 - w^+(z) & \text{if } U^{-1}\big(PT[\text{SEQA}]\big) \geq p^* \end{cases}, \tag{3.29}$$

where the inverse utility function $U^{-1}(\cdot)$ is applied to calculate the certainty equivalent CE. The certainty equivalent is an outcome which gives with certainty the same utility as the utility of a prospect. Recall that the threshold z determines the probability that the negotiation succeeds $(1 - z)$ or fails (z). Then $\pi_1(z)$ and $\pi_2(z)$ are the weighted probabilities of these true probabilities. If the negotiation fails, the PT-value from the resulting SEQA can be either negative or positive depending on the search costs c. When the PT-value is negative, the probability weighting function of losses is applied. In the case that the PT-value of SEQA is positive, the weighted probabilities are determined by examining the order of larger gains, where the gain p^* from NEG can be the largest gain or the certainty equivalent $CE = U^{-1}\big(PT[\text{SEQA}]\big)$ of the PT-value of SEQA can be largest, depending on the PT-parameters and search costs.

The PT-value of SEQA is calculated as:

$$PT[\text{SEQA}] = \int_0^c U(\beta - c)\frac{d}{d\beta}\Big(w^-(L(\beta))\Big)d\beta + \int_c^{\bar{b}} U(\beta - c)\frac{d}{d\beta}\Big(-w^+(1 - L(\beta))\Big)d\beta, \tag{3.30}$$

where $\beta = \max\{b_1^a(v_1), b_2^a(v_2)\}$ denotes the highest of the equilibrium bids of the assymetric bidders in SEQA. The complete integration is over the range $\left(0, \bar{b} = \frac{z}{z+1}\right)$ since the bids can only be between 0 and the maximum bid $\bar{b}$. Outcomes in this case are the maximum bids minus search costs $\beta - c$. The cut-off point c differentiates (with $RP = 0$) between gains and losses: $\beta - c > 0 \iff \beta > c$. Finally, $L(\beta)$ is the distribution function of the maximum of equilibrium bids (for more details see Appendix A):

$$L(\beta) = \Pr\big[\max\{b_1^a(v_1), b_2^a(v_2)\} \leq \beta\big] \tag{3.31}$$

$$= \Pr\big[v_1 \leq \phi_1(\beta)\big] \cdot \Pr[v_2 \leq \phi_2(\beta)] = F_1(\phi_1(\beta))F_2(\phi_2(\beta)) \tag{3.32}$$

3.3 Analysis and Results

In this section, we investigate how search costs affect the PT preferences between the direct auction and the sequential mechanism. We first describe which PT parameters we use for our numerical analysis and shed some light on the interpretation of these parameters. Next, we display for several parameter specifications the effect of search costs on the negotiation penalty, both between auctions (direct versus sequential) and between selling mechanisms (direct auction versus complete sequential mechanism).

3.3.1 Choice of PT Components

One of the challenges in prospect theory is to choose the utility function, the probability weighting function(s), and corresponding parameters. There exists a wide spectrum of available choices for these functions and their parameters, ranging from one-parameter to multiple-parameter specifications. Indeed, several studies have focused on finding the 'optimal ingredients' for the application of PT.

Tversky & Kahneman (1992) (KT) propose in their seminal work on prospect theory a power utility function of the form[16] $u(x) = x^{\alpha}$. Tversky & Kahneman (1992) find that subjects tend to overweight small probabilities and underweight larger probabilities, which would translate to an inverse-S (IS) shaped probability weighting function. The KT PWF has a functional form with one free parameter.

Well-known and often used specifications of two-parameter PWFs were proposed by among more, Goldstein & Einhorn (1987) (GE) and Prelec (1998) (Pr). The advantage of the GE and Pr two-parameter PWFs is that the parameters correspond (not in the same way for GE and Pr) to two clearly interpretable psychological features, which are optimism/pessimism (the curvature of the PWF) and likelihood insensitivity (the elevation of the PWF). Stott (2006) summarizes the results of several other studies that looked into PT parameters and functional forms, and also re-estimates with an own dataset all the parameters for the specifications that were found in different studies. For instance, he finds for the parameter α of the KT power utility function a value of 0.19, which corresponds

[16] Some studies use a functional form for the utility function in PT with different power parameters for gains and losses. However in that case, it is problematic to accurately define loss aversion. For instance with different power parameters, loss aversion depends on the monetary unit; furthermore for some outcomes $y > 0$ it always holds that $U(y) > -U(-y)$. These problems can be avoided by using the same power for losses and gains or by using a different variation of the power family. For details see Wakker (2010) section 9.6.

to a completely different level of concavity (lower value means higher level of concavity) compared to 0.88 found by Tversky & Kahneman (1992).

Balcombe & Fraser (2015) repeated the same kind of procedure as Stott (2006) with even the same data, but now using Bayesian analysis. They find that a power utility form fits best. However, they stress that no single PWF is capable of capturing individual behaviour, particularly they state:

> "While all or nearly all individuals appeared to have concave v-form (utility functions), the individual w-form (probability weightings) were commonly of IS, S, concave or convex functions, consistent with the observation of Wakker (2010, p. 228) that *'In general, probability weighting is a less stable component than outcome utility'*. In behavioural terms what this means is that there are individuals who behave in a purely pessimistic way, purely optimistic way, as well as having the kind of reversal in probability weightings dictated by the S or IS forms. This also means that researchers should be careful in the implementation of the IS approach, as recommended by Tversky & Kahneman (1992). Researchers should not automatically jump to the conclusion that a form that ostensibly facilitates IS behaviour should be imposed on all individuals.

In Table 3.1 we present all the PT specifications we have used in this study, with the corresponding estimated parameters and their source. Not every combination of PT parameters is equally likely, therefore the parameter combinations found in previous studies provide a good starting point. Since these specifications were all found to fit a particular dataset, we will investigate what kind of results our auction-negotiation model produces under these specifications. Furthermore, when investigating the effect of several PT parameters, we will differentiate between the PWF types S-form, IS-form, concave (optimist), and convex (pessimist), as mentioned by Balcombe & Fraser (2015).

The parameters in the utility function and probability weighting functions represent different features. The exponent $\alpha \in (0, 1)$ in the utility function adjusts the concavity/convexity of the utility function: A lower value of α means more concavity (convexity) over gains (losses). The parameter $\lambda > 0$ denotes the loss aversion parameter, a higher value of λ indicates a greater relative sensitivity to losses compared to gains and thus a higher degree of loss aversion. The KT-PWF parameters $\delta, \gamma \in (0.28, 1)$[17] regulate the degree of overweighting of the tails of the probability distribution for losses and gains respectively, lower values indicate more overweighting of the tails.

The GE-PWF parameters a governs the curvature of the PWF and therefore corresponds to likelihood insensitivity. Moreover, values $a < 1$ correspond to an inverse-S (IS) form of the PWF and $a > 1$ to a S form: Lower (higher) values correspond to a stronger IS (S) form. Likelihood insensitivity increases in a further away from 1. The parameter b is related to the elevation of the curve and represents an anti-index of pessimism: Pessimism increases when b decreases. For the Pr-PWF, the parameters have similar (but slightly different) interpretations, likelihood sensitivity increases with higher values of r, and pessimism increases as s increases.

3.3.2 Numerical Analysis

For all specifications mentioned in Table 3.1, we have calculated the PT-values and the certainty equivalents (CE) of the simultaneous auction (SIMA) and the complete sequential mechanism (SEQ). Next, we calculated the negotiation penalty as the difference between

[17] The probability weighting functions are not strictly increasing for values of δ and γ lower than 0.28.

Table 3.1: Overview of used PT parameters and functions

This table shows an overview of used PT inputs. Panel (a) displays the used utility function and panel (b) the several probability weighting functions (PWFs). In panel (c) we have presented several sets of PWF-associated parameters along with the research in which these parameters were found. Furthermore in the last column of panel (c) we have included the code name for all the PWF specifications used. These code names are used in the main text and legends of figures to refer to these cases.

A: Utility function - power utility

$$U(x) = \begin{cases} x^a & \text{for } x \geq 0, \\ -\lambda(-x)^\alpha & \text{for } x < 0 \end{cases}$$

Note: also possible to use different powers for gains (α) and losses (β), then $\lambda = 1$

B: Probability weighting functions (PWFs)

Paper	PWF	Code name	Notes
Tversky & Kahneman (1992)	$w^+(p) = \frac{p^\gamma}{(p^\gamma+(1-p)^\gamma)^{1/\gamma}}$ $w^-(p) = \frac{p^\delta}{(p^\delta+(1-p)^\delta)^{1/\delta}}$	KT	δ: losses, γ: gains
Goldstein & Einhorn (1987)	$w(p) = \frac{bp^a}{bp^a+(1-p)^a}$	GE	$^{(+)}$: gains, $^{(-)}$: losses
Prelec (1998)	$w(p) = exp(-s(-\ln(p))^r)$	Pr	$^{(+)}$: gains, $^{(-)}$: losses
Wu & Gonzalez (1996)	$w(p) = \frac{p^g}{(p^g+(1-p)^g)^d}$	GW	$^{(+)}$: gains, $^{(-)}$: losses

C: Specifications

Paper	PWF	Parameters				Loss aversion	Code name
Tversky & Kahneman (1992)	KT	$\alpha = 0.88$	$\delta = 0.69$	$\gamma = 0.61$		$\lambda = 2..25$	KT-II
Wu & Gonzalez (1996)	KT	$\alpha = 0.88$	$\delta = \gamma = 0.61$			$\lambda = 2..25$	KT-I
Camerer & Ho (1994)	KT	$\alpha = 0.225$	$\delta = \gamma = 0.56$			$\lambda = 1$	KT-CH
Wu & Gonzalez (1996)	KT	$\alpha = 0.5$	$\delta = \gamma = 0.71$			$\lambda = 1$	KT-GW
Stott (2006)	KT	$\alpha = 0.19$	$\delta = \gamma = 0.96$			$\lambda = 1$	KT-St
Bleichrodt & Pinto (2000)	KT	$\alpha = 0.779$	$\delta = \gamma = 0.674$			$\lambda = 1$	KT-BP
Bleichrodt & Pinto (2000)	KT	$\alpha = 1$	$\delta = \gamma = 0.713$			$\lambda = 1$	KT-BP-lin
Abdellaoui (2000)	KT	$\alpha = 0.89$	$\beta = 0.92$	$\delta = 0.70$	$\gamma = 0.60$	$\lambda = 1$	KT-Ab
Wu & Gonzalez (1996)	GE	$\alpha = 0.52$	$b = 0.84$	$a = 0.68$		$\lambda = 1$	GE-GW-I
Gonzalez & Wu (1999)	GE	$\alpha = 0.49$	$b = 0.77$	$a = 0.44$		$\lambda = 1$	GE-GW-II
Birnbaum & Chavez (1997)	GE	$\alpha = 0.82$	$b = 0.31$	$a = 1.59$		$\lambda = 1$	GE-BC
Stott (2006)	GE	$\alpha = 0.19$	$b = 1.40$	$a = 0.96$		$\lambda = 1$	GE-St
Bleichrodt & Pinto (2000)	GE	$\alpha = 0.779$	$b = 0.816$	$a = 0.550$		$\lambda = 1$	GE-BP
Bleichrodt & Pinto (2000)	GE	$\alpha = 1$	$b = 1.127$	$a = 0.573$		$\lambda = 1$	GE-BP-lin
Abdellaoui (2000)	GE	$\alpha = 0.89$	$\beta = 0.92$	$b^+ = 0.65$	$b^- = 0.84$	$\lambda = 1$	GE-Ab
				$a^+ = 0.60$	$a^- = 0.65$		
Bruhin et al. (2010)	GE	$\alpha = 0.941$	$\beta = 1.139$	$b^+ = 0.926$	$b^- = 0.991$	$\lambda = 1$	GE-BFE
				$a^+ = 0.377$	$a^- = 0.397$		
Wu & Gonzalez (1996)	Pr	$\alpha = 0.48$	$s = 1$	$r = 0.74$		$\lambda = 1$	PrI-GW
Stott (2006)	Pr	$\alpha = 0.19$	$s = 1$	$r = 0.94$		$\lambda = 1$	PrI-St
Bleichrodt & Pinto (2000)	Pr	$\alpha = 1$	$s = 1$	$r = 0.589$		$\lambda = 1$	PrI-BP-lin
Bleichrodt & Pinto (2000)	Pr	$\alpha = 0.779$	$s = 1$	$r = 0.553$		$\lambda = 1$	PrI-BP
Bleichrodt & Pinto (2000)	Pr	$\alpha = 1$	$s = 0.938$	$r = 0.604$		$\lambda = 1$	PrII-BP-lin
Bleichrodt & Pinto (2000)	Pr	$\alpha = 0.779$	$s = 1.083$	$r = 0.534$		$\lambda = 1$	PrII-BP
Balcombe & Fraser (2015)	Pr	$\alpha = 0.197$	$s = 0.629$	$r = 0.829$		$\lambda = 1$	PrII-BF
l'Haridon & Vieider (2019)	Pr	$\alpha = 1$	$s^+ = 0.908$	$s^- = 0.941$		$\lambda = 1.939$	PrII-VD
			$r^+ = 0.602$	$r^- = 0.641$			
Wu & Gonzalez (1996)	GW	$\alpha = 0.52$	$g = 0.721$	$d = 1.565$		$\lambda = 1$	GW-GW
Stott (2006)	GW	$\alpha = 0.19$	$g = 0.93$	$d = 0.89$		$\lambda = 1$	GW-St

CEs at *mechanism level* (SIMA - SEQ) and *auction level* (SIMA - SEQA). Then, we investigate whether a negotiation penalty exists for PT agents and how this is affected by search costs. When a specification in Table 3.1 only provided parameters for gains, we used the same parameters for losses in our calculations.

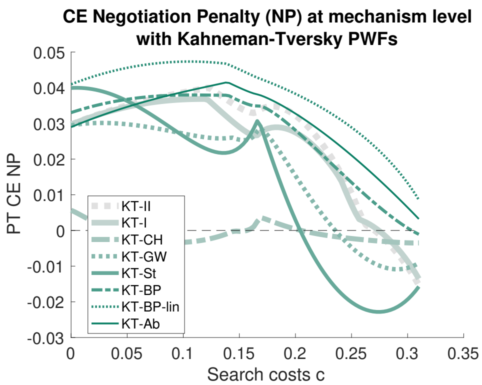
The results at mechanism and auction level are displayed in Figures 3.4 and 3.5 respectively. At the mechanism level, we observe different patterns for the PT negotiation penalty compared to the rational expected values in Figure 3.3. From the rational case, it followed that SIMA is always the superior strategy compared to SEQ in terms of expected values and that there exists a negotiation penalty at mechanism level which decreases mostly in search costs c. However, from the PT framework we observe that for some PT specifications the NP at mechanism level is first clearly increasing for lower search costs and decreasing only for higher levels of c[18]. For other specifications, we even observe negative mechanism NPs for several c, which indicates that for those types of PT agents the preferred strategy is the sequential mechanism (SEQ) rather than the direct auction (SIMA).

At auction level, we observe that the negotiation penalty remains positive for all examined PT specifications. However, the NP is not strictly increasing in c for different PT specifications in contrast to the rational framework. For some PT specifications, we observe a decrease in auction level NP up to $c = 1/6 \approx 0.167$ and an increasing trend again for $c > 1/6$. These observations clearly show us that where it follows from the rational model that SIMA should be the preferred selling strategy, this is not automatically the case for PT agents. PT shows us that, dependent on the parameters of the utility func-

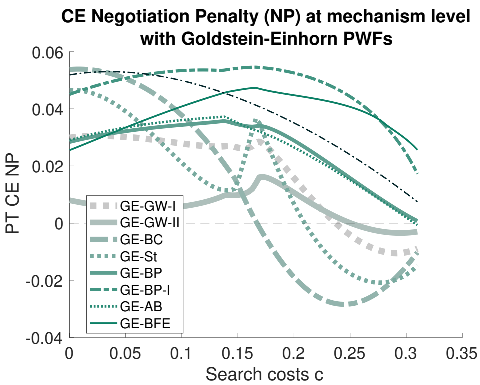
[18] Given that the value of the object is between 0 and 1, very high search costs are not plausible and realistic. The effects of lower level of search costs would therefore be more interesting to focus on. We analyze the complete spectrum for the sake of completeness.

tion and probability weighting function, the effect of search costs can be different, and that even the SEQ can be the preferred mechanism. Hence, this means that there exist PT parameter combinations which could explain why a decision-maker would prefer the sequential mechanism over the simultaneous one, whereas this is not possible in the rational framework.

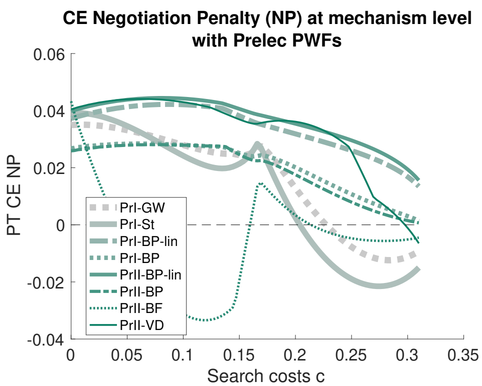
Figure 3.4: CE Negotiation penalty at mechanism level
This figure shows the CE negotiation penalty at mechanism level as function of search costs c for several specifications as described in Table 3.1. The CE negotiation penalty at mechanism level is calculated as the difference between certainty equivalents of PT(SIMA) and PT(SEQ). Per sub-figure the results are displayed regarding one specific type of PWF: (a) Kahneman-Tversky (b) Goldstein-Einhorn (c) Prelec (d) Gonzalez-Wu.



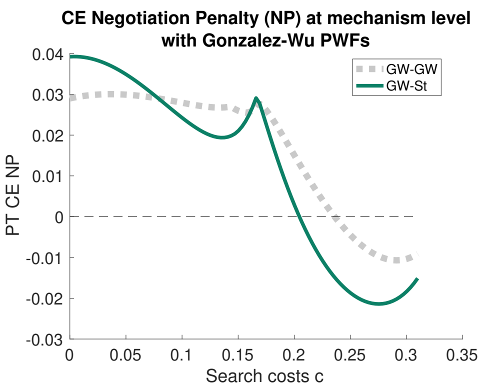
(a) Kahneman-Tversky PWFs



(b) Goldstein-Einhorn PWFs



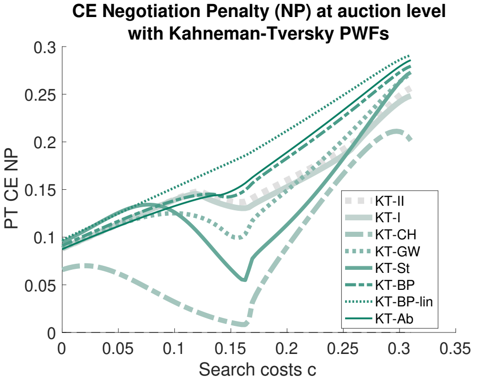
(c) Prelec PWFs



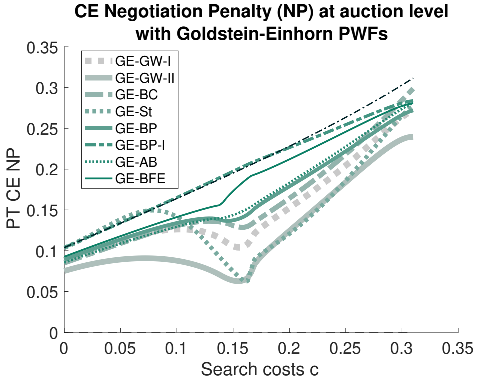
(d) Gonzalez-Wu PWFs

Figure 3.5: CE Negotiation penalty at auction level

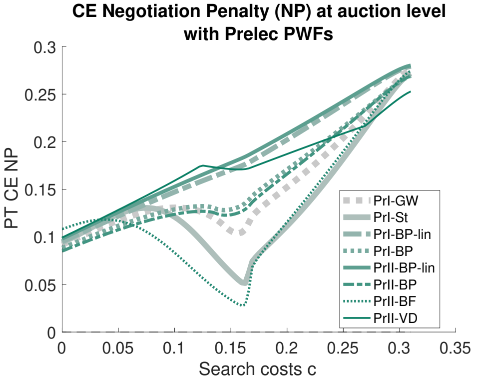
This figure shows the CE negotiation penalty at auction level as function of search costs c for several specifications as described in Table 3.1. The CE negotiation penalty at auction level is calculated as the difference between certainty equivalents of PT(SIMA) and PT(SEQA). Per sub-figure the results are displayed regarding one specific type of PWF: (a) Kahneman-Tversky (b) Goldstein-Einhorn (c) Prelec (d) Gonzalez-Wu.



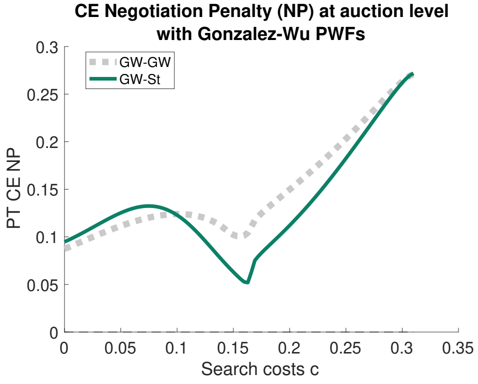
(a) Kahneman-Tversky PWFs



(b) Goldstein-Einhorn PWFs



(c) Prelec PWFs



(d) Gonzalez-Wu PWFs

Comparing the different PT specifications, we observe that in general, the specifications with lower power parameters α, β (around 0.5 or 0.2), show very different patterns for the NP as function of c. The power parameters of the utility function govern the degree of concavity/convexity, where a lower parameter corresponds to a higher degree. We now explore the effects of the PT parameters in more detail. We use the GE-AB specification as base case for our analysis as the GE PWF is a widely used PWF in previous studies and Abdellaoui (2000) provides parameters for both gains and losses. Moreover, the parameters of the GE PWF are well interpretable in terms of optimism and likelihood insensitivity.

We consider variations of the utility function and the probability weighting function separately. Referring to the degree of concavity and convexity, we consider the variations: 'moderate', 'high degree' and 'linear' utility. For the PWF variations, we consider the types: optimist, pessimist, probability overweighting, probability underweighting, S-type PWF, and no probability weighting. An optimist (pessimist) overweights probabilities corresponding to gains (losses) and underweights probabilities corresponding to losses (gains). An probability overweighter (underweighter) structurally overweights (underweights) all probabilities. The S-type PWF underweights small probabilities and overweights large probabilities, this is the other way around for an inverse-S-type (IS) PWF. The base case PWF is of type IS, overweighting corresponds to a strictly concave PWF and underweighting to strictly convex PWF. The used parameter sets for all these cases are in appendix B. Figure E.4 in Appendix E shows how the shape of the GE PWF and the power utility function change with the parameters.

The results of the examined utility function variations are in Figure 3.6. Panel (a) shows the effect of different utility functions at the mechanism level NP. We see that a higher utility power parameter results in higher negotiation penalties. Furthermore, for higher powers it is the case that the mechanism NP is first increasing in c and decreasing for only higher levels of c. Note that the linear utility case demonstrates the sole effect of probability weighting. Comparing this to risk-neutral NP, we see that probability weighting on its own already results in a different relation between NP and c. Lower values of the utility parameters result in lower negotiation penalties and a more or less partially constant or negative relation between c and NP.

In panel (b), we observe the effect of different utility functions on the auction level NP. For lower utility parameters, the NP at auction level is not strictly increasing up to $c = 1/6$. Below $c = 1/6$, the SEQA can still result in gains, and for higher levels of concavity a larger difference in gains results in a smaller difference in utility. For $c > 1/6$, SEQA results surely in losses[19], giving an utility in the loss domain, which increases the auction level negotiation penalty. At the same time, z, which is also the probability of proceeding to SEQA, decreases in c, causing the negotiation penalty at mechanism level to decrease.

The results of the examined PWF variations are in Figure 3.7. In panel (b), we have the effect of several PWFs at the auction level NP. We see that the PWF specifications where (also) large probabilities are overweighted (optimist, overweighter, S-PWF) result in higher NP in general for all levels of c. Overweighting large probabilities clearly dominantly increases the PT-value of SIMA, whereas overweighting only smaller probabilities and underweighting larger probabilities dominantly increases the PT-value of SEQA. In panel (a) we see the effect of PWFs at the mechanism level NP. We see that all specifica-

[19]Figure E.6 in the Appendix shows how search costs c affect the distribution of maximum bids for SEQA. At $c = 1/6$ we have the maximum bid $\bar{b} = 1/6$, which means that for $c > 1/6$ SEQA surely results in a loss.

Figure 3.6: CE NP - Utility function variations

This figure shows the CE negotiation penalty as function of search costs c at mechanism level and auction level for the GE-AB specification as described in Table 3.1 with different variations of the power utility function. The different parameter sets are described in Appendix B. The CE negotiation penalty is calculated at mechanism (auction) level as the difference between certainty equivalents of PT(SIMA) and PT(SEQ) (PT(SEQA)).

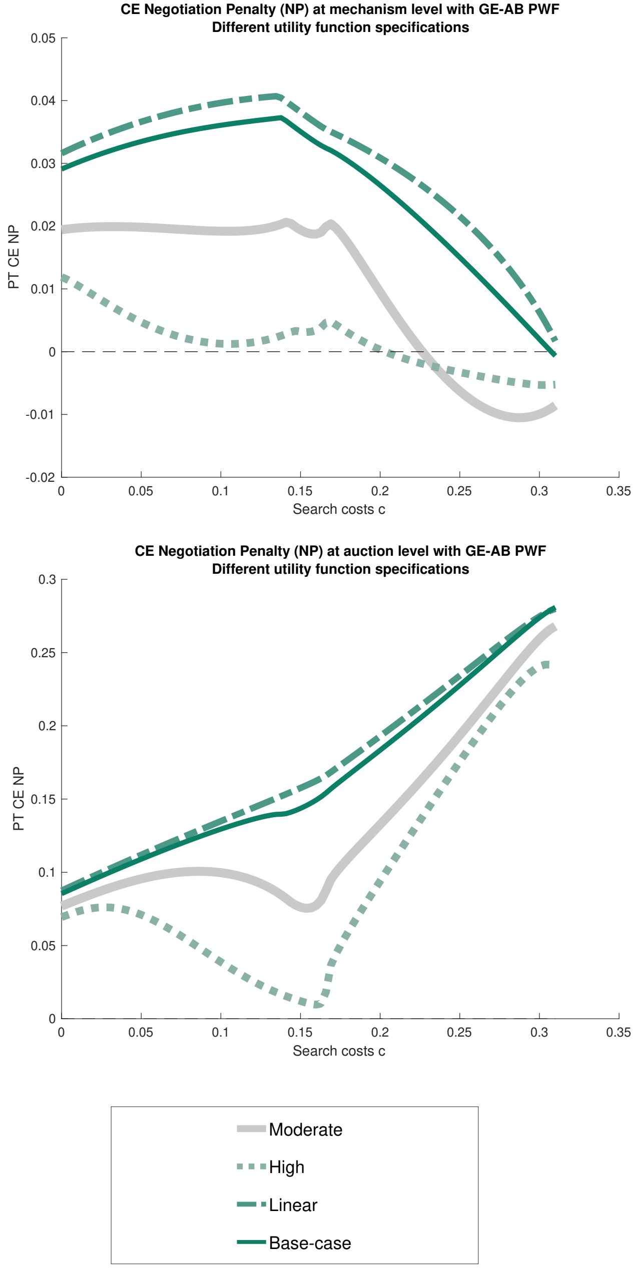
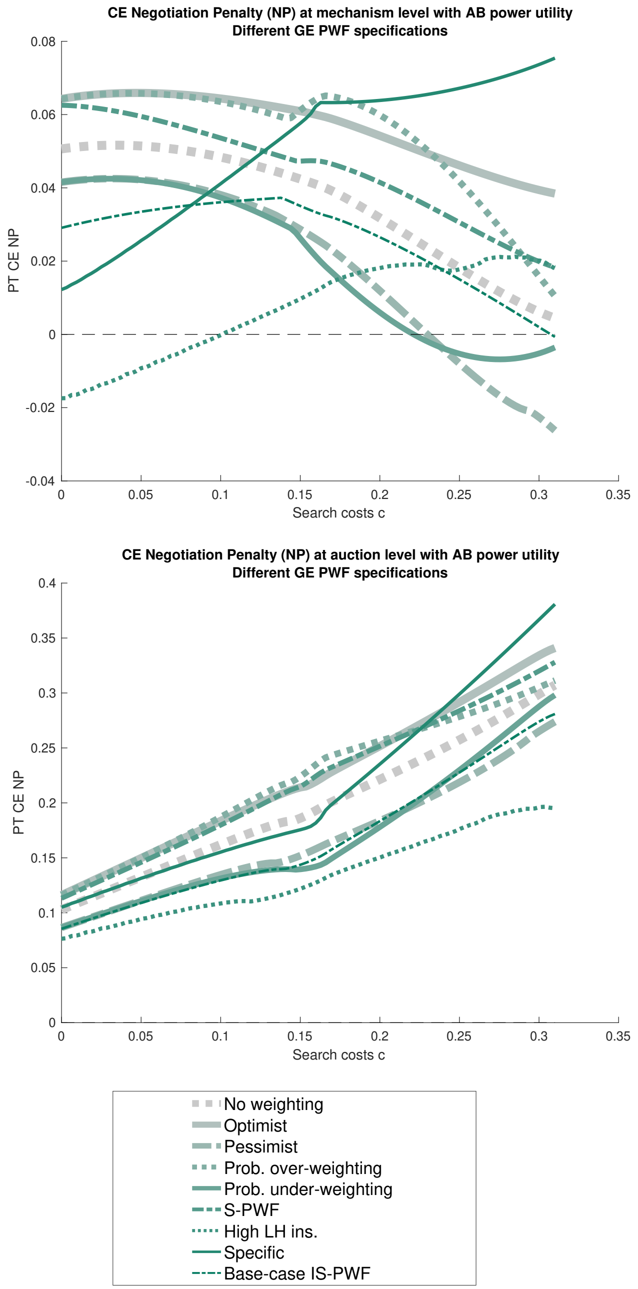


Figure 3.7: CE NP - PWF variations

This figure shows the CE negotiation penalty as function of search costs c at mechanism level and auction level for the GE-AB specification as described in Table 3.1 with different variations of the PWF parameter sets as described in Appendix B. The CE negotiation penalty is calculated at mechanism (auction) level as the difference between certainty equivalents of PT(SIMA) and PT(SEQ) (PT(SEQA)).



tions, except for the base case, specific case, and high likelihood insensitivity result in a (mostly) negative relation between NP and c. Additionally, from the case with no probability weighting we observe a mostly negative relation between search costs and negotiation penalty, in accordance with the rational model.

Hence, this shows us that probability weighting is the dominant factor which causes the relation between search costs and the negotiation penalty at mechanism level to alter from negative to positive, at least for small c and not too concave/convex utility. However, this only happens for a specific type of probability weighting. The base case is namely of the IS-type PWF, where small probabilities are overweighted and large probabilities underweighted. The same holds for the likelihood insensitivity PWF form and the 'specific' form, but then more extreme.

The probability $1 - z$ of the NEG succeeding increases in c from $1/2$ to 1. All these probabilities are underweighted with an IS-type PWF, whereas SEQA gets relatively more weight for smaller c. For larger c however, SEQA results in losses, which causes that the probability of SEQA gets less strongly overweighted, thereby decreasing the difference in PT-values between mechanisms (also see Figure E.6 in Appendix E).

However, with high likelihood insensitivity, the PT-value of SIMA decreases relatively much, leading to a negative negotiation penalty initially for low c. With an inverse-S PWF the values of the auctions (both SIMA and SEQA) are negatively affected as small probabilities are overweighted and larger probabilities are underweighted. The distribution functions of the auctions concern maximum bids or maximum values. Therefore, the probabilities regarding higher outcomes are relatively large[20], and these probabilities are underweighted with an IS-PWF.

[20]For instance for SIMA the probability of the max private value being higher than 0.5 is equal to $1 - H(0.5) = 1 - 0.5^2 = 0.75$.

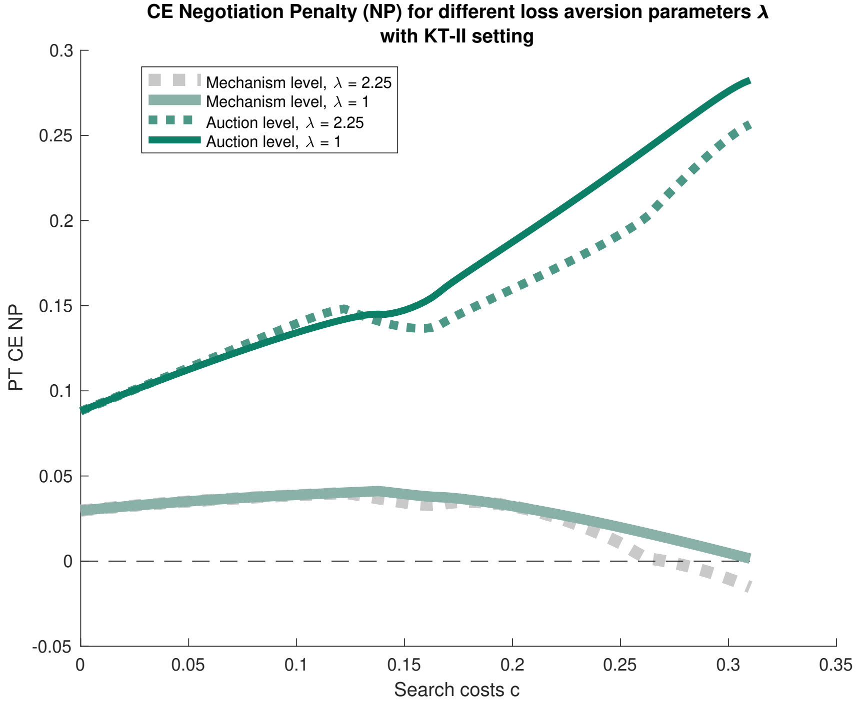
Thus, all in all, there are two main effects of probability weighting: (i) it affects the assigned CE value to the auctions (both SIMA and SEQA); (ii) it affects the probabilities within SEQ, thereby assigning relatively more or less weight to NEG and therewith affecting the NP. The 'specific' PWF form is constructed in such a way that it overweights small probabilities for gains and underweights small probabilities for losses combined with a high degree of likelihood insensitivity. This results in a clearly positive relation between c and NP for all levels of c and emphasizes and illustrates how different types of probability weighting differently affect the preferences between selling mechanisms. These observations motivate us to delve deeper in the effect of the parameters for different PWF types and how these may produce completely different predictions than the rational model, which dictates that the direct auction should be the preferred strategy. Appendix B describes a procedure where we investigate per type of PWF (S, IS, convex, concave) for numerous parameter combinations whether these result in preferring the sequential mechanism over the direct auction ($PT(\text{SEQ}) > PT(\text{SIMA})$. We find that for the IS and concave type of PWFs, also for lower levels of c, around 30-50% of our considered parameter combinations result in preference for SEQ over SIMA. We have to keep in mind however, that not all parameter combinations are equally likely to occur. These results illustrate how the rich domain of PT parameters affects preferences for selling mechanisms and explain why some sellers prefer to choose the sequential mechanism over the simultaneous auction.

Finally, we also investigate the effect of loss aversion in Figure 3.8. We have displayed the NP at both levels for the KT-II setting with loss aversion parameters $\lambda = 1$ and $\lambda = 2.25$. We observe that a higher loss aversion parameter decreases the magnitude of the NP for higher search costs, but the direction remains. This because it dominantly affects the

PT-value of SIMA, as the losses weigh heavier than gains and the integration is over the full range. For SEQA, it is the case that for higher c there are only losses and then loss aversion has no effect since it gets cancelled out in the CE. Also, for higher c the range of integration becomes smaller. All in all the effect is more dominant for SIMA than SEQA.

Figure 3.8: CE Negotiation penalty - different λ

This figure shows the CE negotiation penalty as function of search costs c at mechanism level and auction level for the KT-II specification as described in Table 3.1 with loss aversion parameter $\lambda = 1$ or $\lambda = 2.25$. The CE negotiation penalty is calculated at mechanism (auction) level as the difference between certainty equivalents of PT(SIMA) and PT(SEQ) (PT(SEQA)).



From these analyses following from our theoretic models, both the rational and the behavioural model, we summarize our findings in the following:

Proposition 1: From a rational perspective, there exists an negotiation penalty between selling mechanisms when trying to sell an object. The expected payoffs from a sequential mechanism are lower than the expected payoffs from a direct auction.

Proposition 2: The negotiation penalty at auction level, which is the difference between expected payoffs from the direct auction and the second-stage auction, increases with the costs of an auction (search costs).

Proposition 3: For a prospect theory (PT) agent, the negotiation penalty does not always exist at the mechanism level. A PT agent can therefore prefer the sequential mechanism over the direct auction. The existence of a negotiation penalty and how it is affected by search costs at mechanism level is dependent on PT parameters.

3.4 Empirical Investigation: The Negotiation Penalty in Acquisitions

A setting where sellers often have to choose between selling mechanisms, is with the sale of firms. Several studies have looked into how auctions and negotiations compare in performance with respect to payoffs (premiums). For instance, Boone & Mulherin (2007, 2008) conclude that target cumulative abnormal returns and bid premiums are not significantly different between direct negotiations and auctions (which is in line with our rational model).

Betton et al. (2009) develop a two-stage takeover model to illustrate the benefits of a toehold in takeover bidding from the bidder's perspective. In their model, attempted merger negotiations are also followed by an open auction, however, their model is specific for corporate take-overs and therefore also includes variables such as termination fees, resistance costs, and private benefits of control. Our model considers the sellers' perspective and holds for any general selling object. Moreover, we focus on the choice between selling mechanisms rather than instruments which may improve bidding.

Aktas et al. (2010) attempt to explain the occurrence of the high number of observed negotiations from the bidder's perspective. They examine the bidding behaviour of acquirers in negotiations and find empirically that the threat of potential competitors leads to higher bids, which would be a possible explanation for the high number of negotiated deals. Indeed, our rational model also predicts that a bidder is better off by closing the deal in the negotiation instead of proceeding to the auction when the private value allows for this.

We consider the seller's perspective by investigating why a seller would choose a negotiation over an auction in the first place. The fact that there are sellers that choose a negotiation indicates that there are sellers who make decisions according to PT preferences and not rational theory. To investigate whether our theoretic propositions translate to the context of a real world setting, we employ a dataset of corporate transactions which have taken place through either of the three selling procedures (SIMA, NEG, and SEQA). To that extent we predict the following:

Hypothesis 1: There exists a negotiation penalty in the form of a negative premium difference between firms that were sold via a direct (simultaneous) auction (SIMA) and an auction which followed upon a failed negotiation (SEQA).

Hypothesis 2: Search costs affect the magnitude of the negotiation penalty

Hypothesis 3: Search costs negatively affect the likelihood of choosing the sequential mechanisms (SEQ) over the simultaneous auction (SIMA).

Hypotheses 1 and 2 follow directly from the rational model and relate to the outcomes of the selling procedures. Hypothesis 3 relates to the choice between selling mechanisms. There is no unambiguous relation between search costs and the negotiation penalty at mechanism level in the PT framework. Whether search costs affect the negotiation penalty positively or negatively depends on the PT parameters. However, not every set of parameters is equally likely. Many studies have investigated which PT parameters apply *on average*. Also the search costs relative to multiple million and billion dollar corporate transactions are quite low. Since the outcomes in our model are normalized to be between 0 and 1, we therefore have to consider the relation between search costs and the negotiation penalty for small c in our model. From Figure 3.4 we observe that for lower levels of search costs the majority of examined PT parameter sets following from different studies, indicate that the negotiation penalty at mechanism level increases in search costs. Therefore, we expect that on average search costs will negatively influence the likelihood of choosing the sequential mechanism.

3.4.1 Data and Variables

We obtained deal data from the Thomson ONE Merger & Acquisitions (M&A) database. We collect all completed deals in the period 2002-2014 between U.S. public targets and U.S. acquirers (both public and private). We consider deals in which acquirers purchase 100% of shares[21]. The minimum deal value is set at $50 million. We collect the deal value

[21] We exclude transactions labeled as minority stake purchases; acquisitions of remaining interest; privatizations; spin-offs; re-capitalizations; self-tenders; exchange offers and repurchases.

and the 4-week takeover premium. This gives us a total of 2,216 observations. Next, we require that deals can be matched on the CRSP/Compustat Merged database with a CUSIP or PERMCO identifier to obtain variables of interest and control variables. This results in elimination of 215 deals.

Finally, we require that a merger filing is available in the SEC EDGAR database. If the target company does not have a relevant filing in the SEC EDGAR database, we search for a relevant filing from the acquiring company. If this yields no result, the deal is discarded from our sample. Deals for which the filing is ambiguous on the selling mechanism, are eliminated. Also if a deal turns out to be of a nonrelevant type (e.g. a bankruptcy sale or a restructuring), the deal is dropped from the sample. In this way, a number of 210 deals are eliminated from our sample. Ultimately, the sample consists of 1,791 deals. In Appendix D, a detailed description is provided on the classification of deals into selling mechanisms.

We collect firm and deal specific characteristics to use as control variables, these are in line with Boone & Mulherin (2007) and Aktas et al. (2010). We will include the following control variables in our analysis: *Cash, Goshop, Financial Buyer, Relation, Cross deal, Size (MV Equity), Cash/Assets, PPE/Assets, R&D/Assets, Tobin's Q, Leverage, Intangibles, ROA, Long term debt, Institution owned*. See Table 3.2 for the definitions and construction of these variables.

As a proxy for the premium, we use the ratio of the stock price of the target firm at the moment of announcement over the stock price four weeks before the announcement (Betton & Eckbo, 2000). Here we want to make sure that particular run-up effects from the negotiation phase do not affect our premium proxy for the sequential auction. Therefore, we take into account a 'cooling-down' period between the failure of the negotiation and the completion of the sequential auction. By looking at cumulative abnormal returns

Table 3.2: Description of empirical variables
This table presents the descriptions of the (control)variables used for empirical analysis. All variables are winsorized at 99.5%.

Model Variables	
Premium 4-week	Current stock price divided by common stock price on main stock exchange 4 weeks prior to announcement (TOB and SEC adjusted).
Liquidity index	The ratio between the total value of corporate control transaction and the total book value of assets in the same industry based on the two-digit SIC code and year in the United States of America.
Deal variables	
Cash	Equal to 1 if the deal is entirely paid by cash, and 0 otherwise.
Goshop	Equal to 1 if a go-shop provision is granted after the deal with the acquiror (but results in nothing), and 0 otherwise.
Financial Buyer	Equal to 1 if the winning bidder is a financial buyer, and 0 otherwise.
Relation	Equal to 1 if the winning bidder has a certain relationship with the target, and zero otherwise. Inter alia: Commercial relationship, selling goods, CEO acquiror used to work for target, acquiror has owned shares for quite a while; known due to litigation, regular informal talks, friendship between CEOs.
Cross deal	Equal to 1 if target and acquired do not have the same 4-digit SIC code, but target and acquirer do share the same Fama-French49 industry, indicating the deal is in the same level of supply chain but in a different market.
Target characteristics	
MV Equity	Target's market value of equity: shares outstanding times share price.
Cash/Assets	The amount of cash and cash like items divided by target's book value of assets at the Fiscal Year-End prior to the Fiscal Year in which it is sold.
PPE/Assets	Total net Property, Plant and Equipment divided by target's book value of assets at the Fiscal Year-End prior to the Fiscal Year in which it is sold.
R&D/Assets	Research and Development Expense divided by target's book value of assets at the Fiscal Year-End prior to the Fiscal Year in which it is sold.
Tobin's Q	Target's market value of assets (fiscal year) over book value of assets.
Leverage	Total Debt divided by Total Assets.
Intangibles	Ratio of intangible assets to total assets
ROA	Operating income before depreciation divided by total assets.
Long term debt	Total long term debt
Institution owned	The fraction of the target's equity owned by institutional investors (Banks, Insurance Companies, Investment Companies, Independent Investment Advisors, and All Others, including university endowments and pension funds) the quarter prior to the quarter of the deal.

(CARs) from the moment of negotiation failure, we can find a time window which can be used as cooling-down period. Figures 3.9 and 3.10 show the differences in CARs for a cooling-down period of 30 days versus 60 days. For a cooling-down period of 60 days we observe no upward trend or significant CARs which remains such that the premium can be affected. Therefore, for sequential deals, we consider only those deals that have at least 60 trading days between the completion of the sequential auction and the failure of the negotiation[22].

As a proxy for the search costs, we use the *Liquidity Index* variable, which is defined as the ratio of all corporate transactions in a certain industry in a year, divided by the total assets of all companies in that industry (Aktas et al., 2010). The liquidity index is inversely related to search costs: When the liquidity index increases, search costs decrease.

A further summary of collected variables is presented in Table 3.3, distribution of deal types over years is displayed in Figure 3.11 (and Table E.1 in the Appendix).

[22] This results in dropping 208 deals. We have investigated several other windows as well, the 60-day window turned out to be the smallest window which shows no run-up effects and is, therefore, suitable as cooling-down period.

Figure 3.9: Average CARs from transactions 30 days after negotiation failure
This figure shows the average cumulative abnormal returns (CARs) of target company stocks for all the second-stage transactions starting from minimum 30 days after the related negotiation has failed. The dotted lines represent 95% confidence intervals. The CARs are displayed for all days from 10 days before the negotiation failed up to 40 days after, and shows possible run-up effects after the failure of the negotiation.

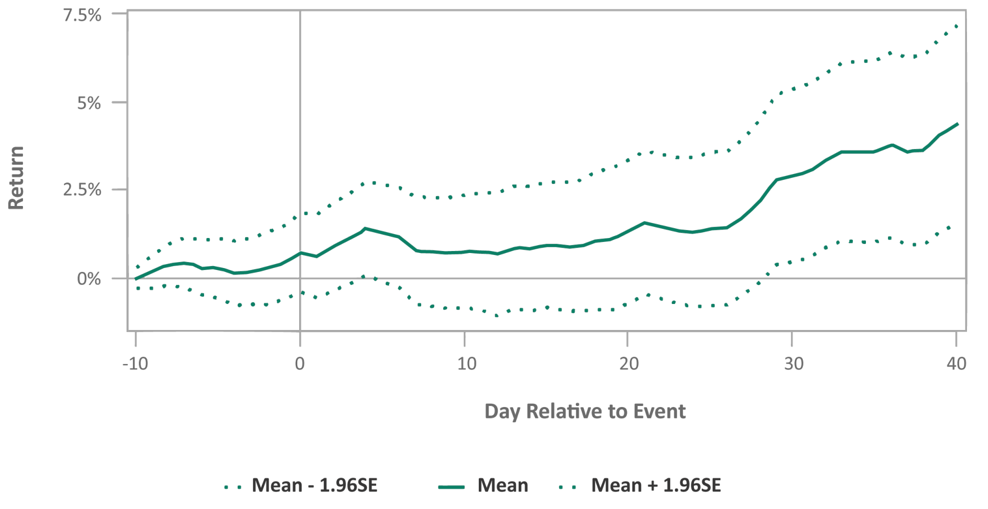


Figure 3.10: Average CARs from transactions 60 days after negotiation failure
This figure shows the average cumulative abnormal returns (CARs) of target company stocks for all the second-stage transactions starting from minimum 60 days after the related negotiation has failed. The dotted lines represent 95% confidence intervals. The CARs are displayed for all days from 10 days before the negotiation failed up to 40 days after, and shows possible run-up effects after the failure of the negotiation.

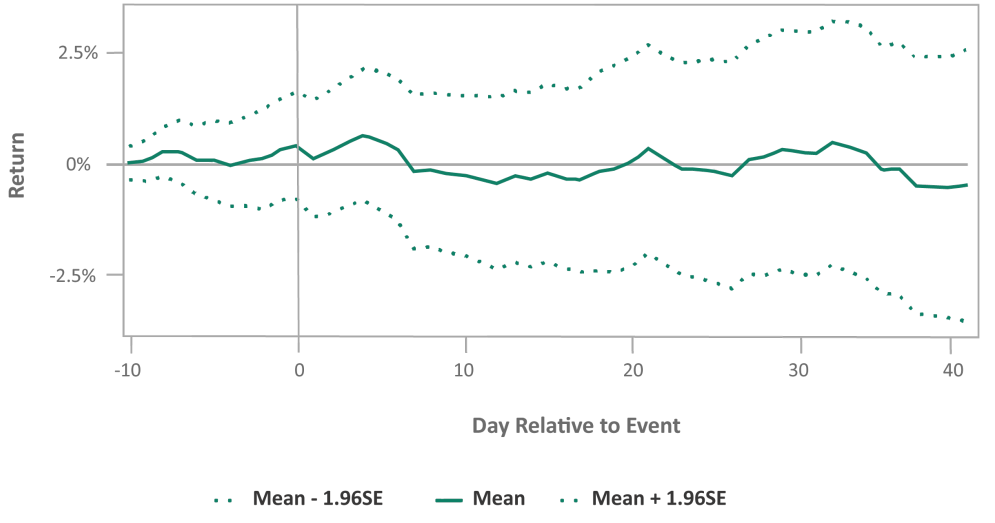


Figure 3.11: Distribution of deal types over years
This figure shows the distribution of deal types in percentages over the years in our sample period. The numbers above the markers indicate the absolute number of deals from that type in that year. We differentiate between the deal types: NEG, a negotiation which succeeded in the first stage of the selling process; SEQA, a sequential auction which followed in the second stage after a failed negotiation in the first stage of the selling process; and SIMA, a direct auction. Classification details are discussed in Appendix D.

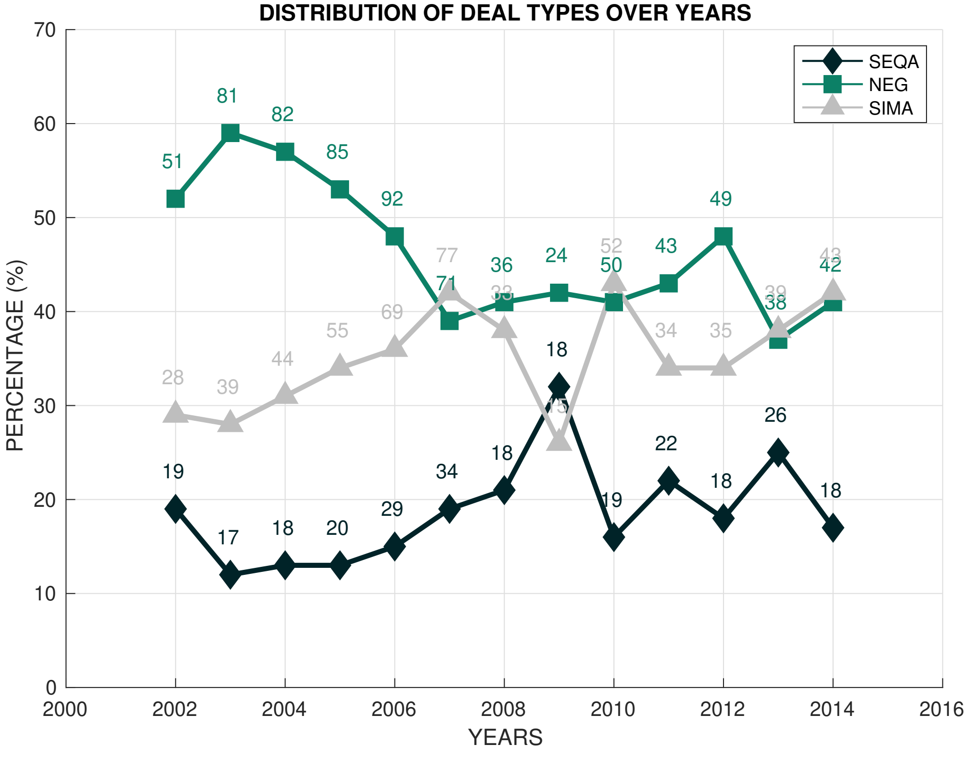


Table 3.3: Summary statistics by deal type
This table shows summary statistics of target company characteristics, deal characteristics and model variables (negotiation price p^* proxied by the 4-week premium and search costs c proxied by the liquidity index). The construction of the variables is described in Table 3.2.

	Full Sample		*SEQA*		*NEG*		*SIMA*		*p-values*		
	N	mean	N	mean	N	mean	N	mean	SEQA = NEG	SEQA=SIMA	NEG = SIMA
Model Variables											
Premium 4-week	1,583	36.68	276	31.07	744	38.04	563	37.63	0.0017	0.0048	0.8588
Liquidity Index	1,583	0.0850	276	0.0869	744	0.0916	563	0.0753	0.6446	0.2219	0.0268
Deal variables											
Cash deal	1,583	0.590	276	0.670	744	0.484	563	0.691	0.8564	0.0778	0.0375
Goshop	1,583	0.0651	276	0.0616	744	0.0847	563	0.0409	0.1936	0.2157	0.0009
Financial Buyer	1,583	0.180	276	0.246	744	0.102	563	0.250	0.0000	0.8982	0.0000
Relation	1,583	0.307	276	0.236	744	0.435	563	0.172	0.0000	0.0365	0.0000
Cross deal	1,583	0.238	276	0.199	744	0.251	563	0.240	0.0719	0.1785	0.6307
Target characteristics											
Size (MV Equity)	1,581	1,421	276	713.1	744	1,971	561	1,040	0.0000	0.0253	0.0000
Cash/Assets	1,539	0.195	270	0.207	721	0.204	548	0.178	0.0000	0.5486	0.0000
PPE/Assets	1,580	0.172	276	0.178	743	0.178	561	0.161	0.9926	0.3133	0.1815
R&D/Assets	1,575	0.144	275	0.135	740	0.130	560	0.169	0.9194	0.5381	0.3812
Tobin's Q	1,580	1.681	276	1.638	743	1.776	561	1.576	0.0645	0.3816	0.0004
Leverage	1,580	0.207	276	0.181	743	0.206	561	0.223	0.1092	0.0118	0.1806
Intangibles	1,580	0.150	276	0.162	743	0.142	561	0.156	0.1335	0.6504	0.2102
ROA	1,580	0.0671	276	0.0668	743	0.0672	561	0.0671	0.9679	0.9762	0.9900
Long term debt	1,581	580.0	276	289.8	744	759.7	561	484.4	0.0000	0.0437	0.0132
Institution owned	1,451	0.559	242	0.568	683	0.560	526	0.553	0.7229	0.5013	0.6643

3.4.2 Results

We conduct linear regressions with inclusion of company and deal control variables; year, industry and year-industry fixed effects; and year-industry clustered standard errors. Our dependent variable is the 4-week premium. We regress the dependent variable on the three deal types (SIMA, NEG, SEQA) and investigate the differences. The results are presented in Table 3.4. We observe a clear significant positive difference in premiums for NEG versus SEQA and SIMA versus SEQA[23]. Testing the coefficients of SIMA and NEG against each other results in no significant difference. This is in line with our rational model which predicts that on average the payoff of SIMA and NEG should be equal.

[23] Repeating the analysis while excluding targets from the financial sector, does not change the results, see Table E.2 in the Appendix.

Table 3.4: Premium differences for three different deal types
Linear regressions with inclusion of company and deal control variables; year, industry and year-industry fixed effects; and year-industry clustered standard errors (clustered t-statistics in parentheses below). Regression specification (4) is with only industry clustered standard errors instead of year-industry. The dependent variable is the 4-week premium. We regress the dependent variable on the three deal types (SIMA, NEG, SEQA), where we have set SEQA as the reference class. The (control)variables are described in Table 3.2.

Reference class: SEQA *Variables*	(1) Baseline and FE	(2) Target controls	(3) Deal controls	(4) Deal controls
NEG	9.109***	11.931***	11.582***	11.582***
	(3.21)	(3.55)	(3.43)	(2.78)
SIMA	8.981***	10.089***	9.790***	9.790**
	(3.13)	(3.13)	(2.96)	(2.58)
Size		-0.000	-0.000	-0.000
		(-0.57)	(-0.14)	(-0.08)
Cash/Assets		-1.224	-0.611	-0.611
		(-0.14)	(-0.07)	(-0.11)
PPE/Assets		-4.743	-3.146	-3.146
		(-0.51)	(-0.32)	(-0.33)
R&D/Assets		5.534*	5.409*	5.409***
		(1.71)	(1.68)	(3.72)
Tobin's Q		-1.787	-1.875	-1.875**
		(-1.24)	(-1.30)	(-2.15)
Leverage		11.923*	12.288*	12.288
		(1.86)	(1.87)	(1.59)
Intangibles/Assets		-19.047**	-15.527*	-15.527*
		(-2.41)	(-1.81)	(-1.84)
ROA		-37.540***	-38.241***	-38.241***
		(-2.86)	(-2.94)	(-3.71)
Long term debt		-0.001	-0.001	-0.001
		(-1.01)	(-1.08)	(-1.14)
Institution owned		-19.462***	-21.098***	-21.098***
		(-4.33)	(-4.45)	(-5.55)
Cash deal			7.568***	7.568***
			(2.98)	(2.85)
Financial buyer			-5.024	-5.024*
			(-1.49)	(-1.72)
Relation			3.107	3.107
			(0.90)	(1.09)
Cross deal			2.832	2.832
			(0.88)	(0.78)
Goshop			1.238	1.238
			(0.34)	(0.37)
Observations	1,451	1,276	1,276	1,276
Adjusted R^2	0.255	0.340	0.347	0.347
Year, Industry, Year-Industry FE	x	x	x	x

Note: clustered t-statistics in parentheses, *** p<0.01, ** p<0.05, * p<0.1

One could argue that one can not simply classify corporate transactions after failed negotiations simply as sequential auctions. Firms can be sold through another negotiation after a failed negotiation as well. Therefore, we include this type of selling procedure in our analysis. The sequential negotiation (SEQN) is a transaction where a firm is sold through a negotiation, after the first negotiation has failed (these types were first gathered under the category SEQA). The results regarding this four types classification are presented in Table 3.5. We still observe significant differences in premium between SIMA/NEG versus SEQA/SEQN (first-stage/direct sales versus second-stage sales). When we thus distinguish between four types instead of three, we still find significant differences in premium. Hence, all in all, these findings confirm the existence of a negotiation penalty at auction level (or second-stage level) and provide support for our first hypothesis.

Next, we include interaction effects of search costs with the different deal types to investigate how search costs affect premium differences. These results can be found in Table 3.6 (and E.3 without financial targets). The interaction effects with search costs are not significant. For the comparison of SEQA vs. SIMA, we do observe, however, that lower search costs (higher liquidity index) lead to higher premiums, which is in line with our model and is intuitively sound. We do not find support, however, for our second hypothesis.

Lastly, we compare the complete mechanisms with each other. Since a decision maker consciously chooses a certain selling mechanism, we have to take this selection into account. We do that by employing a two-stage Heckman treatment selection model, where we first explicitly model the choice in the first stage through a Probit model and then use that to construct a bias correction for the second stage, where we run our actual regression. The results are in Tables 3.7 and 3.8 for the first and second stage respectively.

Table 3.5: Premium differences for four different deal types

Linear regressions with inclusion of company and deal control variables; year, industry and year-industry fixed effects; and year-industry clustered standard errors (clustered t-statistics in parentheses below). The dependent variable is the 4-week premium. We regress the dependent variable on four different deal types (SIMA, NEG, SEQA, SEQN), where we have set SEQA as the reference class. The bottom part of the table shows how the distribution of deals over three types translates into four types. The (control)variables are described in Table 3.2.

Reference class: SEQA	(1)	(2)	(3)
Variables	Baseline + FE	Controls	Controls
NEG	10.739***	12.989***	12.670***
	(3.45)	(3.31)	(3.11)
SEQN	3.652	2.361	2.398
	(0.84)	(0.47)	(0.45)
SIMA	10.577***	11.134***	10.849**
	(3.07)	(2.75)	(2.58)
Size		-0.000	-0.000
		(-0.57)	(-0.14)
Cash/Assets		-1.147	-0.527
		(-0.13)	(-0.06)
PPE/Assets		-4.806	-3.193
		(-0.52)	(-0.32)
R&D/Assets		5.580*	5.458*
		(1.73)	(1.69)
Tobin's Q		-1.784	-1.872
		(-1.23)	(-1.30)
Leverage		12.009*	12.369*
		(1.87)	(1.87)
Intangibles/Assets		-19.071**	-15.551*
		(-2.41)	(-1.81)
ROA		-37.220***	-37.938***
		(-2.86)	(-2.93)
Long term debt		-0.001	-0.001
		(-1.01)	(-1.07)
Institution owned		-19.519***	-21.152***
		(-4.36)	(-4.48)
Cash deal			7.617***
			(3.01)
Financial buyer			-5.034
			(-1.49)
Relation			3.048
			(0.87)
Cross deal			2.771
			(0.84)
Goshop			1.358
			(0.37)

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Table 3.5 – *Continued from previous page*

Reference class: SEQA	(1)	(2)	(3)
Variables	Baseline + FE	Controls	Controls
Observations	1,451	1,276	1,276
Adjusted R^2	0.256	0.341	0.347
Year, Industry, Year-Industry FE	x	x	x

Note: clustered t-statistics in parentheses, *** p<0.01, ** p<0.05, * p<0.1

	Mechanism 4-type				
Mechanism 3-type	NEG	SEQA	SEQN	SIMA	Total
SEQA	0	160	116	0	276
NEG	744	0	0	0	744
SIMA	0	0	0	563	563
Total	744	160	116	563	1,583

Table 3.6: Premium differences and effect of search costs for different deal types
Linear regressions with inclusion of company and deal control variables; year, industry and year-industry fixed effects; and year-industry clustered standard errors (clustered t-statistics in parentheses below). The dependent variable is the 4-week premium. We regress the dependent variable on the three deal types (SIMA, NEG, SEQA), where we have set SEQA as the reference class. Furthermore we include interactions with the liquidity index (search costs) for each of the deal types. The (control)variables are described in Table 3.2.

	Reference class: SEQA		Reference class: SIMA	
	(1)	(2)	(3)	(4)
Variables	NEG & SIMA vs SEQA	NEG vs SEQA	SEQA vs SIMA	NEG vs SIMA
SEQA			-10.577**	
			(-2.13)	
NEG	14.502***	15.214***		2.656
	(3.93)	(3.43)		(1.09)
SIMA	11.332***			
	(3.18)			
Liquidity index	15.276	1.280	101.245*	-2.345
	(0.52)	(0.03)	(1.93)	(-0.14)
SEQA x Liquidity Index			43.408	
			(0.86)	
NEG x Liquitidy Index	-35.266	-54.884		-19.818
	(-1.00)	(-1.01)		(-1.42)
SIMA x Liquidity Index	-16.722			
	(-0.62)			
Size	0.000	0.000	-0.000	0.000

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Table 3.6 – *Continued from previous page*

	Reference class: SEQA		Reference class: SIMA	
	(1)	(2)	(3)	(4)
Variables	NEG & SIMA vs SEQA	NEG vs SEQA	SEQA vs SIMA	NEG vs SIMA
	(0.18)	(0.36)	(-0.24)	(0.71)
Cash/Assets	-0.606	8.099	-8.967	-1.915
	(-0.07)	(0.71)	(-0.68)	(-0.18)
PPE/Assets	-3.672	-13.622	-5.649	3.650
	(-0.36)	(-0.98)	(-0.42)	(0.31)
R&D/Assets	5.446*	3.920	4.285	5.902
	(1.69)	(1.00)	(0.96)	(1.62)
Tobin's Q	-1.867	-3.653**	-0.789	-1.236
	(-1.30)	(-2.35)	(-0.37)	(-0.69)
Leverage	12.128*	10.086	20.007*	11.114*
	(1.94)	(1.17)	(1.89)	(1.69)
Intangibles/Assets	-14.719*	-8.660	-14.522	-15.899
	(-1.70)	(-0.69)	(-1.54)	(-1.63)
ROA	-38.837***	-16.791	-51.001**	-50.836***
	(-3.00)	(-0.84)	(-2.47)	(-3.40)
Long term debt	-0.001	-0.001	-0.003	-0.001
	(-1.11)	(-0.84)	(-1.59)	(-1.20)
Institution owned	-21.682***	-22.633***	-24.088***	-22.065***
	(-4.56)	(-3.64)	(-3.54)	(-4.40)
Cash deal	7.811***	6.164*	8.614**	8.726***
	(3.14)	(1.83)	(2.23)	(3.14)
Financial buyer	-5.595	-6.063	-3.768	-6.157
	(-1.62)	(-1.44)	(-0.77)	(-1.52)
Relation	3.216	6.871	-0.626	3.964
	(0.93)	(1.48)	(-0.17)	(0.99)
Cross deal	2.819	5.362	3.465	3.314
	(0.87)	(0.98)	(0.94)	(0.96)
Goshop	1.962	1.548	3.086	1.393
	(0.54)	(0.38)	(0.56)	(0.29)
Observations	1,276	766	637	1,048
Adjusted R^2	0.350	0.344	0.447	0.400
Year, Industry, Year-Industry FE	x	x	x	x

Note: clustered t-statistics in parentheses, *** p<0.01, ** p<0.05, * p<0.1

Table 3.7: First stage Heckit - Probit regressions

Probit model for the first stage of the Heckman treatment selection procedure. Here we have regressed several binary variables on selection variables through the probit model: e.g. in SEQ vs SIMA, SEQ = 1 and SIMA = 0. Here SEQ denotes the sequential mechanism and thus encompasses both deal types NEG and SEQA. The (control)variables are described in Table 3.2.

Reference class: SIMA	*Probit*		
	(1)	(2)	(3)
Variables	SEQ vs SIMA	SEQA vs SIMA	NEG vs SIMA
Liquidity Index	0.535**	0.651*	0.531*
	(0.04)	(0.07)	(0.09)
Size/1000	0.028**	-0.075**	0.041***
	(0.04)	(0.01)	(0.01)
Cash/Assets	0.042	0.193	-0.019
	(0.84)	(0.53)	(0.93)
PPE/Assets	0.270	0.584**	0.190
	(0.13)	(0.02)	(0.32)
R&D/Assets	-0.107*	-0.103	-0.120*
	(0.08)	(0.22)	(0.06)
Tobin's Q	0.104***	0.042	0.133***
	(0.01)	(0.50)	(0.00)
Leverage	-0.436**	-0.581**	-0.409**
	(0.02)	(0.02)	(0.04)
Intangibles/Assets	-0.096	0.279	-0.245
	(0.64)	(0.29)	(0.28)
ROA	-0.368	-0.380	-0.451
	(0.26)	(0.45)	(0.21)
Long term debt	0.000	0.000	0.000
	(0.87)	(0.42)	(0.83)
Institution owned	0.095	0.140	0.093
	(0.50)	(0.46)	(0.56)
Observations	1,409	749	1,173
Wald Chi^2	76.989	51.08	85.50
Chi^2 p-val	0.000	0.000	0.000

Note: clustered p-values in parentheses, *** p<0.01, ** p<0.05, * p<0.1

Table 3.8: Second stage Heckit - Linear regressions

Linear regressions for the second stage of the Heckman treatment selection procedure with inclusion of company and deal control variables; year, industry and year-industry fixed effects; and year-industry clustered standard errors (clustered t-statistics in parentheses below). The dependent variable is the 4-week premium. We regress the dependent variable on several binary variables: e.g. in SEQ vs SIMA, SEQ = 1 and SIMA = 0. Here SEQ denotes the sequential mechanism and thus encompasses both deal types NEG and SEQA. The variable *Heckman* denotes the Heckman term for correction of selection bias. Furthermore we include interactions with the liquidity index (search costs) for each of the deal types. The (control)variables are described in Table 3.2.

Reference class: SIMA	*Linear regression*		
Variables	(1) SEQ vs SIMA	(2) SEQA vs SIMA	(3) NEG vs SIMA
SEQ	35.591		
	(0.46)		
Liquidity Index	-19.609	161.157***	1.769
	(-0.69)	(3.00)	(0.08)
SEQ x Liquitidy Index	-8.028		
	(-0.42)		
SEQA		-274.117***	
		(-4.55)	
SEQA x Liquidity Index		52.971	
		(1.12)	
NEG			-17.496
			(-0.28)
NEG x Liquidity Index			-20.845
			(-1.40)
Heckman	-22.607	158.547***	12.532
	(-0.47)	(4.47)	(0.32)
Size	-0.000	-0.004***	0.000
	(-0.24)	(-3.76)	(0.52)
Cash/Assets	-0.583	8.813	-2.021
	(-0.06)	(0.62)	(-0.19)
PPE/Assets	-7.128	48.102**	4.994
	(-0.58)	(2.52)	(0.40)
R&D/Assets	6.829*	-4.947	5.004
	(1.83)	(-1.12)	(1.22)
Tobin's Q	-3.002	2.688	-0.283
	(-0.93)	(1.13)	(-0.08)
Leverage	19.960	-28.216*	7.952
	(1.38)	(-1.95)	(0.74)
Intangibles/Assets	-14.331	6.715	-17.555
	(-1.57)	(0.62)	(-1.55)
ROA	-32.913*	-88.557***	-54.150***
	(-1.93)	(-3.85)	(-2.93)
Long term debt	-0.001	-0.001	-0.001
	(-1.32)	(-0.54)	(-1.26)
Institution owned	-22.804***	-14.547**	-21.239***

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Reference class: SIMA	Linear regression		
Variables	(1) SEQ vs SIMA	(2) SEQA vs SIMA	(3) NEG vs SIMA
	(-3.83)	(-2.18)	(-3.83)
Cash deal	6.940***	9.729**	8.806***
	(2.81)	(2.53)	(3.15)
Financial buyer	-6.595**	-4.713	-6.176
	(-2.03)	(-0.97)	(-1.53)
Relation	4.259	-0.761	3.946
	(1.18)	(-0.21)	(0.98)
Cross deal	2.690	2.239	3.298
	(0.84)	(0.62)	(0.95)
Goshop	2.695	3.569	1.353
	(0.74)	(0.63)	(0.28)
Observations	1,276	637	1,048
Adjusted R^2	0.340	0.461	0.400
Year, Industry, Year-Industry FE	x	x	x

Note: clustered t-statistics in parentheses, *** p<0.01, ** p<0.05, * p<0.1

We observe no differences in premium between complete mechanisms when taking selection in account, this would mean that given the context, sellers choose their mechanism on average efficiently. The difference in premium between SEQA and SIMA remains significant, and the difference between SIMA and NEG remains insignificant. From the Probit model, we infer that higher search costs (lower liquidity index) lead to a lower likelihood of choosing the sequential mechanism. This may sound counterintuitive, as one would think that with high search costs the decision-maker would rather want to 'try' the negotiation to avoid search costs. However, the fear of the subsequent negotiation penalty causes the decision-maker to actually choose more often for the direct auction when search costs are high, which is in line with our PT model (majority of well-known parameter combinations). Hence, these results provide support for our third hypothesis.

3.4.3 Limitations and Future Research

We modelled the choice between the selling mechanisms on purpose as stylized as possible, in order to keep it applicable to any general setting. Therefore, we have not incorporated setting-specific parameters. The model in this form, however, can be extended in several ways.

First of all, for simplicity we have now considered only two bidders, whereas often it is the case that multiple bidders engage in an auction. Extending the SIMA equilibrium bidding functions for multiple bidders is straight-forward, the equilibrium conditions hold for any general number of n bidders. Deriving the SEQA equilibrium functions is more troublesome. Assuming that the first bidder has private values distributed on $[0, z]$ with distribution F_1 and all other $n-1$ bidders' values are i.i.d. distributed on $[0, 1]$ with distribution F_j for $j = \{2, ..., n\}$, the bidding functions are found by optimizing with respect to b_i and solving the differential equations which follow from the first order condition of the expected payoffs:

$$\Pi(v_1, b_1) = F_j\big(\phi_j(b_1)\big)^{n-1}(v_1 - b_1) \tag{3.33}$$

$$\Pi(v_j, b_j) = F_1\big(\phi_1(b_j)\big)F_j\big(v_j\big)^{n-2}(v_j - b_j), \tag{3.34}$$

Explicit solutions to the differential equations that follow from optimizing are only obtainable in specific cases. When no explicit solution is available, it is not possible to obtain an analytical expression for the PT integration and we have to rely on numerical methods. Moreover, the framework can be extended for an uncertain number of bidders or by incorporating an arrival process for bidders such that the time dimension and associated costs are taken into account as well. For now, we have aggregated all costs under the title *search costs c*.

Second, we have now assumed that only the seller, who is in fact the decision-maker acts according to PT. This can be extended to both sellers and bidders being PT agents. Deriving the equilibrium bidding functions of the PT bidders means maximizing the PT-values instead of the expected values. For instance, for SIMA with private values between 0 and 1, this implies maximizing with respect to β:

$$w^{+}\Big(G\big(b^{-1}(\beta)\big)\Big)U(v_i - \beta) \tag{3.35}$$

where there are only positive payoffs because a bidder will not bid more than her private value. For SEQA (with two bidders) we would maximize:

$$w^{+}\Big(F_j\big(\phi_j(b_i)\big)\Big)U(v_i - b_i). \tag{3.36}$$

Other types of auctions can be considered as well, here we have chosen to look at the first-price auction as it is intuitive and the most well-known auction type[24].

A limitation of our empirical analysis is that we have not incorporated setting-specific parameters in our model, such as, for example, termination fees or resistance costs, that may apply to corporate transactions. In our model, the success of the negotiation depends only on the offered price, which may not be realistic for corporate transactions where a lot of other factors play a role, such as possible realizable synergies, compatibility of two firms etc. Many of these factors can be, however, expressed through the private value for the

[24] Another well-known auction type is the second-price auction where the winner pays the second-highest bid. Krishna (2009) shows that for a second-price auction the dominant strategy is to bid your own private value, even in the case of asymmetric bidders. He furthermore shows that the expected revenue from both auction types (first- and second-price) is equal, where the second-price auction however has more variable revenues.

firm. We direct further empirical investigations to future research.

An interesting suggestion for future research would be to test the predictions of our model in a lab setting. With a group of participants, we could first extract preference parameters through simple prospects and elicitation, and then test whether subjects with specific parameters choose (dependent on search costs) according to the predictions of our model between a direct auction or negotiation with a possible subsequent auction.

3.5 Conclusion

In this study, we modelled the choice between selling mechanisms for the sale of a general object. We modelled this choice both from a rational perspective and a prospect theory (PT) perspective.

We compared a direct auction (SIMA) with a sequential selling mechanism (SEQ). In the SEQ the seller starts with a negotiation (NEG) and proceeds to an auction (SEQA) when this negotiation fails. Organizing an auction is costly and we denote these aggregated (direct and indirect) costs as 'search costs'.

From the rational model, we find that there exists a 'negotiation penalty' which is the difference in expected payoffs between selling procedures. This negotiation penalty exists both at mechanism level (SIMA - SEQ) and auction level (SIMA - SEQA). At mechanism level, the negotiation penalty decreases in search costs and at auction level the negotiation penalty increases in search costs. The rational model therefore predicts that the direct auction should always be the preferred mechanism, which is in accordance with classical economic theory arguing that competition drives prices up.

We find that for a prospect theory (PT) agent, dependent on the utility function and type of probability weighting, it is possible to prefer the sequential mechanism. Furthermore, we find for linear utility and not too concave/convex utility that the relation between search costs and negotiation penalty at mechanism level can be (partially) positive, which is in contrast with the rational model. We find that this difference in direction is caused by probability weighting, and in particular the underweighting of small probabilities and overweighting of larger probabilities.

With a dataset of corporate transactions through either of the selling procedures NEG, SEQA or SIMA, we also empirically investigate how our model's predictions translate to a real context. We find significant positive differences in premiums for NEG over SEQA and SIMA over SEQA. This confirms the existence of the negotiation penalty at auction level and therefore indicates that trying the negotiation is not free of costs. We find no significant differences in premiums between SIMA and NEG, which is in accordance with our rational model. Finally, we find that on average, higher search costs lead to a lower likelihood of choosing the sequential mechanism, which is not predicted by the rational model, but is predicted by the PT model for the majority of well-known PT specifications.

Our findings provide insights for sellers choosing between selling procedures and may have implications for deal and contracting procedures. All in all, our study shows that the outcomes of selling mechanisms are in line with a rational model, but choice-making between selling mechanisms is in line with a behavioural (PT) model.

A Derivation Expected Value SEQA

Using the equilibrium bidding functions and distributions for the private values (v_1, v_2) we can derive the expected payoff for the seller from the sequential mechanism. The expected value from the negotiation (NEG) is p^*. To obtain the expected value of the sequential auction (SEQA) we set the cumulative distribution function (CDF) of equilibrium bids L as follow:

$$L(\beta) = \Pr\big[\max\{b_1^a(v_1), b_2^a(v_2)\} \leq \beta\big]. \tag{37}$$

Now let $\phi_i(\cdot)$ be the inverse function of the assymetric bidding function b_i^a and let $\phi_i'(\cdot)$ be its derivative:

$$\phi_i(\beta) = \frac{2\beta}{1 + k_i\beta^2} \tag{38}$$

$$\phi_i'(\beta) = \frac{2 - 2k_i\beta^2}{(k_i\beta^2 + 1)^2} \tag{39}$$

$$k_1 = \frac{1}{z^2} - 1 \tag{40}$$

$$k_2 = 1 - \frac{1}{z^2} \tag{41}$$

Then we have

$$L(\beta) = \Pr\big[\max\{b_1^a(v_1), b_2^a(v_2)\} \leq \beta\big] \tag{42}$$

$$= \Pr\big[v_1 \leq \phi_1(\beta)\big] \cdot \Pr[v_2 \leq \phi_2(\beta)] = F_1(\phi_1(\beta))F_2(\phi_2(\beta)) \tag{43}$$

$$l(\beta) = \frac{d}{d\beta}L(\beta) = \frac{\phi_1'(\beta)}{z}\phi_2(\beta) + \frac{\phi_1(\beta)}{z}\phi_2'(\beta), \tag{44}$$

where respectively F_1 and F_2 are the cumulative distribution functions of the uniformly independent distributed private values $v_1 \sim U(0,z)$ and $v_2 \sim U(0,1)$; and $l(\beta)$ is the probability distribution function (PDF) of equilibrium bids. By substituting the actual functions, we obtain for the PDF

$$l(\beta) = \frac{(4\beta z^3(2z^4 + 2\beta^4(-1+z^2)^2))}{((-z^2+\beta^2(-1+z^2))^2(z^2+\beta^2(-1+z^2))^2)}$$

Then, for the integral form of the expected value over $l(\beta)$, we have the primitive function:

$$\int \beta l(\beta) d\beta = \tag{45}$$

$$z^2\left(-\frac{4\beta^3 z}{\beta^4(z^2-1)^2 - z^4} + \frac{\log\left(z - \beta\sqrt{z^2-1}\right)}{(z^2-1)^{3/2}} - \frac{\log\left(\beta\sqrt{z^2-1}+z\right)}{(z^2-1)^{3/2}} + \frac{2\tan^{-1}\left(\frac{\beta\sqrt{z^2-1}}{z}\right)}{(z^2-1)^{3/2}}\right) \tag{46}$$

The expected value of the sequential auction is obtained through

$$\mathbb{E}[\text{SEQA}] = \int_0^{\bar{b}=\frac{z}{z+1}} \beta l(\beta) d\beta$$

Filling in $\beta = 0$, gives 0, hence, the expected value is obtained by filling in $\beta = \frac{z}{z+1}$ in the primitive function, Equation (46), and this gives:

$$\mathbb{E}[\text{SEQA}] = \frac{z}{z+1} + z^2\left(\frac{\log\left(\frac{z\left(-\sqrt{z^2-1}+z+1\right)}{z+1}\right)}{(z^2-1)^{3/2}} - \frac{\log\left(\frac{z\left(\sqrt{z^2-1}+z+1\right)}{z+1}\right)}{(z^2-1)^{3/2}} + \frac{2\tan^{-1}\left(\frac{\sqrt{z^2-1}}{z+1}\right)}{(z^2-1)^{3/2}}\right) \tag{47}$$

B Variations of the PT Components

For Figures 3.6 and 3.7 we consider several variations of the utility function and probability weighting function. The parameters for these variations are presented below. When considering variations of the utility function in the analysis, we keep the PWF parameters constant as in GE-AB in Table 3.1. When considering variations of the PWF, we keep the utility parameters constant as in GE-AB (base-case). The functional forms of the variations of the PWF and utilify function described below are also plotted in Figure E.5.

$w(p) = \frac{bp^a}{bp^a+(1-p)^a}$	gains: $^{(+)}$, losses: $^{(-)}$			
	a^+	b^+	a^-	b^-
Base-case	0.6	0.65	0.65	0.84
Optimist	1	1.8	1	0.5
Pessimist	1	0.5	1	1.8
Probability overweighting	1	1.8	1	1.8
Probability underweighting	1	0.5	1	0.5
S-type PWF	1.5	1.6	1.5	1.2
No probability weighting	1	1	1	1
High likelihood insensitivity	0.15	1	0.15	1
Specific form	0.2	2	5.15	0.03

	Gains: $u(x) = x^\alpha$	Losses: $u(y) = y^\beta$
	α	β
Base-case	0.89	0.92
Moderate concavity	0.49	0.52
High concavity	0.19	0.22
Linear utility	1	1

C Analysis per PWF Shape Type

We investigate how different PWF types affect preferences between selling mechanisms. In particular, we are here interested in PT parameters which produce preference for the sequential mechanism over the direct auction.

We consider a grid of parameter combinations over the GE PWF parameters a and b, and over the search costs variable c for two (only two for the sake of computation time) different values of power utility parameter $\alpha = 0.2$ (high level of concavity/convexity) and $\alpha = 0.9$ (low level of concavity/convexity). Moreover, Table 3.1 shows that several studies have found values for α around 0.2 and 0.9, which is an additional reason that we choose to analyze only these two values. For every parameter combination, we investigate whether the PT-value of the sequential mechanism (SEQ) or simultaneous auction (SIMA) is higher.

The Figures E.7, E.8, E.9, and E.10 show the analysis of parameter combinations. For 30 points of c in the range $[0, 0.15]$ we looked at the following parameter combinations, where we use the same parameters for gains as for losses:

1. S-type PWF: 50 points $a \in [1.1, 2]$; 50 points $b \in [0.1; 2]$; $\alpha \in \{0.2, 0.9\}$.
2. IS-type PWF: 50 points $a \in [0.1, 0.9]$; 50 points $b \in [0.1; 2]$; $\alpha \in \{0.2, 0.9\}$.
3. convex-type PWF: $a = 1$; 50 points $b \in [0.1; 0.9]$; $\alpha \in \{0.2, 0.9\}$.
4. concave-type PWF: $a = 1$; 50 points $b \in [1.1; 2]$; $\alpha \in \{0.2, 0.9\}$.

For the S and IS type PWFs, this boils down to 5000 parameter combinations per considered value of c.

The parameter combinations which produce higher PT-values for the sequential mechanism than for the simultaneous auction are plotted in a 3D-scatter plot. The size of the sphere indicates whether one or both of the α-values give $PT(\text{SEQ}) > PT(\text{SIMA})$, where a larger sphere means that it holds for both values. The color intensity corresponds to the minimum of α-values $(0.2, 0.9)$ for which $PT(\text{SEQ}) > PT(\text{SIMA})$, where a darker color intensity corresponds to a lower number.

Furthermore, the corresponding 2D planes are presented, along with the percentage of parameter combinations per c which give $PT(\text{SEQ}) > PT(\text{SIMA})$. Finally, the average, median, minimum, and maximum negotiation penalty *between PT-values* at mechanism level per c are displayed.

D Extracting Data from SEC Filings

The SEC merger filings contain 'background of the merger' sections which contain details about the process leading up to the eventual deal. For mergers, we look for the SEC Form DEFM14A and/or Form S-4; for tender offers, we look for Schedule 14D-9 filings[25]. Determining the selling procedure of a deal requires a cautious and extensive reading of the filings. Not all filings are phrased in an identical fashion and often important information is omitted.

We categorize all deals into one of four classifications: direct negotiations (NEG), direct (simultaneous) auctions (SIMA), sequential negotiations (SEQN), and sequential auctions (SEQA). We eventually combine the SEQN and SEQA into SEQA[26]. In general, the four classifications are determined on the following criteria:

- A deal is classified as direct negotiation (NEG) if only one bidder is involved in the complete selling process.
- A deal is classified as simultaneous auction (SIMA) if more than one potential bidder is solicited at the initiation of the sales process.
- A deal is classified as sequential negotiation (SEQN) if the process started with a *serious* one-on-one negotiation which got terminated, and another one-on-one negotiation commenced.
- A deal is classified as sequential auction (SEQA) if the process started with a *serious*

[25] These codes can have some small variations, depending on whether the filing is preliminary or whether it is a filing with an amendment added to it (e.g. PREM14C, S-4/A, SC 14D9C, SC 14D9/A).

[26] A sequential negotiation can be considered a sequential auction where the first bidder does not participate anymore in the second stage.

one-on-one negotiation which got terminated, after which multiple bidders were involved.

'Seriousness' naturally remains a matter of judgement. Primarily, we consider the exchange of information between parties as indications of a serious negotiation. To that extent, we search for phrases or terms in the SEC filings (background of merger section) which indicate exchange of information. Some cases left room for interpretation, but in general we look for items of the following non-exhaustive list of indicative events and phrasings:

- Signing of confidentiality agreement
- Mention of non-public information being exchanged
- Mention of due diligence being conducted
- Mention of negotiations
- Occurrence of management meetings (after signing of confidentiality agreement)
- Mention of 'extensive discussions', including:
  - Frequency of discussion meetings
  - Subject of the discussions:
    * Synergies
    * Complimentarity/integrability of businesses
  - Signing of a confidentiality agreement to facilitate extensive discussions
- Explicit mentioning of termination or a variation thereof
- Mention of exclusivity
- Indication of an offer price
- Hiring of an investment bank and/or legal advisor
- Mention of 'preliminary' in combination with 'due diligence'

Furthermore, besides the 'seriousness' criterion, we require that the time gap between a failed first-stage negotiation and a second-stage auction does not exceed one year. If the time gap does exceed one year, we consider the failed first-stage negotiation to be independent from the subsequent sales process.

Important to note is that not all first-stage negotiations before a second-stage process are explicitly terminated. In some cases, the target implicitly terminates the first-stage negotiations by engaging in discussions with other bidders. In these cases in particular, it is of paramount importance to assess the degree of seriousness of the first-stage negotiation. Target firms often engage in preliminary talks with an initial bidder (these talks are often initiated by the initial bidder), in the meanwhile preparing a formal auction with a financial advisor. These preliminary talks can be serious, but more often than not, we find that such preliminary talks are insufficiently serious to be classified as failed first-stage negotiations.

E Additional Figures and Tables

Figure E.1: Bidding functions for $z = 0.2$
This figure shows the asymmetric bidding functions for both bidders $b_1^a(v_1)$ and $b_2^a(v_2)$ along with the bidding function for the high-type deviating bidder $h_1(v_1)$ for an arbitrary value of $z = 0.2$.

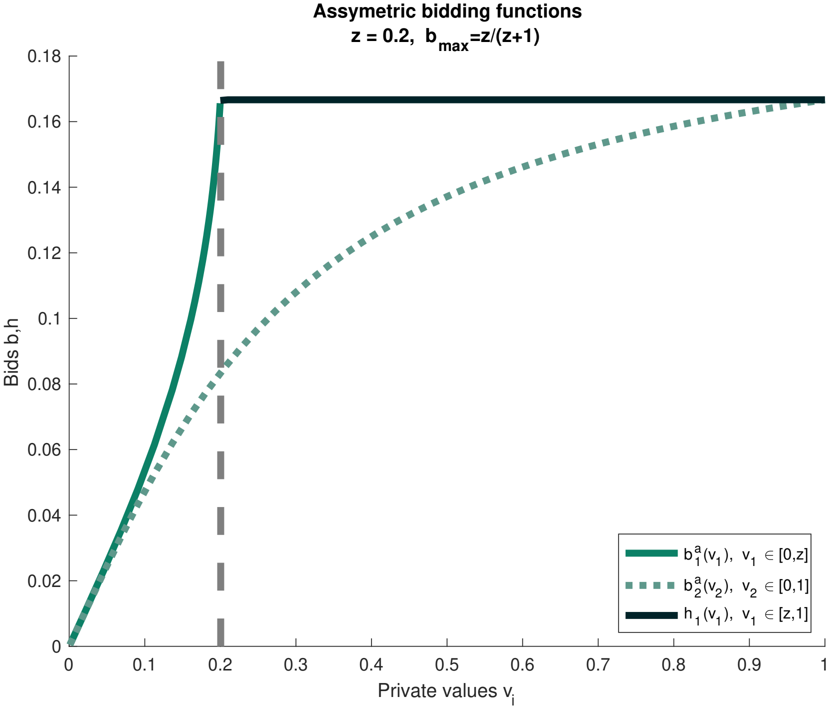


Figure E.2: Bidding strategies for B_1 with $c = 1/12$, $z = 1/3$
This figure shows the expected payoffs for bidder B_1 resulting from different strategies that are possible to follow for B_1 in the case of $c = 1/12 \Longrightarrow z = 1/3$. The expected payoff for the negotiation is the private value minus the equilibrium bid $v_1 - p^*$. The expected payoffs for B_1 from the auction is $\Pr(b_1 > b_2)[v_1 - b_1]$, where b_1 and b_2 denote the bids from bidders B_1 and B_2 respectively, dependent on which strategy the bidders follow. The expected payoffs in the same orders as in the legend are therefore:

$$\mathbb{E}[AUC] \text{ for } B_1 = \begin{cases} v_1\left[v_1 - \frac{1}{2}v_1\right] \\ \phi_2\left(\frac{1}{2}v_1\right)\left[v_1 - \frac{1}{2}v_1\right] \\ \phi_2(b^a(v_1))[v_1 - b^a(v_1)] \\ 1\left[v_1 - \bar{b}\right] \end{cases}$$

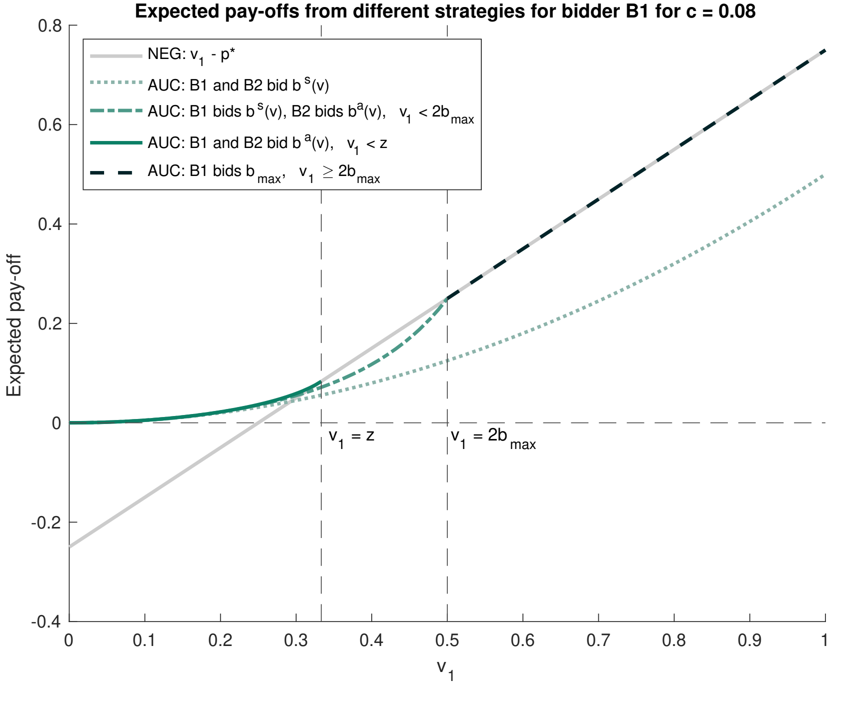


Figure E.3: Bidding strategies for B_1 with $c = 1/6, z = 1/5$

This figure shows the expected payoffs for bidder B_1 resulting from different strategies that are possible to follow for B_1 in the case of $c = 1/6 \Longrightarrow z = 1/5$. The expected payoff for the negotiation is the private value minus the equilibrium bid $v_1 - p^*$. The expected payoffs for B_1 from the auction is $\Pr(b_1 > b_2)[v_1 - b_1]$, where b_1 and b_2 denote the bids from bidders B_1 and B_2 respectively, dependent on which strategy the bidders follow. The expected payoffs in the same orders as in the legend are therefore:

$$\mathbb{E}[AUC] \text{ for } B_1 = \begin{cases} v_1\left[v_1 - \frac{1}{2}v_1\right] \\ \phi_2\left(\frac{1}{2}v_1\right)\left[v_1 - \frac{1}{2}v_1\right] \\ \phi_2(b^a(v_1))[v_1 - b^a(v_1)] \\ 1\left[v_1 - \bar{b}\right] \end{cases}$$

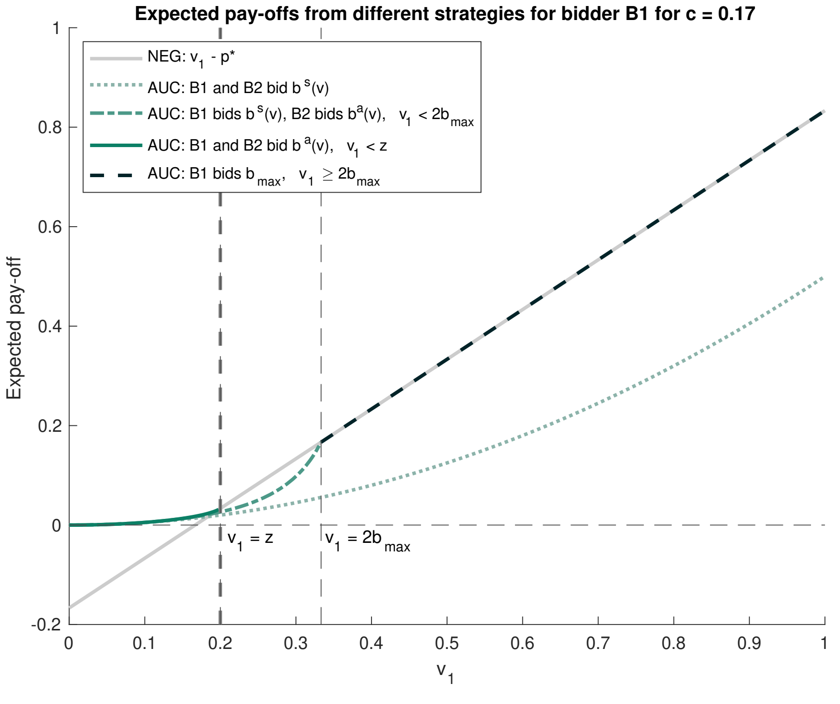


Figure E.4: GE PWF for different parameter combinations
This figure shows how the shape of the GE PWF changes according to different parameters specifications of a and b.

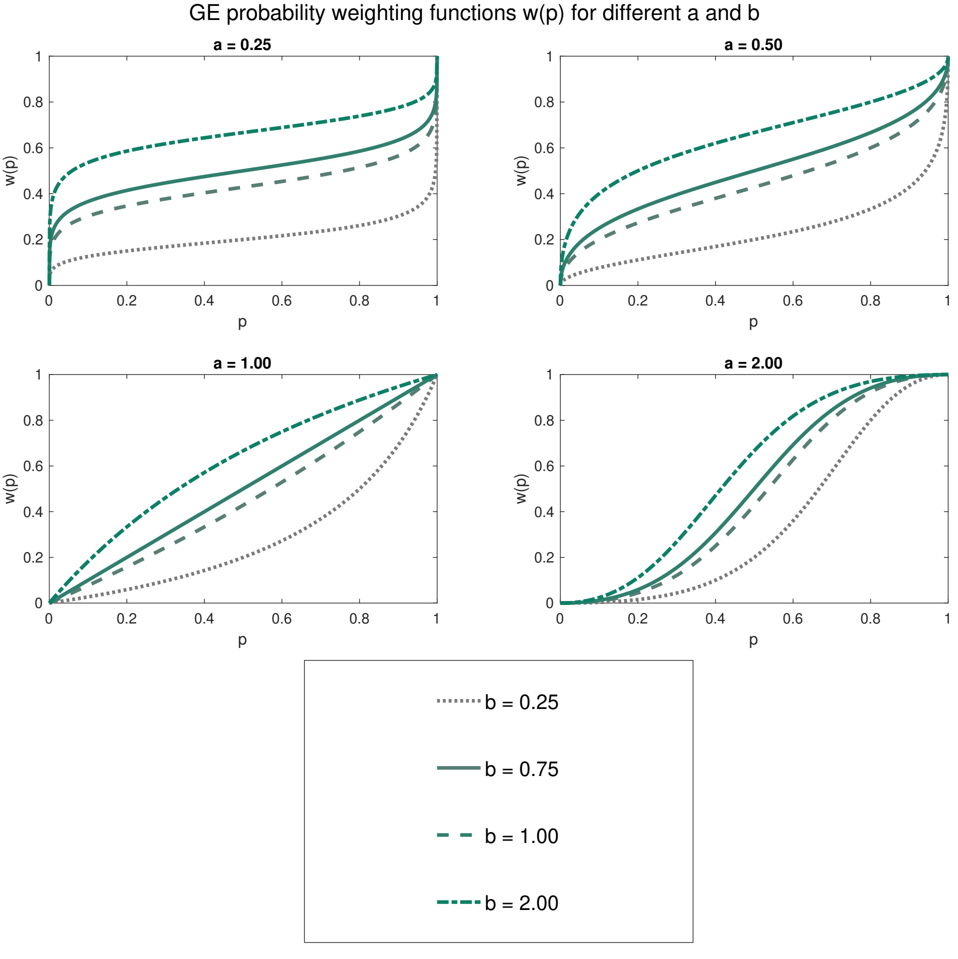


Figure E.5: Used variations of PWF and utility function

This figure displays the several variations of the GE probability weighting function and power utility function as described in Appendix C. These variations are used to calculate the CE negotiation penalties at mechanism and auction level displayed in Figures 3.6 and 3.7.

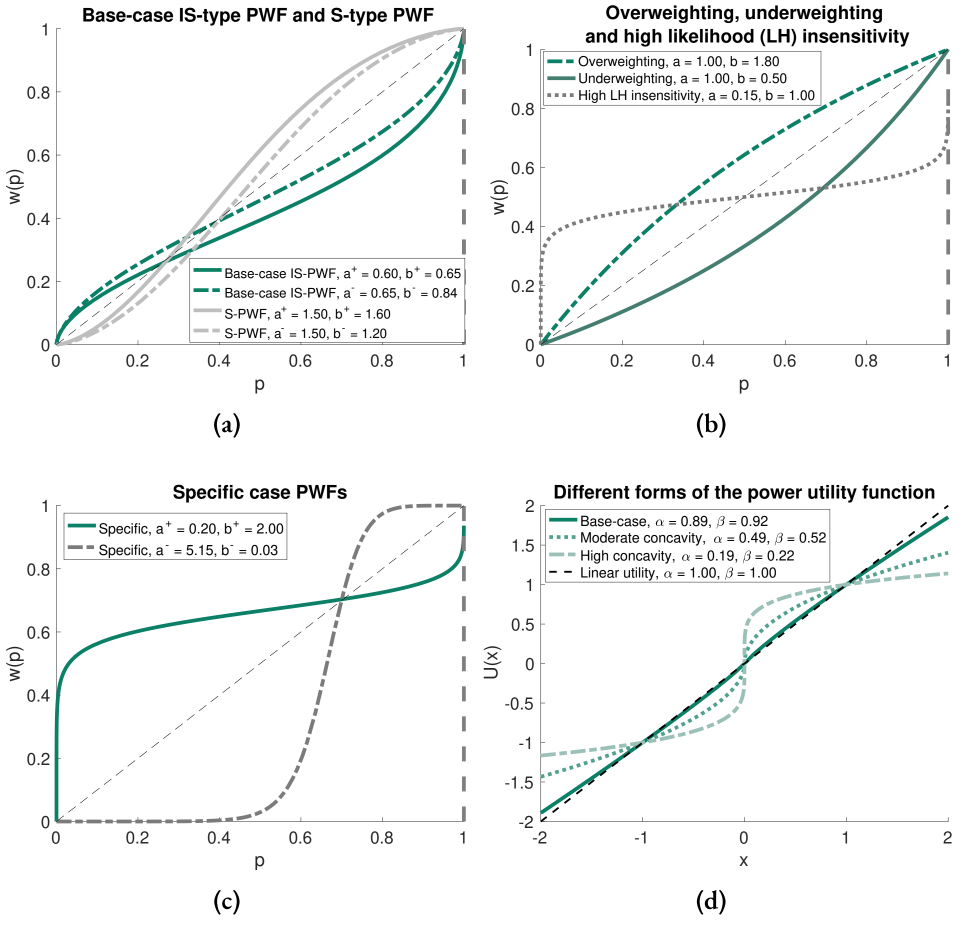


Figure E.6: Threshold and CDFs of maximum bids

This figure shows the threshold z as function of search costs c. The value z is also the probability that the negotiation (NEG) fails and hence, the probability that the sequential auction (SEQA) takes place. We also display the weighted probabilities obtained with the GE-AB PWF. Furthermore we have displayed for several c the cumulative probability distributions of the maximum bids in a sequential auction (SEQA) as in Equation (43).

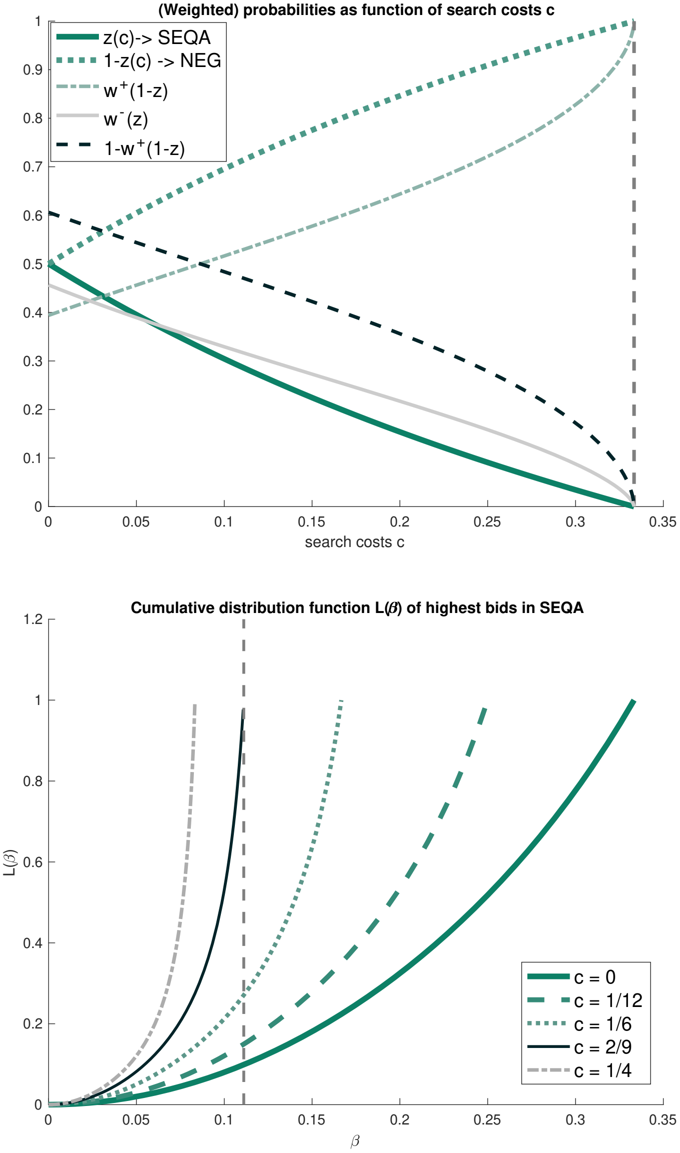
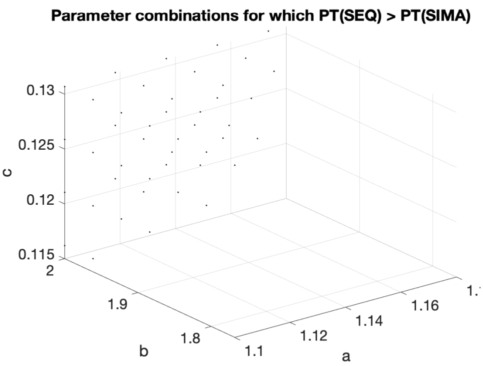
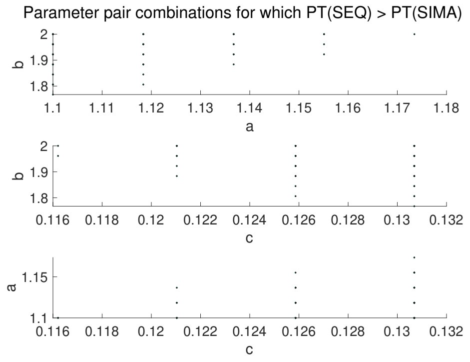


Figure E.7: Effect of parameters for S-type PWF

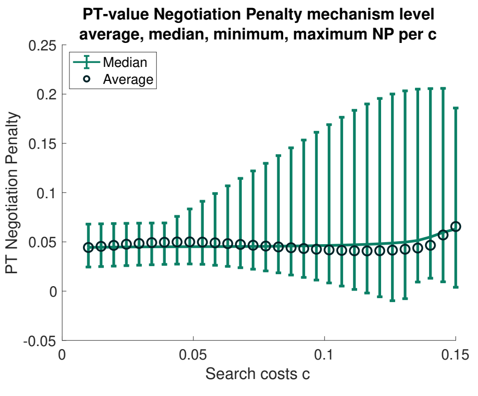
This figure shows (a) a 3D-scatter which displays those parameter combinations which give higher PT-values for SEQ than SIMA. The parameter sets which are considered for this analysis are described in Appendix B. The size of the sphere indicates whether only one or both of the α-values gives $PT(\text{SEQ}) > PT(\text{SIMA})$, where a larger sphere means that it holds for both values. The color intensity corresponds to the minimum of α-values $(0.2, 0.9)$ for which $PT(\text{SEQ}) > PT(\text{SIMA})$, where a darker color intensity corresponds to a lower number. These parameter combinations are displayed per 2D-plane in subfigure (b). Subfigure (c) shows the average, median, minimum and maximum negotiation penalty at mechanism level over all analyzed parameter combinations per c. Finally subfigure (d) displays the percentage of all parameter combinations per c which give $PT(\text{SEQ}) > PT(\text{SIMA})$.



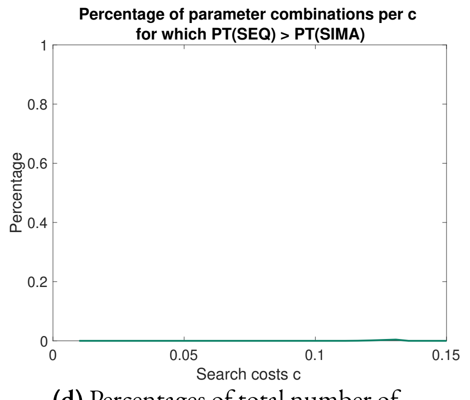
(a) Combinations which give $PT(\text{SEQ}) > PT(\text{SIMA})$



(b) Combinations planes



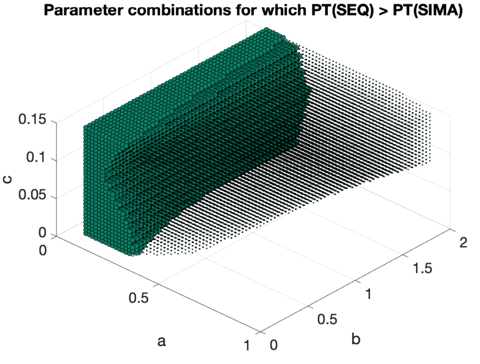
(c) Average, median, min and max NP



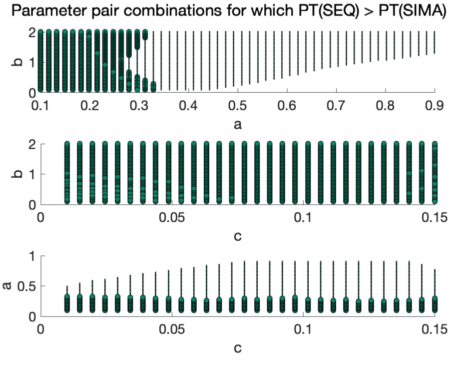
(d) Percentages of total number of combinations

Figure E.8: Effect of parameters for IS-type PWF

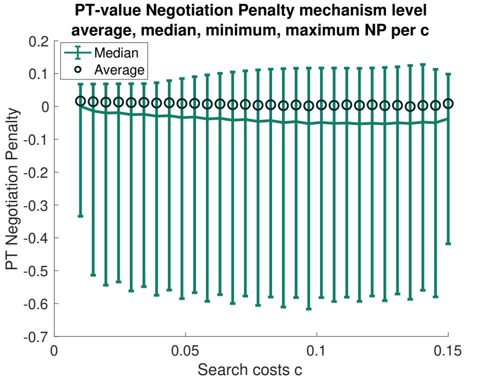
This figure shows (a) a 3D-scatter which displays those parameter combinations which give higher PT-values for SEQ than SIMA. The parameter sets which are considered for this analysis are described in Appendix B. The size of the sphere indicates whether only one or both of the α-values gives $PT(\text{SEQ}) > PT(\text{SIMA})$, where a larger sphere means that it holds for both values. The color intensity corresponds to the minimum of α-values $(0.2, 0.9)$ for which $PT(\text{SEQ}) > PT(\text{SIMA})$, where a darker color intensity corresponds to a lower number. These parameter combinations are displayed per 2D-plane in subfigure (b). Subfigure (c) shows the average, median, minimum and maximum PT negotiation penalty at mechanism level over all analyzed parameter combinations per c. Finally subfigure (d) displays the percentage of all parameter combinations per c which give $PT(\text{SEQ}) > PT(\text{SIMA})$.



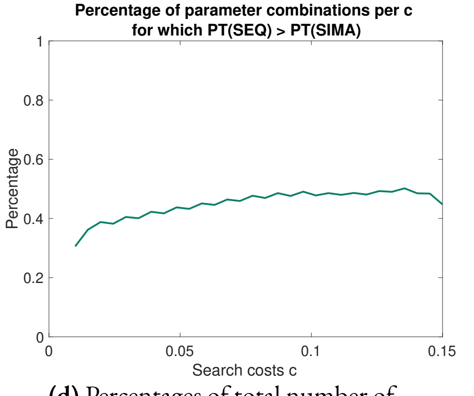
(a) Combinations which give $PT(\text{SEQ}) > PT(\text{SIMA})$



(b) Combinations planes



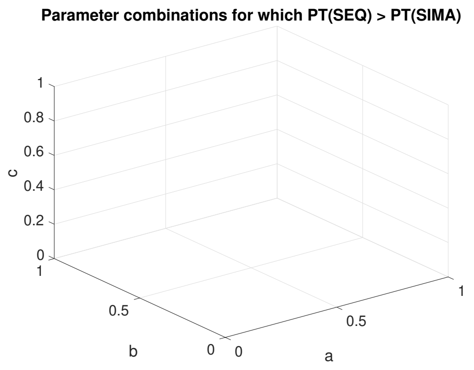
(c) Average, median, min and max NP



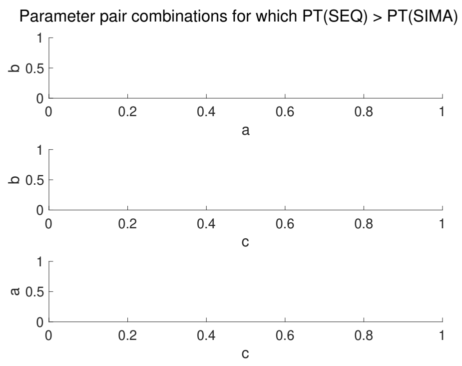
(d) Percentages of total number of combinations

Figure E.9: Effect of parameters for convex-type PWF

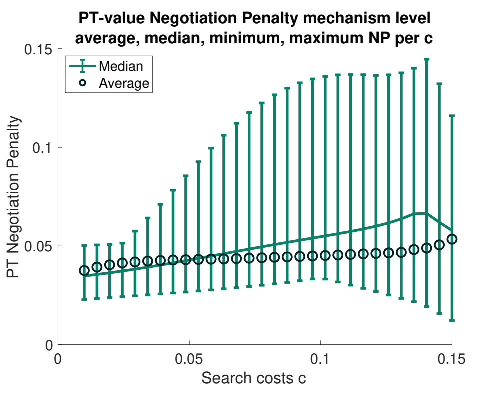
This figure shows (a) a 3D-scatter which displays those parameter combinations which give higher PT-values for SEQ than SIMA. The parameter sets which are considered for this analysis are described in Appendix B. The size of the sphere indicates whether only one or both of the α-values gives $PT(\text{SEQ}) > PT(\text{SIMA})$, where a larger sphere means that it holds for both values. The color intensity corresponds to the minimum of α-values $(0.2, 0.9)$ for which $PT(\text{SEQ}) > PT(\text{SIMA})$, where a darker color intensity corresponds to a lower number. These parameter combinations are displayed per 2D-plane in subfigure (b). Subfigure (c) shows the average, median, minimum and maximum negotiation penalty at mechanism level over all analyzed parameter combinations per c. Finally subfigure (d) displays the percentage of all parameter combinations per c which give $PT(\text{SEQ}) > PT(\text{SIMA})$.



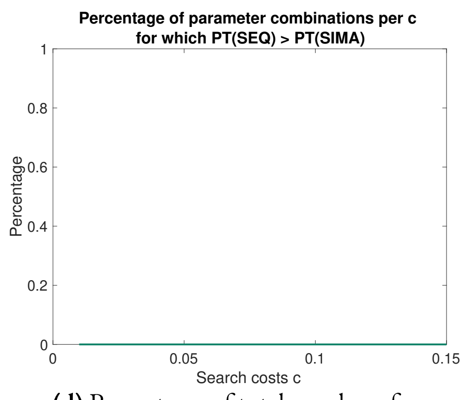
(a) Combinations which give $PT(\text{SEQ}) > PT(\text{SIMA})$



(b) Combinations planes



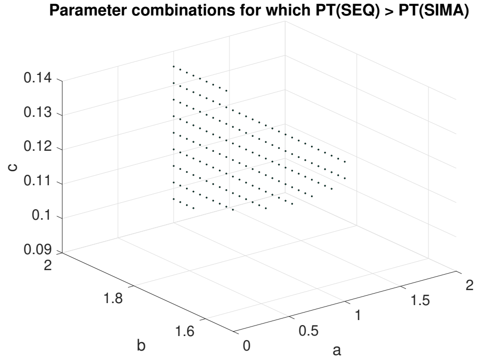
(c) Average, median, min and max NP



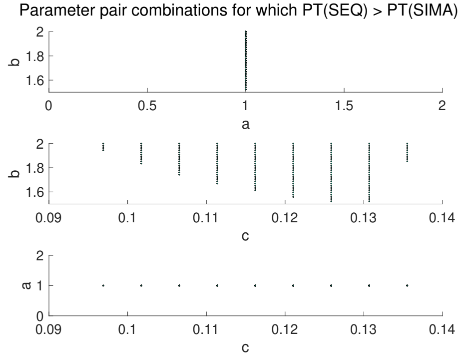
(d) Percentages of total number of combinations

Figure E.10: Effect of parameters for concave-type PWF

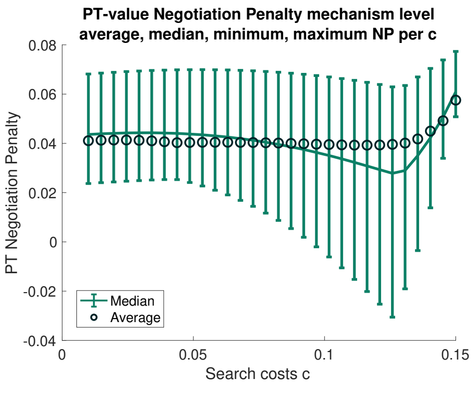
This figure shows (a) a 3D-scatter which displays those parameter combinations which give higher PT-values for SEQ than SIMA. The parameter sets which are considered for this analysis are described in Appendix B. The size of the sphere indicates whether only one or both of the α-values gives $PT(\text{SEQ}) > PT(\text{SIMA})$, where a larger sphere means that it holds for both values. The color intensity corresponds to the minimum of α-values $(0.2, 0.9)$ for which $PT(\text{SEQ}) > PT(\text{SIMA})$, where a darker color intensity corresponds to a lower number. These parameter combinations are displayed per 2D-plane in subfigure (b). Subfigure (c) shows the average, median, minimum and maximum negotiation penalty at mechanism level over all analyzed parameter combinations per c. Finally subfigure (d) displays the percentage of all parameter combinations per c which give $PT(\text{SEQ}) > PT(\text{SIMA})$.



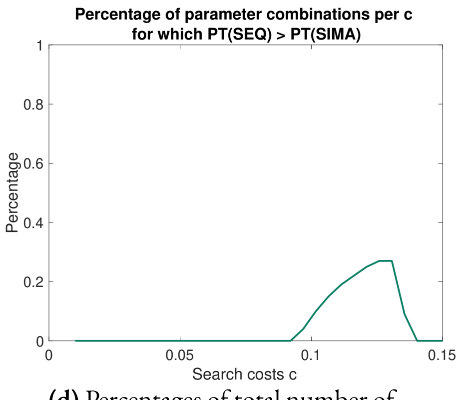
(a) Combinations which give $PT(\text{SEQ}) > PT(\text{SIMA})$



(b) Combinations planes



(c) Average, median, min and max NP



(d) Percentages of total number of combinations

Table E.1: Distribution of deal types over years

This table shows the distribution of deal types over the years in our sample period. We differentiate between the deal types: NEG, a negotiation which succeeded in the first stage of the selling process; SEQA, a sequential auction which followed in the second stage after a failed negotiation in the first stage of the selling process; and SIMA, a direct auction. Classification details are discussed in Section D.

	SEQA		SEQN		SIMA		Total
year	*N*	%	*N*	%	*N*	%	*N*
2002	19	19%	51	52%	28	29%	98
2003	17	12%	81	59%	39	28%	137
2004	18	13%	82	57%	44	31%	144
2005	20	13%	85	53%	55	34%	160
2006	29	15%	92	48%	69	36%	190
2007	34	19%	71	39%	77	42%	182
2008	18	21%	36	41%	33	38%	87
2009	18	32%	24	42%	15	26%	57
2010	19	16%	50	41%	52	43%	121
2011	22	22%	43	43%	34	34%	99
2012	18	18%	49	48%	35	34%	102
2013	26	25%	38	37%	39	38%	103
2014	18	17%	42	41%	43	42%	103
Total	276	17%	744	47%	563	36%	1,583
NEG/SEQ (%)			72.94%				

Table E.2: Premium differences for different deal types with exclusion of financial targets
Linear regressions with inclusion of company and deal control variables; year, industry and year-industry fixed effects; and year-industry clustered standard errors (clustered t-statistics in parentheses below). Financial targets are excluded. The dependent variable is the 4-week premium. We regress the dependent variable on the three deal types (SIMA, NEG, SEQA), where we have set SEQA as the reference class. The (control)variables are described in Table 3.2.

Reference class: SEQA *Variables*	(1) Baseline and FE	(2) Target controls	(3) Deal controls
NEG	11.388***	15.357***	15.400***
	(3.13)	(3.45)	(3.47)
SIMA	10.991***	13.608***	12.875***
	(3.04)	(3.34)	(3.13)
Size		-0.001**	-0.001**
		(-2.60)	(-2.07)
Cash/Assets		-9.838	-6.757
		(-0.84)	(-0.59)
PPE/Assets		-16.359	-12.937
		(-1.44)	(-1.04)
R&D/Assets		5.279*	4.998
		(1.67)	(1.59)
Tobin's Q		-2.048	-1.949
		(-1.36)	(-1.28)
Leverage		16.667**	18.249**
		(2.03)	(2.15)
Intangibles/Assets		-28.537***	-22.061*
		(-2.74)	(-1.94)
ROA		-43.876***	-44.635***
		(-3.10)	(-3.22)
Long term debt		0.001	0.001
		(0.88)	(0.84)
Institution owned		-13.458**	-14.956**
		(-2.41)	(-2.50)
Cash deal			10.933***
			(3.01)
Financial buyer			-2.627
			(-0.63)
Relation			4.721
			(1.00)
Cross deal			7.287
			(1.26)
Goshop			-1.196
			(-0.29)
Observations	1,009	872	872
Adjusted R^2	0.256	0.345	0.357
Year, Industry, Year-Industry FE	x	x	x

Note: clustered t-statistics in parentheses, *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table E.3: Premium differences and effect of search costs for different deal types with exclusion of financial targets

Linear regressions with inclusion of company and deal control variables; year, industry and year-industry fixed effects; and year-industry clustered standard errors (clustered t-statistics in parentheses below). Financial targets are excluded. The dependent variable is the 4-week premium. We regress the dependent variable on the three deal types (SIMA, NEG, SEQA), where we have set SEQA as the reference class. Furthermore we include interactions with the liquidity index (search costs) for each of the deal types. The (control)variables are described in Table 3.2.

	Reference class: SEQA		Reference class: SIMA	
	(1)	(2)	(3)	(4)
Variables	NEG & SIMA vs SEQA	NEG vs SEQA	SEQA vs SIMA	NEG vs SIMA
SEQA			-17.465**	
			(-2.56)	
NEG	19.994***	21.909***		4.199
	(3.99)	(3.55)		(1.12)
SIMA	15.149***			
	(3.31)			
Liquidity index	21.833	15.635	87.581*	4.503
	(0.66)	(0.36)	(1.67)	(0.24)
SEQA x Liquidity Index			66.932	
			(1.17)	
NEG x Liquitidy Index	-44.037	-69.426		-23.813
	(-1.14)	(-1.14)		(-1.41)
SIMA x Liquidity Index	-21.501			
	(-0.72)			
Size	-0.001	-0.000	-0.001	-0.000
	(-1.40)	(-0.16)	(-1.26)	(-0.89)
Cash/Assets	-6.497	-0.267	-16.359	-4.538
	(-0.57)	(-0.02)	(-0.94)	(-0.32)
PPE/Assets	-12.921	-28.961	-20.585	-1.314
	(-1.03)	(-1.46)	(-1.23)	(-0.08)
R&D/Assets	5.073	3.690	4.191	5.374
	(1.61)	(0.99)	(1.01)	(1.50)
Tobin's Q	-1.907	-4.034**	-0.718	-1.169
	(-1.25)	(-2.59)	(-0.32)	(-0.57)
Leverage	17.533**	14.781	29.219**	14.928*
	(2.23)	(1.25)	(2.07)	(1.74)
Intangibles/Assets	-20.526*	-17.821	-26.666**	-17.176
	(-1.79)	(-0.98)	(-2.06)	(-1.28)
ROA	-45.232***	-23.840	-57.506***	-56.350***
	(-3.29)	(-1.05)	(-2.75)	(-3.46)
Long term debt	0.001	0.000	0.004	0.001
	(0.90)	(0.18)	(1.57)	(0.62)
Institution owned	-15.971***	-18.728**	-16.136*	-15.608**
	(-2.64)	(-2.32)	(-1.80)	(-2.42)

Continued on next page

Table E.3 – *Continued from previous page*

	Reference class: SEQA		Reference class: SIMA	
Variables	(1) NEG & SIMA vs SEQA	(2) NEG vs SEQA	(3) SEQA vs SIMA	(4) NEG vs SIMA
Cash deal	11.502***	7.714*	14.219**	13.582***
	(3.28)	(1.72)	(2.19)	(3.44)
Financial buyer	-3.424	-3.025	-0.820	-3.478
	(-0.80)	(-0.54)	(-0.14)	(-0.69)
Relation	4.896	10.032	-2.502	6.934
	(1.04)	(1.48)	(-0.57)	(1.19)
Cross deal	7.335	13.582	6.637	8.903
	(1.28)	(1.39)	(1.08)	(1.38)
Goshop	-0.361	-1.445	1.365	-1.155
	(-0.09)	(-0.29)	(0.22)	(-0.21)
Observations	872	526	431	692
Adjusted R^2	0.361	0.358	0.478	0.409
Year, Industry, Year-Industry FE	x	x	x	x

Note: clustered t-statistics in parentheses, *** p<0.01, ** p<0.05, * p<0.1

Table E.4: Second stage Heckit - Linear regressions with exclusion of financial targets
Linear regressions for the second stage of the Heckman treatment selection procedure with inclusion of company and deal control variables; year, industry and year-industry fixed effects; and year-industry clustered standard errors (clustered t-statistics in parentheses below). Financial targets are excluded. The dependent variable is the 4-week premium. We regress the dependent variable on several binary variables: e.g. in SEQ vs SIMA, SEQ = 1 and SIMA = 0. Here SEQ denotes the sequential mechanism and thus encompasses both deal types NEG and SEQA. The variable *Heckman* denotes the Heckman term for correction of selection bias. Furthermore we include interactions with the liquidity index (search costs) for each of the deal types. The (control)variables are described in Table 3.2.

Reference class: SIMA	*Linear regression*		
Variables	(1) SEQ vs SIMA	(2) SEQA vs SIMA	(3) NEG vs SIMA
SEQ	97.875		
	(1.21)		
Liquidity Index	-33.064	133.443**	-4.919
	(-1.04)	(2.25)	(-0.20)
SEQ x Liquitidy Index	-0.667		
	(-0.03)		
SEQA		-199.315**	
		(-1.98)	
SEQA x Liquidity Index		70.468	
		(1.26)	
NEG			49.189
			(0.81)
NEG x Liquidity Index			-21.095

Continued on next page

Table E.4 – *Continued from previous page*

Reference class: SIMA	*Linear regression*		
Variables	(1) SEQ vs SIMA	(2) SEQA vs SIMA	(3) NEG vs SIMA
			(-1.17)
Heckman	-61.557	110.643*	-28.015
	(-1.23)	(1.82)	(-0.74)
Size	-0.001	-0.004**	-0.001
	(-1.63)	(-2.52)	(-1.05)
Cash/Assets	-5.469	-4.850	-4.427
	(-0.45)	(-0.26)	(-0.31)
PPE/Assets	-21.742	18.818	-4.344
	(-1.46)	(0.66)	(-0.26)
R&D/Assets	8.805**	-2.382	7.393*
	(2.36)	(-0.49)	(1.91)
Tobin's Q	-5.267	1.795	-3.313
	(-1.51)	(0.65)	(-0.88)
Leverage	36.496**	-6.575	21.904*
	(2.25)	(-0.28)	(1.77)
Intangibles/Assets	-17.761	-10.698	-13.488
	(-1.50)	(-0.69)	(-0.96)
ROA	-30.994*	-84.069***	-49.043**
	(-1.68)	(-3.40)	(-2.51)
Long term debt	0.001	0.004	0.001
	(0.49)	(1.54)	(0.44)
Institution owned	-18.766**	-9.390	-17.489**
	(-2.47)	(-1.04)	(-2.45)
Cash deal	9.670***	14.047**	13.256***
	(2.73)	(2.15)	(3.32)
Financial buyer	-4.090	-0.891	-3.394
	(-1.01)	(-0.15)	(-0.67)
Relation	6.360	-2.236	6.981
	(1.27)	(-0.50)	(1.20)
Cross deal	6.943	6.886	8.948
	(1.20)	(1.15)	(1.39)
Goshop	0.981	1.200	-1.002
	(0.24)	(0.20)	(-0.18)
Observations	872	431	692
Adjusted R^2	0.346	0.482	0.410

Note: clustered t-statistics in parentheses, *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Our comforting conviction that the world makes sense rests on a secure foundation: our almost unlimited ability to ignore our ignorance.

Daniel Kahneman

4

Real Options in Incomplete Markets: A Simplified Prospect Theory Approach‡

One of the most inconclusive topics of debate in company valuation is how to value investment opportunities. Within real options theory, investment opportunities are viewed as options on real assets (Myers,

‡This chapter is based on Matawlie & Smit (2020b)

1977). Under the crucial assumption that the investment payoff is replicable by traded assets, real option (RO) valuation models use the methodology for financial options to value investment decisions. Real options models are suitable to value investments involving high amounts of uncertainty, and these models can deal with volatile business environments more explicitly than traditional static valuation models and they can account for decision-making flexibility in staged investments (Dixit & Pindyck, 1994).

Prospect theory (PT) (Kahneman & Tversky, 1979; Tversky & Kahneman, 1992) is a prominent behavioural theory and also relates to decisions under uncertainty and risk. PT describes some of the dominant behavioral predispositions that guide decisions over uncertain outcomes[1]. Both real options and prospect theory are affected by truncation of outcomes. Real options theory considers investments under risk and uncertainty; prospect theory considers decisions under risk and uncertainty that involve gains and losses relative to a reference point, thereby weighting the probabilities of outcomes. The integration of real options and prospect theory therefore seems natural and valuable. Especially because the replicability condition within real options is sometimes deemed "the Achilles' heel" of real options theory (Kogut & Kulatilaka, 2004). After all, for many investment situations, it may not be realistic to assume that the underlying assets can be perfectly spanned by traded assets in complete financial markets. For instance, investments in start-ups or R&D relate almost per definition to underlying values which are at best, imperfectly, or not even at all correlated with traded financial assets (incomplete financial markets settings). When option value cannot be estimated objectively using the replication argument, the appli-

[1] Prospect theory incorporates several innovative elements relative to expected utility theory, which are reference level dependence, loss aversion, probability weighting and a risk seeking (risk averse) attitude over losses (gains). These elements enable the explanation of several behavioural traits, which cannot be captured by expected utility theory (for an overview see Barberis (2013)). With prospect theory we refer to 'cumulative prospect theory' (Tversky & Kahneman, 1992) which is an improvement of the original prospect theory (OPT) (Kahneman & Tversky, 1979).

cation of standard real option theory seems questionable. There can be a discrepancy in perceived risk and market risk in the sense that people are sensitive to personal preferences when deciding about risky or uncertain outcomes.

This begs the question of how individual preferences and behaviour may affect investment decisions through real options valuation. Since PT is able of capturing preferences, we attempt to integrate PT with RO in one simplified framework for valuing investment decisions as real options in incomplete markets. By combining real options theory and insights from prospect theory in one framework, we attempt to explain and/or better understand investment behaviour in these contexts. Polkovnichenko & Zhao (2013) show with empirical non-experimental evidence that even in *complete* financial markets, behavioural theory can be related to option theory as they show that the empirical pricing kernels of index options are in accordance with rank-dependant utility and probability weighting with an inverse-S shape for the probability weighting function.

Several studies have dealed with real options in incomplete markets through an expected utility framework[2]. These approaches determine real option value by the maximization of utility of consumption or utility of wealth; together with portfolio allocation. For that purpose, most studies determine the optimal stopping time (exercise of the option) in an continuous time framework with infinite time horizon. One of the general findings of this approach is that risk aversion erodes real option value.

However, there is a growing strand of literature which shows that agents do not always act in accordance with predicted behaviour following from expected utility maximization. Some studies therefore took up the challenge of applying prospect theory (PT) in a continuous time framework with infinite time horizon. For instance, Ebert & Strack (2015)

[2]Among others: Henderson (2007); Hugonnier & Morellec (2007); Miao & Wang (2007); Grasselli (2011).

came to the conclusion that a PT agent will never exercise a call-type real option, even if the agent can gain a strict positive payoff by exercising immediately. Henderson et al. (2017) tampers this conclusion by showing that a PT agent who is able to randomize between strategies, can voluntarily exercise the real option.

Continuous time frameworks with an infinite time horizon are mathematically elegant and enable a closed form solution. However, we may wonder whether an agent intuitively evaluates decisions continuously or more on a discrete basis. Whereas the studies mentioned above have already focused on the optimal stopping time in a continuous real option context with prospect theory, many investment decisions are at a discrete fixed moment or have multiple possibilities of discrete exercise moments. Thereby, not all investment decisions are stopping time decisions, many are investment-amount decisions. Furthermore, there are many applications where the relevant outcomes follow a discrete distribution (e.g., success/failure (technical uncertainty within R&D, approval/disapproval of a new medicine, etc.) rather than a continuous distribution.

Discrete-time settings with finite time horizon are in accordance with most of relevant applications, where the investment opportunity does not last forever. Think about the opportunity to invest either now or after one period; or the fixed moments in time for several investment rounds in a start-up. Such settings are very relevant for the valuation of early-stage venture capital and investments by angel investors. Venture capital types of investments such as contingent investment rounds are often represented as compound real options (options on options) (Sahlman, 1999; Seppä & Laamanen, 2001; Smit & Trigeorgis, 2004). Compound real options have not yet been examined within the prospect theory framework. Moreover, most applications of prospect theory are in discrete time. Hence, in this study we focus on finite-time (compound) real options in a discrete context. We approach this through a binomial tree model in the spirit of Cox et al. (1979) integrated with prospect theory. We thereby give up the mathematical allegiance of a closed form solution, however these binomial tree models are mathematically tractable and offer an intuitive tool for real option valuation of a great variety of investment opportunities.

Both prospect theory and real options focus on decision-making under risk and uncertainty: the former offering behavioral clarification and the latter providing a valuation method for investment decisions. Barberis & Huang (2008) use PT to relate low average returns to the high positive skewness of private business and they identify a pressing yet up-to-date direction for research: To think more deeply about the applications of PT to investments with a skewed payoff. We take up part of the challenge and we present the first binomial prospect theory and real options integrated model for incomplete markets, which is applicable to a wide range of investment opportunities.

We model, among more explicitly, the sequential nature of venture capital as a portfolio of real options of which the valuation is affected by the individual prospect theory preferences of the agent. Moreover, we also explicitly investigate the effect of the reference point in decision making, we illustrate and confirm its major importance in decision making as already emphasized by Markowitz (1952). With these efforts, we aim to contribute to the strands of real options literature and the behavioural (finance) literature.

We find that probability weighting functions play an important role in determining the value of real options through prospect theory. Optimists (pessimists) value a real option higher (lower) compared to the base case. Furthermore, the reference point also heavily affects RO value and investment decisions. One advantage of our framework is that we can choose the reference point flexibly, such that it can represent, for instance, a minimum desired gain, below which all outcomes are considered losses. Agents with very high reference points may value real options higher in monetary terms for low levels of volatility compared to agents with lower reference points. For a high reference point agent, a relatively high monetary value can correspond to a loss. Whereas for a low reference point agent, a relatively low monetary value can correspond to a gain. Through this mechanism, the reference points also affect the timing of exercise and exit for real options.

This chapter is structured as follows, Section 4.1 reviews the literature on real options in incomplete markets settings, and discusses the basic concepts of the real options binomial tree model and of prospect theory. Section 4.2 develops the integrated PT-RO model. Section 4.3 presents some applications of the model and we end with a discussion in Section 4.4 and some conclusions in Section 4.5.

4.1 Literature on Real Options and Prospect Theory

This section reviews the literature on prospect theory and real options in incomplete markets settings. Furthermore, it covers the basic concepts of real options theory along with risk-neutral valuation and covers the basic concepts of prospect theory.

4.1.1 Real Options

Real options theory has as a purpose to model investment decisions under risk and uncertainty and to deal more explicitly with volatile business environments and contingent sequential decisions. Applications involve abandonment of production facilities, serial acquisition strategies, expansion opportunities, etc. We can distinguish between the valuation of simple real options, where the investment decision is analogous to the exercise of a plain financial call or put option; and the compound real option, where agents face a repeated contingent decision (option). The valuation of real options, just as the pricing of financial options, is based on a theoretically strong arbitrage argument which involves dynamic replication and therefore does not rely on preferences and risk-attitude of the investor in the valuation. In incomplete markets, replication via dynamic spanning cannot be realized and real option value depends on preferences of the investor. Given persistent preferences, we argue that they should be embedded somehow in valuation methods. For example, think about trying to value the opportunity to invest in a start-up for an individual angel investor: The individual's preferences may affect both the valuation and related investment decisions.

In real option (RO) valuation, the binomial model of Cox et al. (1979) is a widely used approach because of its simplicity, versatility, and tractability. A RO model's application rests crucially on the assumption of a complete and frictionless market, just as these conditions are required for an accurate discounted cash flows (DCF) valuation of the underlying asset and the dynamic construction of a perfect hedge (Black & Scholes, 1973; Cox & Ross, 1976). With these underlying assumptions, the application of a binomial model in the real options framework enables the use of risk-neutral probabilities (for details, see Appendix A). The risk-neutral transformation is justified in complete settings, because such settings guarantee that for each real option payoff one can instantaneously construct a portfolio that consists of a particular amount of the underlying asset (or a perfectly correlated twin security) and a borrowed amount at the risk-free rate, such that the portfolio precisely replicates the future payoffs of the option in every possible state of the economy (Cox et al., 1979).

As a consequence, risk can be hedged entirely and utility and market risk perceptions become irrelevant (Kogut & Kulatilaka, 1994; Trigeorgis, 1993; Smit & Trigeorgis, 2004). The risk-neutral transformation overcomes the issues associated with the changing risk profile of a real option and the challenge of adjusting correctly for risk at each stage, permitting the use of the risk-free rate as the discount factor in the calculation of the present value of the option.

4.1.2 Prospect Theory

Prospect Theory (PT) is a prominent behavioural theory which formulates a model for decisions under risk and uncertainty (Tversky & Kahneman, 1992). With their initial paper, Kahneman & Tversky (1979) demonstrated how people systematically violate the predictions of expected utility theory. With (cumulative) prospect theory, they presented a model that captures the experimental evidence on risk taking, including the documented violations of expected utility. Prospect theory can explain, for instance, why some people continue gambling when they suffered a big loss, even when their intention was to quit as soon as they would start making a loss in the first place, for an overview see (Barberis, 2013).

Prospect theory without the probability weighting component, that is with a S-shaped utility function representing a risk seeking (risk averse) attitude for losses (gains), is extensively applied and successful in explaining various empirical phenomena such as individual trading behavior (Henderson, 2012) or life insurance decisions (Gottlieb, 2012). Barberis (2012) formulates a prospect theory model for casino gambling, also in a binomial tree setup and closely related to the prospect theory real options framework that we develop; his model is able to capture several features of actual casino gambling behaviour.

Henderson et al. (2018) use prospect theory in full, including probability weighting, to study a continuous-time optimal stopping model for an asset sale, to explain the disposition effect. They find that introducing probability weighting greatly improves the predictive power of models of PT investors and that predictions from their model for the disposition effect match in magnitude with those calculated by Odean (1998). Moreover, they state that the PT agent with probability weighting provides a better fit to observed behavior than the PT agent without probability weighting, or a classical maximizer of expected utility.

4.1.3 Real Options in Incomplete Markets

Several studies have investigated how to value real options in incomplete markets settings, mostly by approaching the valuation problem through behavioural theories. Earlier studies followed the way of expected utility maximization. Utility-based valuation derives from the seminal works of Merton (1969, 1975) who developed the original dynamic stochastic model of expected utility maximization.

Miao & Wang (2007) develop a utility-based real options model using CARA utility to analyze an agent's interdependent real investment, consumption, and portfolio choice decisions, where investment payoffs follow arithmetic Brownian motion. They found among more that the motive of precautionary savings influences the way project volatility affects implied option value. Along the same line, Henderson (2007) considered a risk-averse agent with exponential utility, who makes an investment decision while also being able to trade a risky asset and a risk-free bond. The risky asset is partly correlated with the investment opportunity's payoffs, which follow geometric Brownian motion in their case. They find that a lower correlation between the project value and the risky asset or higher risk aversion reduces the investment threshold and option value. More importantly, they find that the real options models of complete and incomplete settings can give conflicting investment signals. Grasselli (2011) translates the utility maximization approach for real options in incomplete markets from the continuous-time, infinite time horizon setting to a discrete–time, finite horizon framework, to obtain an explicit valuation algorithm.

Bensoussan et al. (2010) consider utility maximization with joint decisions of stopping times, portfolio investment strategies, and/or consumption rules in a monopoly setting and in a Stackelberg leader-follower game. They show that optimal investment policies for both the leader and the follower deviate from those of the single decision maker. Furthermore, they mention that besides employing utility functions, other approaches to deal with real options pricing in incomplete markets include minimizing tracking error and selecting a martingale measure for pricing using minimal martingale or minimal entropy methods.

Besides using expected utility as behavioural theory, some recent studies employed prospect theory in a way of valuing real options in incomplete markets settings. Moreover, with expected utility theory, the valuation of real options is dependent on the utility of total wealth or utility of consumption. Valuing the real option then comes down to finding the optimal choices for portfolio selection, investment decisions and consumption levels, all at the same time. Prospect theory enables the valuation of a prospect on its own, without considering total wealth and other decisions. Since a real option resembles a prospect, in the sense that the state-dependent payoffs can be obtained with particular probabilities, the use of prospect theory for valuing real options in incomplete markets seems appropriate.

Ebert & Strack (2015) apply prospect theory in a dynamic continuous time context, not specifically focused on its application to real options. Under a condition described as 'probability weighting being stronger than loss aversion', they obtain the striking result that a naive PT agent never stops gambling. In the real options context, this means that the agent would never exercise an American-style perpetual real option; even when exercising immediately if the option is in the money would lead to a positive payoff compared to doing nothing. Henderson et al. (2017) adds nuance to the conclusions of Ebert & Strack (2015) by showing, also in a general setting, that a PT agent voluntarily stops (exercises the real option) when randomizing between strategies is allowed. Never stopping therefore does not remain the unique prediction if a wider class of strategies is allowed.

4.1.4 Real Options Concepts

We now describe the binomial tree model and the risk-neutral valuation method for real options (in complete markets). Consider a strategic decision which can be viewed as a real option (e.g., option to invest, option to abandon, etc.[3]. Within real options theory, the present underlying value of the real option is often proxied by the present value of cash flows of the firm or the project when no perfect twin security is available (Copeland & Antikarov, 2001; Smit & Trigeorgis, 2004). This assumption still permits the application of traditional financial options modeling to real assets. The present value is often estimated using the discounted cash flow (DCF) approach. If the option payoffs are replicable by a portfolio of assets, the non-arbitrage argument implies that the portfolio of assets which replicate the real option payoffs and the real option itself should have the same price (for details see Appendix A). Below we sketch the steps of the binomial tree method of valuing real options.

More concrete: Let V_0 be the present value of all expected future cash flows of a firm. Assume this value can move up or down in the next period with factors $u = e^{\sigma\sqrt{\Delta t}}$ and $d = 1/u$, where σ denotes the volatility of the firm value. The time periods are defined in

[3] For an overview of several type of real options see Smit & Trigeorgis (2004).

terms of equidistant time steps, where the size of each step Δt is derived by dividing the total lifetime T of a project or strategic opportunity by the number of evaluation periods n. As n approaches infinity, the time steps Δt become infinitely small, then converging to the continuous Black-Scholes framework.

In the next period, the underlying value of the real option, V_0, takes either of the values $V^u_{\Delta t} = V_0 \cdot u$ or $V^d_{\Delta t} = V_0 \cdot d$ with probabilities p and $(1-p)$ respectively. Denote by V^s_t the discounted value of all expected future cash flows at time t in state s (for example, after three 'up-movements' $s = uuu$, or after three alternating movements starting with up, $s = udu$). If we denote the real option value at time t in state s by F^s_t, the value of a 'European-style' (i.e., the decision moment is solely at T) real option is given by:

$$F^s_t = e^{-r\Delta t}\Big[\hat{p} \cdot F^{su}_{t+\Delta t} + (1-\hat{p}) \cdot F^{sd}_{t+\Delta t}\Big], \tag{4.1}$$

where su and sd represent a up- and down-movement from state s respectively. Furthermore r denotes the risk-free rate and $\hat{p}$ denotes the *risk-neutral probability*:

$$\hat{p} = \frac{e^{r\Delta t} - d}{u - d}. \tag{4.2}$$

Note that $F^s_T = \Pi(V^s_T)$, where $\Pi(\cdot)$ represents the payoff function of the real option (e.g., for an option to invest: $\Pi(V) = \max[V - I, 0]$ with I being the investment amount)[4].

[4] The value of an 'American-style' (i.e. the exercise moment can be at every period) real option in the binomial framework is given by:

$$F^s_t = \max\Big[\Pi(V^s_t),\ e^{-r\Delta t}[\hat{p}F^{su}_{t+\Delta t} + (1-\hat{p})F^{sd}_{t+\Delta t}]\Big], \tag{4.3}$$

.

4.1.5 Prospect Theory Concepts

Prospect theory states that people make decisions based on the PT-value, an adapted expected value, where outcomes are evaluated through an utility function (value function) and probabilities are weighted with a probability weighting function (PWF). The probability weighting function assigns decision weights to the (objective) probabilities, often in such a way that the tails of the distribution are overweighted. Prospect theory posits that people use such transformed probabilities rather than objective probabilities to base their decisions on. Some other typical characteristics are that the utility function is convex over losses and concave over gains. Furthermore, the utility function is kinked at the origin, which displays a feature known as loss aversion. Loss aversion encompasses a behavioural trait that losses seem to have a larger psychological impact for decision-makers than gains of the same size, which was found through empirical evidence (Tversky & Kahneman, 1992).

Besides the utility function and the probability weighting function, the prospect theory value in general also depends on the reference point of the decision-maker. The reference point determines whether an outcome of a prospect is considered as a gain or loss by the decision-maker. Whereas the reference point is often set at 0, it can take different values. The reference point (RP) works through as a parameter of the utility function.

Consider a gamble $\mathcal{X} = \big(x_u, p; x_d, (1-p)\big)$ with $x_u \geq x_d$. This notation denotes a gamble where you receive an outcome x_u with probability p and an outcome x_d with probability $(1-p)$. We calculate the PT-value of $\mathcal{X}$ as follows[5]:

$$PT(\mathcal{X}) = \pi_u U(x_u; RP, \lambda) + \pi_d U(x_d; RP, \lambda), \tag{4.4}$$

[5] For the PT-value of a gamble with multiple discrete or continuous outcomes see Appendix B.

where $U(\,\cdot\,; RP, \lambda)$ denotes the utility function with reference point RP and loss aversion parameter λ:

$$U(y; RP) = \begin{cases} u(y - RP) & \text{if } y \geq RP \\ -\lambda u(-(y - RP)) & \text{if } y < RP \end{cases} \tag{4.5}$$

with u being the function that assigns utility to outcomes. The loss aversion parameter λ represents the factor with which losses 'hurt' more than a gain of the same magnitude is 'enjoyed'. Finally, (π_u, π_d) is one of the following:

$$(\pi_u, \pi_d) = \begin{cases} \big(w^+(p), 1 - w^+(p)\big) & \text{if } (x_u, x_d) \geq RP \\ \big(1 - w^-(1-p), w^-(1-p)\big) & \text{if } (x_u, x_d) \leq RP \\ \big(w^+(p), w^-(1-p)\big) & \text{if } x_d < RP, x_u \geq RP \end{cases} \tag{4.6}$$

4.2 The Prospect Theory Real Options Framework

We now develop the integrated prospect theory real options (PT-RO) binomial framework. A discrete-time approach by means of a binomial tree model in the spirit of Cox et al. (1979) offers a tractable valuation framework. Furthermore, through the binomial tree model, more advanced contingency structures (such as compound options) and exercise rules can be incorporated in a relatively simple way. We assume backward induction rather than the resolute choice approach propagated by Machina (1989) and McClennen et al. (1990). Backward induction has emerged as the most natural and almost exclusively used approach in finance and other fields and is naturally close to the backward valuation of real options in a binomial tree.

When the underlying state variable in a RO model is not traded in financial markets, a perfect riskless hedge is unattainable, and as a consequence, the risk-neutrality condition cannot be met. Given that the risk-neutrality condition must be relaxed in incomplete markets, the main condition permitting the use of risk-neutral probabilities $\hat{p}$ and the risk-free rate as discount factor no longer holds.

While risk-neutral valuation is no longer directly viable, one could argue that the PT framework is comparable to this method in certain respects. Firstly, the PT probability weighting function applies a nonlinear transformation to true probabilities. Probability weighting may capture some strategic attitude towards probabilistic risk along with belief (Wakker, 2004). We apply the probability weighting function to the true probabilities of outcomes and use these weighted probabilities as surrogate for the risk-neutral probabilities

Secondly, the attractiveness of a project is evaluated through the assessment of risk associated with the (perceived) probabilities and the utility of monetary outcomes, and thus enters into the valuation through the parameters of the PT utility function. Therefore, similar to the risk neutral valuation method, the present value of a project is corrected for project risk (or more precisely: For an agent's preferences over the risky outcomes of the project) in the numerator. By adjusting for project risk through the probability weighting function and the utility function in the numerator, the denominator will need to reflect the time value of money only, justifying the use of the risk-free rate as discount factor. Using a high risk-adjusted discount rate, such as the typical 25-70% rates of return targeted by venture capitalists (Damodaran, 2009), would cause a disproportionately high pricing of risk.

Taking these arguments in account, we propose the following steps for calculating the prospect theory real options (PT-RO) value of a European-style real option:

1. Calculate the utility of the real option payoffs at $t = T$ by applying the utility function $U(\;\cdot\;; RP, \lambda)$ to the option payoffs $\Pi(V_T^s)$, where s denotes the state at time T and V_T is the value of the underlying real asset of the real option at time T.

2. Dependent on whether a payoff is considered a gain or loss, apply the probability weighting function for gains $w^+(\cdot)$ or losses $w^-(\cdot)$ to the probabilities corresponding with the payoffs: p (up-movement from the previous time-state) and $(1-p)$ (down-movement from the previous time-state) and calculate the weighted probabilities (π_u, π_d) as in Equation (4.6).

3. Multiply the weighted probabilities (π_u, π_d) with the corresponding utilities from an up-movement and down-movement respectively, and add these products to obtain the PT-value at $t = T$.

We now have the PT-values at $t = T$ coming from up- and down-movements from the states at time $t = T - \Delta t$. These PT-values cannot be directly discounted with the risk-free rate since they are not monetary values. Therefore,

4. Compute the certainty equivalent (CE) of the PT-value via the inverse of the utility function $U^{-1}(\;\cdot\;; RP, \lambda)$ (when clear, we will omit the loss aversion parameter λ in the notation). The obtained CE is in monetary units.

5. Discount the CE with the risk free rate, this gives the PT-RO value $\mathcal{R}$ at time $t = T - \Delta t$ and state s:

$$\mathcal{R}^s_{T-\Delta t} = e^{-r\Delta t}\left\{U^{-1}\left[\pi_{su}\cdot U\left(\Pi(V^{su}_T); RP\right)+\pi_{sd}\cdot U\left(\Pi(V^{sd}_T); RP\right); RP\right]\right\}, \tag{4.7}$$

where again su and sd represent an up- and down-movement from state s respectively and r denotes the risk-free rate.

6. Use backward induction to calculate the PT-value of the real option at every intermediate period t as:

$$\mathcal{R}^s_t = e^{-r\Delta t}\left\{U^{-1}\left[\pi_{su}\cdot U\left(\mathcal{R}^{su}_{t+\Delta t}; \check{RP}\right) + \pi_{sd}\cdot U\left(\mathcal{R}^{sd}_{t+\Delta t}; \check{RP}\right); \check{RP}\right]\right\}. \tag{4.8}$$

For a European-style RO, the only moment that gains can be realised is at $t = T$, hence, the 'in-between' reference point $\check{RP}$ can be different[6] from RP. Since the seminal work of Markowitz (1952) on reference points and the development of prospect theory with reference point dependence as an important element by Kahneman & Tversky, there has been much discussion about what the reference point should actually be or what it should reflect. Determining the 'correct' reference point in this sense remains a great challenge. We contribute to this discussion by developing a framework which allows for flexible and changing reference points.

[6]Our PT-RO framework offers much flexibility for the reference point. For intermediate periods $t < T$ it can for example be set to $\check{RP}_t = \frac{t}{T} \cdot RP$, to let the desired gains increase linearly over time: For example, when an investor desires a gain of $25\% \cdot I$ at T, (s)he may desire $12.5\% \cdot I$ halfway through.

4.3 Numerical Analysis

In this section, we perform numerical analysis using the PT-RO framework for different type of real options, and we illustrate how the PT-RO valuation compares to risk-neutral valuation for various parameter settings. We first outline the PT functional forms and parameters which we will use in our analyses.

4.3.1 Prospect Theory Parameters

In previous studies on PT parameters and functional forms, it is often found that a power-utility form fits very well for subjects behaving according to prospect theory (e.g. Stott, 2006; Balcombe & Fraser, 2015). Therefore, we employ the following utility function in our PT-RO framework:

$$U(y; RP) = \begin{cases} (y - RP)^{\alpha} & \text{if } y \geq RP \\ -\lambda(-(y - RP))^{\alpha} & \text{if } y < RP \end{cases}, \tag{4.9}$$

where λ denotes the loss aversion parameter, RP is the reference point and the parameter α governs the level of concavity (over gains) and convexity (over losses) of the utility function. Lower values of α correspond to a higher degree of concavity/convexity of the utility function. For the loss aversion parameter λ, we choose a value of 2.25, which was found by Tversky & Kahneman (1992). For the power parameter[7] α we use a value of 0.9 which

[7] Some studies use a functional form for the utility function in PT with different power parameters for gains (α) and losses (β). However in that case, it is problematic to accurately define loss aversion. For instance with different power parameters, loss aversion depends on the monetary unit; furthermore for some outcomes $y > 0$ it always holds that $U(y) > -U(-y)$. These problems can be avoided by using the same power for losses and gains or by using a different variation of the power family. For details see Wakker (2010, section 9.6).

is the rounded average of the power utility parameters found for both gains and losses by Abdellaoui (2000) and is also in accordance with other studies (Tversky & Kahneman, 1992; Bleichrodt & Pinto, 2000; Bruhin et al., 2010, e.g.).

For the probability weighting function (PWF) we employ a two-parameter specification, proposed among others by Goldstein & Einhorn (1987) (GE):

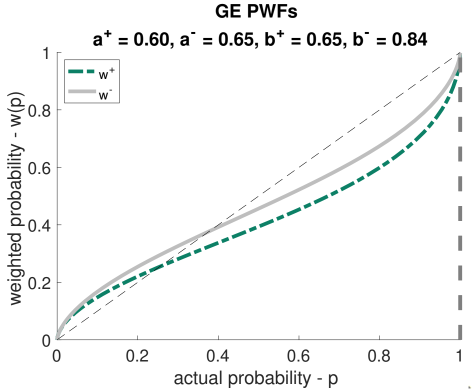
$$w(p) = \begin{cases} w^{+}(p) = \frac{b^{+} \cdot p^{a^{+}}}{b^{+} \cdot p + (1-p)^{a^{+}}} & \text{if } p \text{ corresponds to a } y \geq RP \\ w^{-}(p) = \frac{b^{-} \cdot p^{a^{-}}}{b^{-} \cdot p + (1-p)^{a^{-}}} & \text{if } p \text{ corresponds to a } y < RP \end{cases} \tag{4.10}$$

An advantage of the GE-type PWF is that its parameters correspond to two clearly interpretable psychological features: The parameter b governs the curvature of the PWF which corresponds to optimism/pessimism; as b decreases, the degree of pessimism increases. The parameter a governs the elevation of the PWF which corresponds to likelihood insensitivity; as a decreases, the degree of likelihood insensitivity increases. Several studies have looked into the right specification and parameters of the GE PWF (e.g. Gonzalez & Wu, 1999; Bleichrodt & Pinto, 2000; Abdellaoui, 2000; Stott, 2006). As a base case for our analysis, we use the parameters that were found by Abdellaoui (2000), as this study investigated which parameters fit for both the gains and losses domain. These parameters are: $a^{+} = 0.60, b^{+} = 0.65, a^{-} = 0.65, b^{-} = 0.84$. The PWFs and utility function with the mentioned parameters are plotted in Figure 4.1.

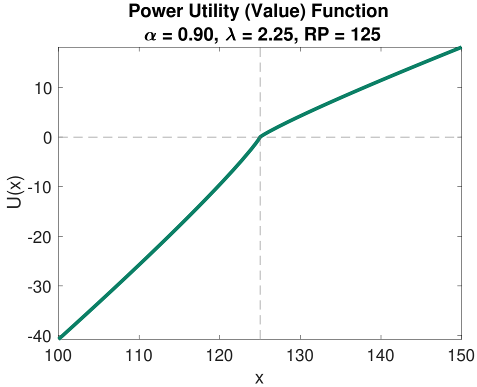
In the following sections we will discuss several type of real options in a discrete context which we analyze with the PT-RO framework. An overview of these options along with examples of the context is presented in Table 4.1

Figure 4.1: Probability weighting function (PWF) and Utility Function

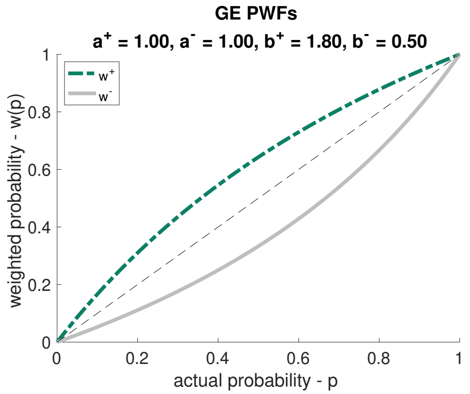
This figure shows (a) the probability weighting function (PWF) with functional form according to Goldstein & Einhorn (1987) defined in equation (4.10) and parameters according to Abdellaoui (2000): $(a^+ = 0.6, b^+ = 0.65, a^- = 0.65, b^- = 0.84)$. Furthermore it shows (b) the power utility function defined in equation (4.9) with power-parameter $\alpha = 0.9$, loss aversion parameter $\lambda = 2.25$ and an arbitrarily chosen (for illustrational purposes) reference point of $RP = 125$. Subfigures (c) and (d) show the used optimistic $((a^+ = 1, b^+ = 1.8, a^- = 1, b^- = 0.5))$ en pessimistic $((a^+ = 1, b^+ = 0.5, a^- = 1, b^- = 1.8))$ PWF specifications.



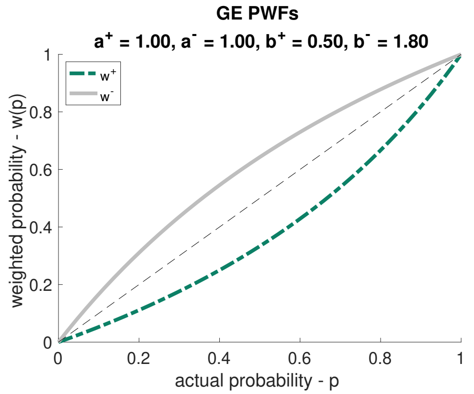
(a) Abdellaoui PWF



(b) KT Utility Function



(c) Optimist PWF



(d) Pessimist PWF

Table 4.1: Real options for numerical analysis

This table describes the several type of real options which we examine with numerical analysis through the PT-RO framework.

Type of real option	Investment type	Context	Typical industries	PT-RO Findings
Option to invest	Irreversible investment under uncertainty relating to a discrete context.	Irreversible investment opportunity relating to technical (innovation) uncertainty regarding success or failure of new products; approval or disapproval of new medicines; equity strategic alliance.	Technology, IT etc., private companies in all competitive industries	Optimistic (pessimistic) probability weighting increases (decreases) PT-RO values for all levels of volatility. Reference points affect the course of PT-RO values as function of volatility; PT-RO values do not necessarily decrease in the magnitude of the reference point. For ITM options and low levels of volatility, the relation between PT-RO values and volatility is negative.
Bermudan style timing real option	Timing option with discrete moments in time as decision moment.	Fixed discrete moments for the introduction of a new product (e.g. clothing line) or event (e.g. new festival).	Fashion, clothing, events, seasonal etc.	Agents with higher reference points exercise their option later compared to lower reference points agents[a].
Compound real option	Irreversible investment as link in a chain of interrelated projects (which result in future growth opportunities) at discrete moments.	Early investment in R&D, lease on undeveloped land or angel investments in different investment rounds.	All industries that involve sequential investment processes e.g pharmaceuticals, biotechnology etc.; start-up ventures	Reference points affect the investment/exit conditions of (angel) investors. Higher reference points agents are more inclined to continue investing under unfavourable conditions.

[a] In continuous time, with an American-style real option to invest, Ebert & Strack (2015) show that agents never exercise their option.

4.3.2 The Simple Real Option to Invest

The real option to invest describes a business opportunity, where the future investment is irreversible, as an option on real assets (Dixit & Pindyck, 1994). When the option to invest relates to an investment project of which the proceeds are in no way correlated to a traded asset, the replication assumption does not hold, and therefore, risk-neutral valuation is not applicable. Furthermore, there are many business decisions which relate to binomial outcomes and discrete decision moments. Think about the development of a new product with technical uncertainty (success or failure). Deciding about the investment for implementation immediately may yield a negative net present value. However, staging the investment in phases of pilot production and test marketing, and postponing the decision of implementation to a later fixed moment when the technical uncertainty has resolved and more information is available, may make the total investment worthwhile after all. We will now first discuss how we calculate the PT-RO values for a simple real option to invest. Next, we will discuss some observations following from our numerical analysis.

PT-RO Values of the Simple Real Option to Invest

Consider an investment opportunity which can be postponed to a later moment. Suppose that the cash flows from the investment opportunity are uncertain and not correlated with a traded asset. Let V_0 be the present value of cash flows that the investor can receive from the investment opportunity. The investor decides after one period, that is, at time $t = T = 1$, whether to invest an amount I or not. By that time, the value of the project can have moved up with probability p to $V_T^u = V_0 \cdot u$ with $u = e^{\sigma\sqrt{\Delta t}} > 1$ or it can have moved down to $V_T^d = V_0 \cdot d$, with $d = 1/u < 1$ and corresponding probability $1 - p$. Since the investor is not obligated but instead has the *option* to invest at maturity, the payoff of the real option therefore is $\max(V_T - I, 0)$.

The PT-RO valuation of such an investment opportunity also depends on the reference point of the investor. When does the investor consider the payoffs of the option as a gain and when as a loss? Say that the investor considers a positive payoff still as a loss if, despite being a positive payoff, the return on the investment is not above a certain threshold. That is, the investor desires:

$$\frac{V_T - I}{I} > \xi \Longleftrightarrow V_T - I > \xi I. \tag{4.11}$$

Here, ξI determines the reference point (RP) of the investor[8], ξ can be equal to the risk-free rate for instance, but also to 25% (commonly used internal rate of return (IRR) for private equity funds) or even 0. If $(V_T - I)$ is larger than $RP = \xi I$, the payoff will be perceived as a gain, and otherwise as a loss. For such a real option to invest with $T = 1$ and with $n = 1$ such that $\Delta t = T/n = 1$, the PT-RO value at $t = 0$ is given by:

$$\mathcal{R}_0 = e^{-rT}\left\{U^{-1}\Big[\pi_u \cdot U\big(\max[V_T^u - I, 0]; \xi I\big) + \pi_d \cdot U\big(\max[V_T^d - I, 0]; \xi I\big)\ ; \xi I\Big]\right\}, \tag{4.12}$$

For our numerical analysis, we set the following parameters: The present value of cash-flows V_0 is equal to 100, the probability of an up-movement is $p = 0.5$, and the risk-free rate is $r = 2\%$. For the investment amount I, we consider three cases: $I = 80$, the option to invest is *in the money* (ITM); $I = 100$, the option to invest is *at the money* (ATM); $I = 120$ the option to invest is *out of the money* (OTM). We consider several reference

[8] Note that when the investor 'does nothing', because $\max[V - I, 0] = 0$, the invested amount is 0. However since the payoff is also 0, it can still 'feel' as a loss, as the desire was to have a minimum gain of ξI. Still, the framework can be accounted for changing reference points by making it dependent on time, state and underlying value: $RP(V_t^s)$.

points $RP = \xi I$ with $\xi = \{0, r, 0.10, 0.25\}$. That is, a desired minimal return of: 0, the risk-free rate, 10%, and 25%, respectively. We then calculate the PT-RO values and analyze its sensitivity with respect to the volatility of the underlying value σ.

Furthermore, we also consider the case of an 'optimistic' investor, i.e. the PWFs are strictly concave; and the case of a 'pessimistic' investor, i.e. the PWFs are strictly convex[9]. The parameter sets for these types of PWF are the following, optimist: $(a^+ = 1, b^+ = 1.8, a^- = 1, b^- = 0.5)$; pessimist: $(a^+ = 1, b^+ = 0.5, a^- = 1, b^- = 1.8)$. The results are displayed in Figure 4.2. Furthermore, in Figure 4.3 we have displayed again the PT-RO values for the same settings but now also for maturity $T = 3$ with number of evaluation periods $n = T$ and in-between reference point $\check{RP} = 0$.

Valuation Results of the Real Option to Invest

From Figure 4.2, we can observe some interesting characteristics regarding the dynamics of the PT-RO framework. For instance, we observe how with the ITM case the PT-RO values are initially decreasing in volatility, whereas a general result from option theory is that call option values increase in volatility. For the ITM options, it holds that for low levels of volatility, the option will be exercised in both states, as both states will still yield positive payoffs[10]. As long as the down-state payoff is not capped at 0, however, the down-state payoff is decreasing in volatility.

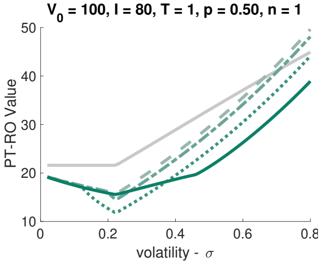
Hence, if more weight is put through probability weighting on utilities following from down-state payoffs relative to the up-state payoffs, the PT-RO values will be decreasing

[9]Optimistic and pessimistic here refer to the way of probability weighting. With optimistic (pessimistic) probability weighting, probabilities are consistently overweighted for gains (losses) and underweighted for losses (gains).

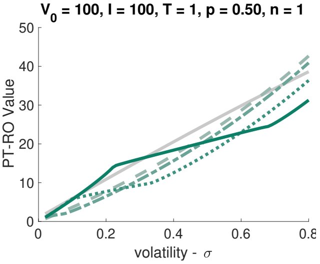
[10]With risk-neutral valuation the option value is constant when the option is exercised in both states. The risk-neutral probabilities are then such that the option value is $V - e^{-r}I$, which is equal to around 21.58 in our setting.

Figure 4.2: PT-RO values $\mathcal{R}$ for the real option to invest for $T = 1$

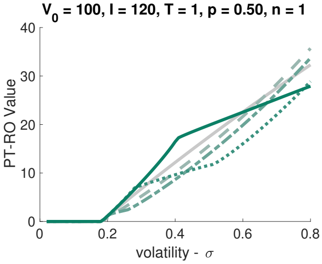
This figure shows the prospect theory real option (PT-RO) values $\mathcal{R}$ for a simple (European-style) real option to invest with maturity $T = 1$ and number of evaluation periods $n = 1$. The values are plotted as a function of the volatility of the underlying project-value σ for different moneyness levels (ITM: $I = 80$, ATM: $I = 100$, OTM: $I = 120$) and different probability weighting function (PWF) parametersets, Abdellaoui (2000): $(a^+ = 0.6, b^+ = 0.65, a^- = 0.65, b^- = 0.84)$; Optimist: $(a^+ = 1, b^+ = 1.7, a^- = 1, b^- = 1.9)$; Pessimist: $(a^+ = 1, b^+ = 0.45, a^- = 1, b^- = 0.3)$. The parameter of the power utility function is $\alpha = 0.9$ The loss-aversion parameters is $\lambda = 2.25$. The PT-RO values are plotted for several reference points (RP) which are $\{0, rI, 0.10I, 0.25I\}$. For the purpose of comparison the risk neutral value (RNV) of the real option is also plotted for all settings. Finally, the probability of an up-movement and down-movement of the underlying value V_t are both 0.5.



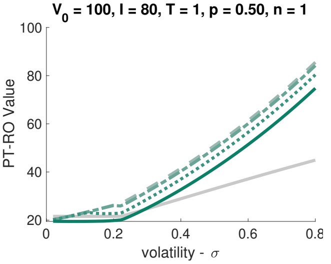
(a) ITM - Abdellaoui



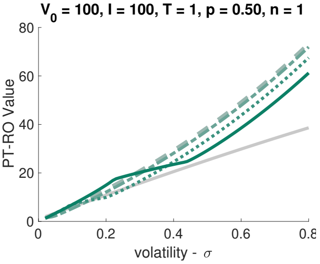
(b) ATM - Abdellaoui



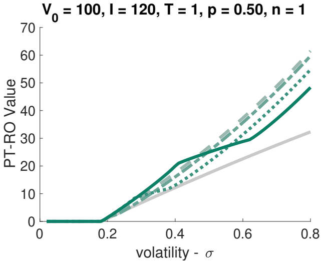
(c) OTM - Abdellaoui



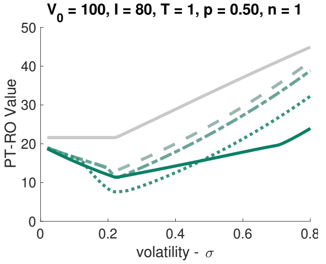
(d) ITM - Optimist



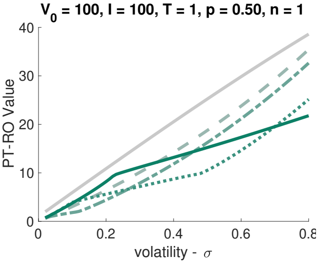
(e) ATM - Optimist



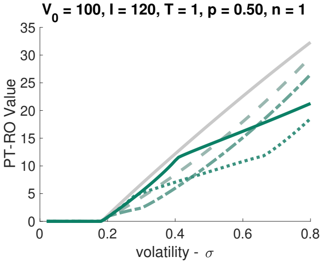
(f) OTM - Optimist



(g) ITM - Pessimist



(h) ATM - Pessimist



(i) OTM - Pessimist

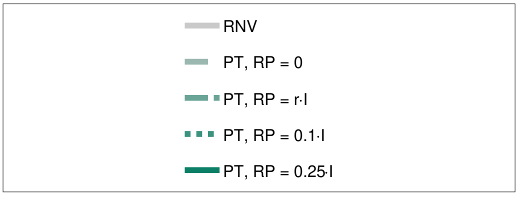
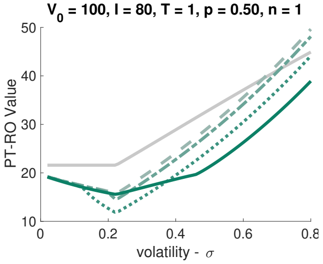
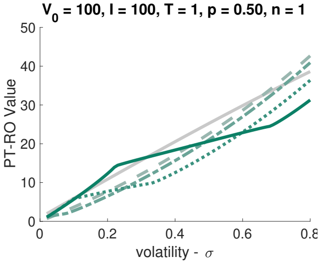


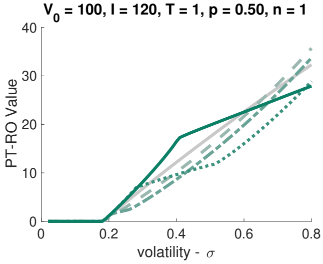
Figure 4.3: PT-RO Values $\mathcal{R}$ for the real option to invest for $T = 1$ and $T = 3$
This figure shows the prospect theory real option (PT-RO) values $\mathcal{R}$ for a simple (European-style) real option to invest with maturity $T = 1$ (upper row) and $T = 3$ (bottom row) and number of evaluation periods $n = T$. The values are plotted as a function of the volatility of the underlying project-value σ for different moneyness levels (ITM: $I = 80$, ATM: $I = 100$, OTM: $I = 120$) and probability weighting function (PWF) parameterset from Abdellaoui (2000): $(a^+ = 0.6, b^+ = 0.65, a^- = 0.65, b^- = 0.84)$. The parameter of the power utility function is $\alpha = 0.9$ The loss-aversion parameters is $\lambda = 2.25$. The PT-RO values are plotted for several reference points (RP) which are $\{0, rI, 0.10I, 0.25I\}$. For the purpose of comparison the risk neutral value (RNV) of the real option is also plotted for all settings. Finally, the probability of an up-movement and down-movement of the underlying value V_t are both 0.5.



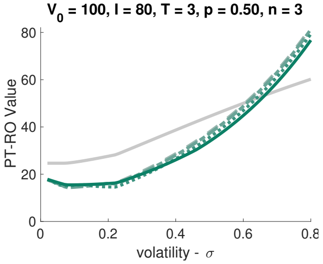
(a) ITM - $T = 1$



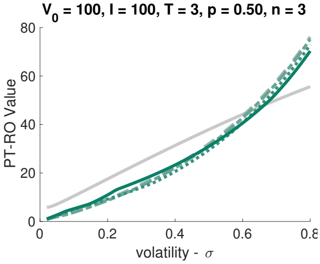
(b) ATM - $T = 1$



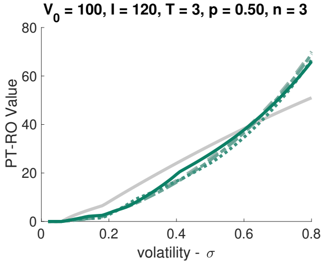
(c) OTM - $T = 1$



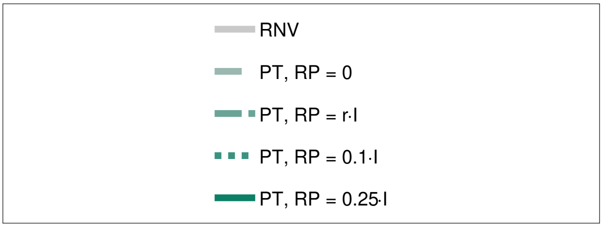
(d) ITM - $T = 3$



(e) ATM - $T = 3$



(f) OTM - $T = 3$



up to the point where down-state payoffs are capped at 0[11]. This is clearly visible with the Abdellaoui and even more with the pessimist specifications of the PWF. On the other hand, with the optimist PWF, more weight is put on the up-state payoffs and therefore we do not have decreasing PT-RO values. For ATM and OTM, we have no decreasing PT-RO values since the down-state payoff is constant and equal to 0 for every level of volatility.

Furthermore, for the decreasing PT-RO values in the ITM case, we also observe some kinks after which the PT-RO values seem to decrease even harder. These kinks correspond to levels of volatility at which the down-state payoff, despite remaining positive, becomes below the reference point. An outcome below the RP is considered a loss, and hence, the utility of loss is amplified with the loss aversion parameter $\lambda = 2.25$. Still, for most RP's, the PT-values remain positive and loss aversion only amplifies the decrease in PT-values[12].

This is not the case for $\xi = 0.25$. Here the PT-values are already negative for the lowest level of volatility possible[13]. Hence, the downward slope remains constant up to the point where the down-state payoffs are capped at 0 (first kink). Still, the down-state payoff of 0 is considered a major loss relative to $RP = 0.25I$ and therefore dominates through loss-aversion the PT-value which remains negative, causing the PT-RO values to increase slow compared to the cases of other RPs. Only for higher levels of volatility, the payoffs in the up-state become high enough to result in positive PT-value, such that the

[11] This is when $V_d < I \iff \sigma > 0.2231$.

[12] For example consider $\sigma = 0.2$ with the Abdellaoui PWF. This gives up-state payoff $x_u = V_u - I \approx 42.14$, and down-state $x_d = V_d - I = 1.87$. For reference point $RP = 0.1I = 8$, this gives utilities $u(x_u - RP) = 23.99$ and $-\lambda u(-(x_d - RP)) = -11.50$. Ultimately with weighted probabilities this results in a PT-value of 4.19. This PT-value translates to a discounted certainty equivalent of 12.67, which is the PT-RO value. Hence, despite that the utility over losses is heavier weighted, the PT-value remains positive in this case.

[13] For lowest level of volatility $\sigma = r$, the payoffs in up-state and down-state are around 22 and 18 respectively. The RP is equal to 20 and therefore in between the payoffs, such that the losses dominate and this results due to loss aversion in negative PT-values.

PT-RO values increase again at comparable rate as the other RPs (second kink)[14].

Furthermore, from Figure 4.2 it seems at first sight that the PT-RO values decrease in ξ, which indeed holds for $\xi = 0, r, 0.10$, but not for $\xi = 0.25$, for which we also observe a clearly different course of the chart. Intuitively, we may expect that a higher reference point leads to lower PT-RO values, and this is also true up to a certain point. However, it turns out that this direction is not one way[15]. For every level of volatility, there exists a turning point at a certain ξ^* up to which the PT-values and there along with the PT-RO values are decreasing in ξ, until the PT-value becomes negative[16]. Then, the PT-RO values start increasing again in monetary terms.

However, a higher PT-RO value in monetary terms for higher reference points does not necessarily correspond with higher utility. For an agent with a high reference point, the CE may seem higher in monetary terms, however it can 'hurt' more, since the distance to the reference point is bigger[17]. The monetary value of the real option for a high-RP agent is higher, but feels as a loss, whereas a relatively lower monetary real option value for the lower-RP agent feels as a gain.

For ATM and OTM options we have dynamics more or less in the same line. For OTM options we first have low levels of volatility where the real option remains out of the money

[14] This is less the case for the optimist PWF, as due to more weight on up-state utilities, the PT-values become positive already for a lower level of volatility than at which the down-state payoffs are capped at 0.

[15] If we look at numerical values for $RP = 0.25I = 20$ we see that with $\sigma = 0.2$ we have $u(x_u - RP) = 16.24$ and $-\lambda u(-(x_d - RP)) = -30.52$, this gives a PT-value of -7.53 and a PT-RO value of 15.84. Here we see that the PT-RO value for the reference point with $\xi = 0.25$ gives a higher PT-RO value than with $\xi = 0.1$.

[16] For instance for $\sigma = 0.2$ (Abdellaoui PWF) the PT-value of the option payoffs at maturity becomes negative for a ξ between 0.15 and 0.16, where $RP = \xi I$.

[17] Relating to our numbers: For an agent with reference point 8, receiving with certainty an amount now of 12.67 (gain compared to 8) gives a PT-value of 4.19. Whereas for an agent with reference point 20, a PT-value of -7.53 translates to receiving an amount now with certainty of 15.84 (loss compared to 20).

regardless of the state, which results in PT-RO values of zero. For higher reference points it is the case that for low levels of volatility both the up-state and down-state payoffs feel as a loss, since both are lower than the RP. Note that loss aversion does not impact risk aversion for pure gain prospects or loss prospects. Loss aversion only impacts risk aversion for mixed prospects, amplifying it there[18].

At some level of volatility, the payoff in the up-state becomes higher than the reference point, giving positive utility and making the total PT-value less negative; this corresponds to the first kink. The second kink corresponds to the PT-values becoming positive. For the optimist (pessimist) PWF these kinks appear for lower (higher) levels of volatility compared to the base case. These findings demonstrate the effect of reference points, loss aversion and different types of probability weighting on the PT-RO values. These dynamics extend to $T = 3$ as we see in Figure 4.3. However since the in-between reference points are the same, the PT-RO values for the different reference point become closer to each other.

Finally, it is noteworthy that for many settings the PT-RO values are often lower than the risk-neutral values. This is in line with the findings of Miller & Shapira (2004), who use questionnaires to investigate the effect of behaviour and heuristics on real option valuation and state that buyers and sellers price options below their expected values.

4.3.3 The Real Option to Invest with Lost Dividends

Now consider an investment opportunity where the investor can invest an amount I at any discrete time $t \leq T$ and then receives the value of the project at that moment in time V_t. The investor has this opportunity only once, but has the opportunity to invest either

[18]Moreover, if the reference point is roughly in the middle of the domain, the impact of loss aversion on risk aversion will be maximal.

now or after every time period for a maximum of T elapsed time periods. Think about the introduction of a new product which can only occur at fixed moments, such as the introduction of a new clothing line at the beginning of a season, or the introduction of a new festival in this summer, or the next summer. With every period Δt that the decision-maker does not invest, the project value V_t decreases with a factor $\phi = e^{-q\Delta t}$, which can be, for example, viewed as lost dividends or depreciation. Such an investment opportunity is analogous to the exercise of an Bermudan-style call option on a dividend paying stock.

To determine the PT-RO value of such a real option, we first correct the future underlying values for the lost 'dividends' by multiplying every V_t^s with $\phi^{t-\Delta t}$. For the Bermudan-style real option, we have for the PT-RO value:

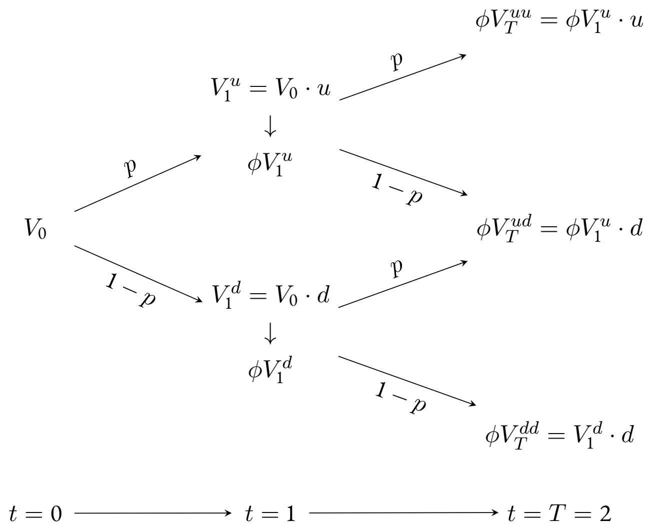
$$\mathcal{F}^s_{T-\Delta t} = e^{-r\Delta t}\left\{U^{-1}\left[\pi_{su} \cdot U\left(\Pi\left(\phi^{T-1}V_T^{su}\right); RP\right)\right.\right. \\ \left.\left. + \pi_{sd} \cdot U\left(\Pi\left(\phi^{T-1}V_T^{sd}\right); RP\right); RP\right]\right\} \tag{4.13}$$

$$\mathcal{F}^s_t = e^{-r\Delta t}\left\{U^{-1}\left[\pi_{su} \cdot U\left(\mathcal{R}^{su}_{t+\Delta t}; \check{RP}\right) + \pi_{sd} \cdot U\left(\mathcal{R}^{sd}_{t+\Delta t}; \check{RP}\right); \check{RP}\right]\right\} \\ \text{for } t < (T - \Delta t) \tag{4.14}$$

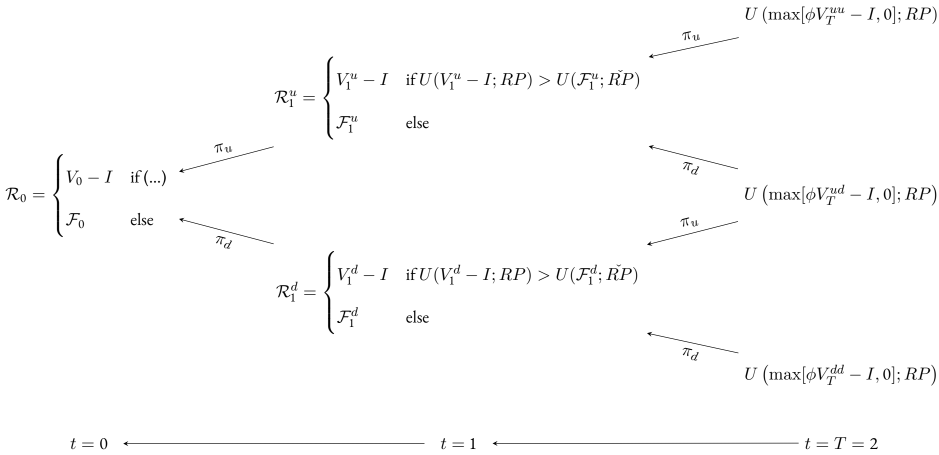
$$\mathcal{R}^s_t = \begin{cases} \phi^{t-\Delta t}V_t^s - I & \text{if } U(\phi^{t-\Delta t}V_t^s - I; RP) > U(\mathcal{F}^s_t; \check{RP}) \\ \mathcal{F}^s_t & \text{else} \end{cases} \tag{4.15}$$

$$\text{where: } \Pi\left(\phi^{T-1}V_T^{su}\right) = \max\left[\phi^{T-1}V_T^{su} - I, 0\right] \tag{4.16}$$

That is, in every period at every state, compare (Equation (4.15)) whether the utility of getting the payoff at that moment in time (exercising), is higher than the utility of the option value (waiting). Here, the utility of waiting is with respect to the in-between reference point $\check{RP}$ and exercising is with respect to the maturity reference point RP, since exercising means receiving a payoff and that should be evaluated against that reference point (e.g. desired return). The value of waiting is denoted by $\mathcal{F}_t^s$ whereas $\mathcal{R}_t^s$ denotes the PT-RO value including the possibility of immediate exercise at t. The trees below show an example for $T = 2$. First we determine how the underlying value V_t evolves over time, including dividends which are lost:



Then the PT-RO values are determined by first calculating the real option payoffs at maturity, next determining the PT-values at maturity, obtaining the certainty equivalent, and discounting this back one period. Finally, at every intermediate period, the PT-RO value is determined by checking whether exercising (direct payoff at that point) or waiting (option value from the future) gives a higher PT-value (utility):



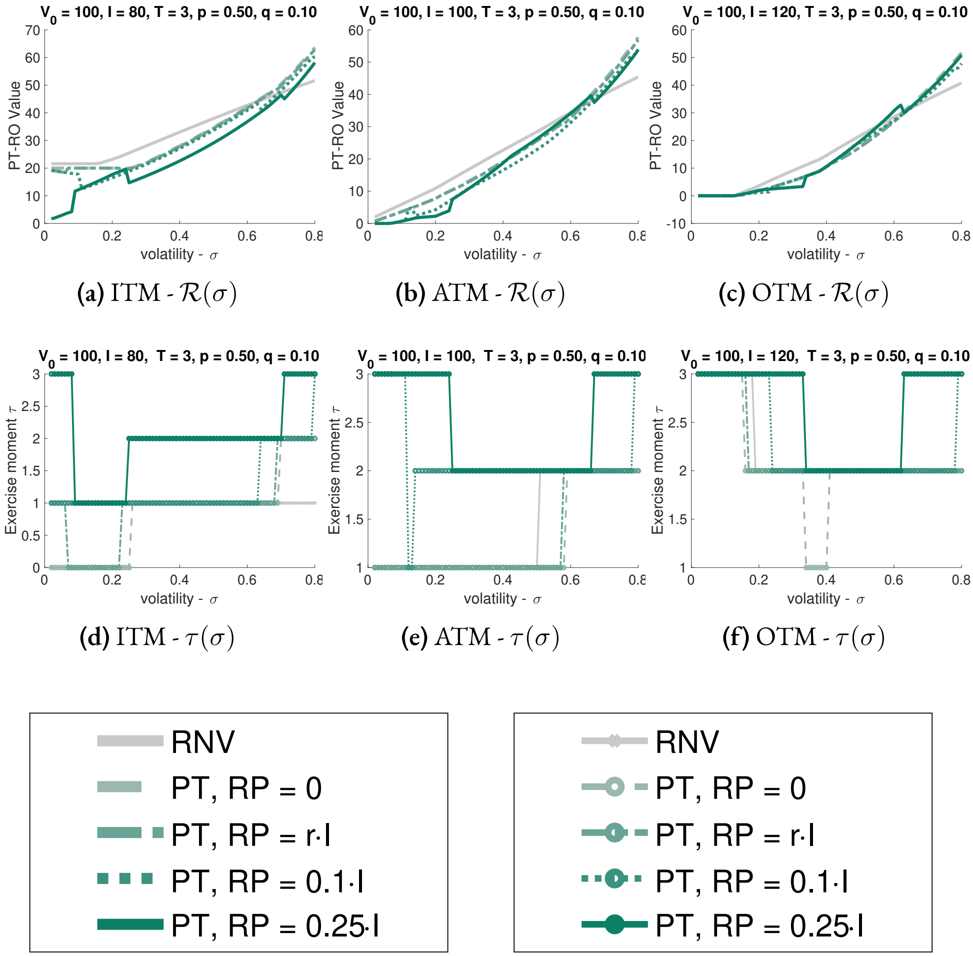
Now for a specific numerical example, we consider the same parameter settings as for the simple real option to invest. We calculate the PT-RO values and analyze the sensitivity with respect to the volatility σ and the dividend yield q. Furthermore, we determine the exercise moments $\tau \in \{0, 1, 2, 3\}$ per σ and q. The results are displayed in Figures 4.4 and 4.5 for maturity $T = 3$ with number of evaluation periods $n = T$ and in-between reference point $\check{RP} = 0$.

From Figure 4.4 we can learn about the exercise behaviour for agents with different reference points. We observe that for a very high reference point ($\xi = 0.25$), the investor waits in general longer before exercising the real option. Regardless of the volatility level, an agent with lower reference point always exercises earlier or at the same time. This also holds for the medium high reference point ($\xi = 0.10$) relative to the reference points which are lower.

For the ITM real option, we observe that for the two lowest reference points, it is the case that for low levels of volatility the exercise moment is even earlier than what stems from risk-neutral valuation. For higher reference points, it seems that higher levels of

Figure 4.4: $\mathcal{R}(\sigma)$ **and** $\tau(\sigma)$ **for the real option to invest with dividends**

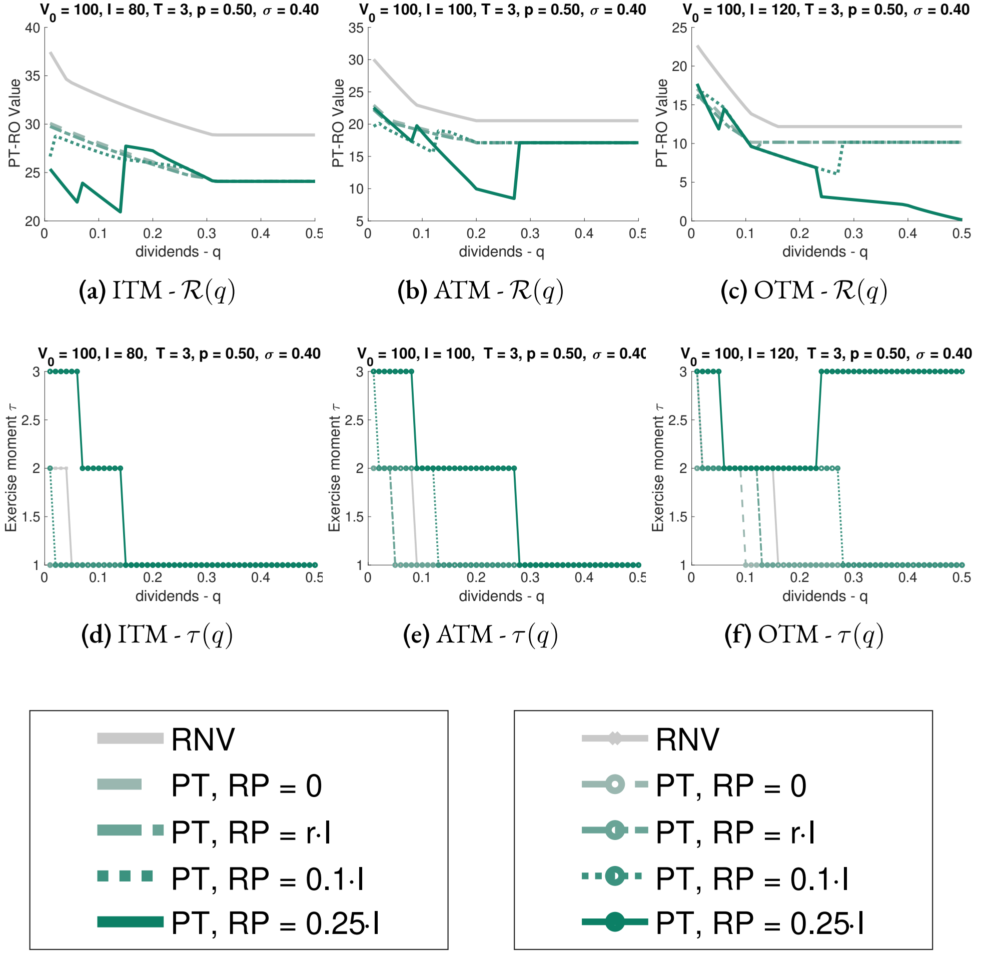
This figure shows the prospect theory real option (PT-RO) values $\mathcal{R}$ (upper row) and exercise moments τ (bottom row) for an Bermudan real option to invest with maturity $T = 3$ and number of evaluation periods $n = T$. The values are plotted as a function of the volatility of the underlying project-value σ for different moneyness levels (ITM: $I = 80$, ATM: $I = 100$, OTM: $I = 120$) and and probability weighting function (PWF) parameterset from Abdellaoui (2000): $(a^+ = 0.6, b^+ = 0.65, a^- = 0.65, b^- = 0.84)$. The parameter of the power utility function is $\alpha = 0.9$ The loss-aversion parameters is $\lambda = 2.25$. The PT-RO values are plotted for several reference points (RP) which are $\{0, rI, 0.10I, 0.25I\}$. For the purpose of comparison the risk neutral value (RNV) of the real option is also plotted for all settings. Finally, the probability of an up-movement and down-movement of the underlying value V_t are both 0.5.



(a) ITM - $\mathcal{R}(\sigma)$ **(b)** ATM - $\mathcal{R}(\sigma)$ **(c)** OTM - $\mathcal{R}(\sigma)$

(d) ITM - $\tau(\sigma)$ **(e)** ATM - $\tau(\sigma)$ **(f)** OTM - $\tau(\sigma)$

Figure 4.5: $\mathcal{R}(q)$ **for the real option to invest with dividends**
This figure shows the prospect theory real option (PT-RO) values $\mathcal{R}$ (upper row) and exercise moments τ (bottom row) for an Bermudan real option to invest with maturity $T = 3$ and number of evaluation periods $n = T$. The values are plotted as a function of the lost dividends q for different moneyness levels (ITM: $I = 80$, ATM: $I = 100$, OTM: $I = 120$) and probability weighting function (PWF) parameterset from Abdellaoui (2000): $(a^+ = 0.6, b^+ = 0.65, a^- = 0.65, b^- = 0.84)$. The parameter of the power utility function is $\alpha = 0.9$ The loss-aversion parameters is $\lambda = 2.25$. The PT-RO values are plotted for several reference points (RP) which are $\{0, rI, 0.10I, 0.25I\}$. For the purpose of comparison the risk neutral value (RNV) of the real option is also plotted for all settings. Finally, the probability of an up-movement and down-movement of the underlying value V_t are both 0.5.



(a) ITM - $\mathcal{R}(q)$ **(b)** ATM - $\mathcal{R}(q)$ **(c)** OTM - $\mathcal{R}(q)$

(d) ITM - $\tau(q)$ **(e)** ATM - $\tau(q)$ **(f)** OTM - $\tau(q)$

volatility in general lead to waiting longer. For ATM options we observe similar behaviour: The higher the reference point, the less the high level of volatility is required to wait longer with exercising. For OTM options, we observe that the higher the reference point, the higher the level of volatility is required to start exercising the real option earlier. From Figure 4.5 we observe along all moneyness levels: The lower the reference point, the lower the 'dividend' level q is required to start exercising earlier.

4.3.4 Venture Capital - the Compound Real Option

Consider an investment opportunity in venture capital with multiple financing rounds. The (angel) investor pays a certain amount I_0 upfront. Then the investor can choose to invest further at later fixed moments in time, dependent on the development of the project. When developments are unfavourable, the investor can choose to not invest further. This can be seen as a compound real option to invest.

Suppose there are three possible investment moments, which are at $t = \{0, 1, 2\}$. Investing at t gives the investor the right but not the obligation to invest further at $t + 1$. Investing until maturity, $t = T = 2$, will eventually grant the investor the project-value at that moment. Let the investments I_1 and I_2 at $t = 1$ and $t = T = 2$, respectively be fixed. What would the investor be willing to invest upfront, that is, I_0 at $t = 0$? For this we have to determine the PT-RO value $\mathcal{R}_0$ of this compound-style real option at $t = 0$. However, thereby we have to take into account that the investor may have a reference point which is also dependent on the upfront investment I_0. Suppose that the reference point of the investor relates to a minimal return over all the (time-value of money corrected) invested amounts.

Then we have for the reference point RP:

$$\frac{V_2^s - I_2 - e^r I_1 - e^{2r} I_0}{I_2 + e^r I_1 + e^{2r} I_0} > \xi \Longleftrightarrow V_2^s - I_2 > \xi(I_2 + e^r I_1 + e^{2r} I_0) + e^r I_1 + e^{2r} I_0$$

$$RP(I_0) = \xi(I_2 + e^r I_1 + e^{2r} I_0) + e^r I_1 + e^{2r} I_0 \tag{4.17}$$

Furthermore, at intermediate periods, the investor has to decide whether (s)he wants to continue with the investment. In order to obtain payoffs or option value from the future periods, the investor has to invest; otherwise, when (s)he chooses not to invest, the option value will become zero at that period. Thus, the PT-RO value is calculated as follow (for $n = T = 2$ evaluation periods):

$$\mathcal{F}_1^s = e^{-r\Delta t}\Big\{U^{-1}\Big[\pi_{su} \cdot U\big(\max[V_T^{su} - I_2, 0]; RP(I_0)\big) + \pi_{sd} \cdot U\big(\max[V_T^{sd} - I_2, 0]; RP(I_0)\big)\,; RP(I_0)\Big]\Big\} \tag{4.18}$$

$$\mathcal{R}_1^s = \max\left[\mathcal{F}_1^s - I_1, 0\right] \tag{4.19}$$

$$\mathcal{F}_0^s = e^{-r\Delta t}\Big\{U^{-1}\Big[\pi_u \cdot U\big(\mathcal{R}_1^u; \check{RP}\big) + \pi_d \cdot U\big(\mathcal{R}_1^d; \check{RP}\big)\,; \check{RP}\Big]\Big\} \tag{4.20}$$

$$\mathcal{R}_0 = \max\left[\mathcal{F}_0 - I_0, 0\right] \tag{4.21}$$

To determine what the investor would be willing to invest maximally upfront we solve numerically for I_0 in $\mathcal{F}_0 - I_0 = 0$, where we have to keep in mind that I_0 appears in (4.18) as well[19].

[19] This method can be extended to more financing rounds, or choosing one unknown total investment variable $\mathcal{I}$ such that the investment amount per period is equal to $I_t = \mathcal{I}/T$ and then solving for $\mathcal{I}$.

We set again $V_0 = 100, p = 0.5$, and $r = 2\%$. For the follow-up investments we assume $I_1 = I_2$ with the following values: $I_1 = I_2 = 40$ (ITM), $I_1 = I_2 = 50$ (ATM), $I_1 = I_2 = 60$ (OTM)[20]. We consider the several reference points $\xi = \{0, r, 0.10, 0.25\}$, where RP is as in (4.17). We then calculate the PT-RO value and analyze its sensitivity with respect to the volatility σ. Furthermore, we also investigate in which situations the investor chooses to defer (not invest further) at $t = 1$, the variable $\mathcal{D}$ represents the following:

$$\mathcal{D} = \begin{cases} 0 & \text{if investor does not defer at } t = 1 \\ -1 & \text{if investor defers only at down state } \{t = 1, s = d\} \\ 2 & \text{if investor defers at both states } \{t = 1, s = u \wedge s = d\} \end{cases} \tag{4.22}$$

Figure 4.6 displays the results. The max upfront investment is determined in such a way that the PT-RO value at $t = 0$ is equal to 0. The max upfront investment I_0 can therefore be compared to the risk-neutral (compound) option value of the total investment opportunity with contingent investment rounds at $t = 1$ and $t = 2$. The risk-neutral value represents the amount an investor would be willing to maximally invest upfront for this venture capital opportunity when risk-neutral valuation holds. We again observe that the PT option values are in general lower than the risk-neutral values. In the previous subsection, we analyzed the exercise timing of PT agents in terms of the exercise moment τ. Now we investigate in which state(s) at $t = 1$ (the in between period) the PT agents would decide to exit (not invest further in this and the next investment round).

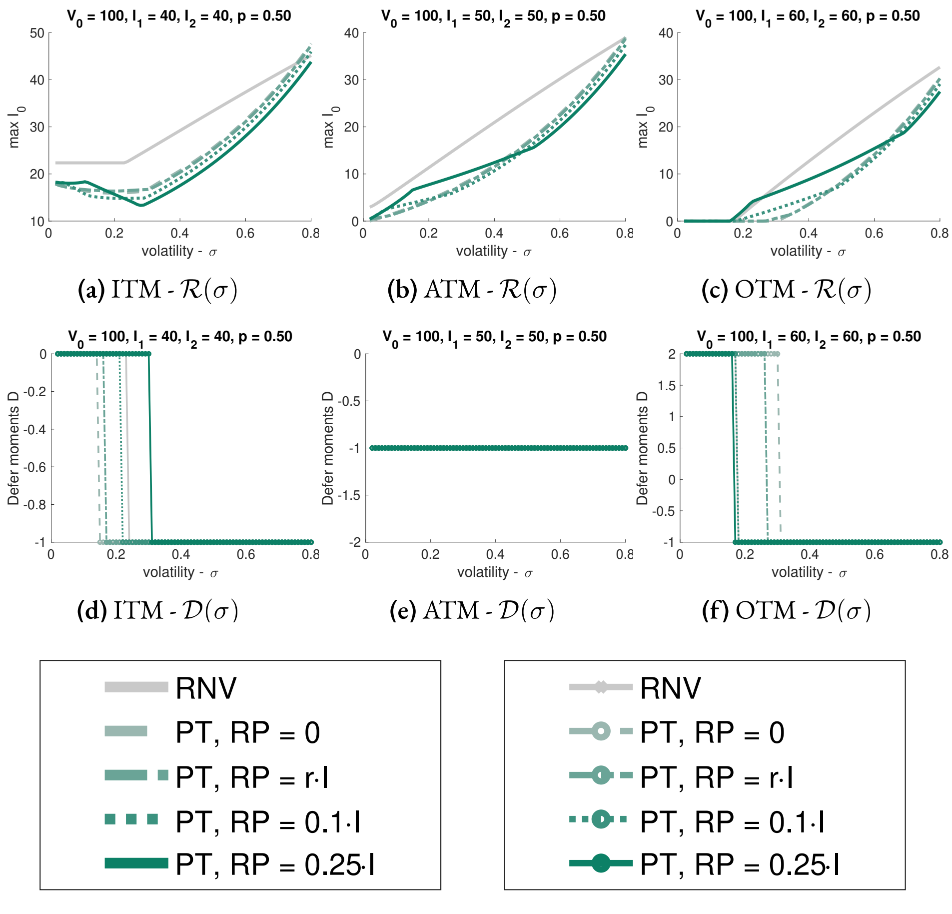
[20] We also investigated cases of asymmetric distributions between I_1 and I_2 such as $I_1 = 30, I_2 = 70$ or $I_1 = 10, I_2 = 90$, however the distribution of the total follow-up investment amount over I_1 and I_2 seems to have little effect on the PT-RO values.

Figure 4.6: Max I_0 and $\mathcal{D}(\sigma)$ for venture capital compound real option to invest

This figure shows the maximum upfront investment I_0 (upper row) of a PT-agent for a venture capital opportunity with three fixed investment rounds at $t = \{0, 1, 2\}$. The max upfront investment is determined in such a way that the prospect theory real option (PT-RO) value $\mathcal{R}$ at $t = 0$ is equal to 0. The max upfront investment I_0 can therefore be compared to the risk-neutral (compound) option value of the contingent investment rounds at $t = 1$ and $t = 2$. Furthermore this figure shows the defer moments $\mathcal{D}$ (bottom row) defined as:

$$\mathcal{D} = \begin{cases} 0 & \text{if investor does not defer at } t = 1 \\ -1 & \text{if investor defers only at down state } \{t = 1, s = d\} \\ 2 & \text{if investor defers at both states } \{t = 1, s = u \wedge s = d\} \end{cases} . \tag{4.23}$$

The values are plotted as a function of the volatility of the underlying project-value σ for different moneyness levels (ITM: $I_1 = I_2 = 40$, ATM: $I_1 = I_2 = 50$, OTM: $I_1 = I_2 = 60$) and probability weighting function (PWF) parameterset from Abdellaoui (2000): $(a^+ = 0.6, b^+ = 0.65, a^- = 0.65, b^- = 0.84)$. The parameter of the power utility function is $\alpha = 0.9$ The loss-aversion parameters is $\lambda = 2.25$. The PT-RO values are plotted for several reference points (RP) which are $\{0, rI, 0.10I, 0.25I\}$. For the purpose of comparison the risk neutral value (RNV) of the real option is also plotted for all settings. Finally, the probability of an up-movement and down-movement of the underlying value V_t are both 0.5.



(a) ITM - $\mathcal{R}(\sigma)$ **(b)** ATM - $\mathcal{R}(\sigma)$ **(c)** OTM - $\mathcal{R}(\sigma)$

(d) ITM - $\mathcal{D}(\sigma)$ **(e)** ATM - $\mathcal{D}(\sigma)$ **(f)** OTM - $\mathcal{D}(\sigma)$

For the ITM real option, we observe that initially at low volatility levels agents do not exit in between ($\mathcal{D} = 0$), regardless of the reference point. As volatility increases, we see that the lower the reference point, the lower the level of volatility that triggers an agent to exit in the down-state ($\mathcal{D} = -1$) at $t = 1$. Interesting to see is that for three out of four of our examined reference points (all but $\xi = 0.25$), it is the case that exit occurs for a lower level of volatility compared to risk-neutral valuation. For the highest reference point, exit occurs for relatively high levels of volatility. For the OTM real option, it is the other way around: Initially, for low levels of volatility, exit occurs in both states ($\mathcal{D} = 2$) at $t = 1$. However, the higher the reference point, the earlier (that is, for a lower level of volatility) the agent does not exit anymore in the up-state, but only in the down-state ($\mathcal{D} = -1$).

Hence, the reference point plays an important role in determining when an investor will stop investing and when (s)he will continue, which may help to explain the escalation of commitment phenomenon (Staw, 1981)[21].

4.3.5 Equity Strategic Alliance

An equity strategic alliance is created when one company purchases a certain equity percentage of the other company. Strategic alliances are agreements between two or more independent companies to cooperate in business objectives. An equity alliance offers the option to acquire a controlling stake when the agreement ends (fixed moment) and is thus a specific type of real option to invest (in a discrete context, therefore, different from a continuous acquisition option). Kogut (1991) and Chi (2000) describe how the acquisition of a joint venture is a real option. A strategic alliance is often formed between private companies. Therefore, the underlying value of the acquisition option is not correlated with

[21] The failure to terminate projects has also been studied and confirmed in the venture capital context (Valliere & Peterson, 2005; Guler, 2007; Steinkühler & Nathusius, 2010).

market traded assets and the replication argument does not hold. The PT-RO framework can then be applied to value the acquisition opportunity.

Research has shown that direct control acquisitions fail to deliver value for the acquiring firm (see e.g., Malmendier & Tate, 2008; Stulz et al., 1990; Malmendier et al., 2018). Another possibility is to sequence the acquisition by first acquiring part of the equity ($< 50\%$) in the target firm and then having the option to acquire the rest of the firm later. We model the acquisition option (very simply) in the following way: Let X be the acquiring firm with firm-value V_t^X and let Y be the target firm with firm-value V_t^Y. With the acquisition, the acquirer X can realize synergies $\gamma > 0$ over the combined firm value, such that the combined firm value is $V_0^{XY} = (V_0^X + V_0^Y)(1+\gamma)$. When firm X chooses to acquire a controlling stake in firm Y immediately, without sequencing, it has to pay a premium ϕ over the target firm value, such that the net present value (NPV) for firm X is equal to $NPV = V_0^{XY} - V_0^X - (1+\phi)V_0^Y$.

Otherwise, X can choose to acquire a minority stake of size ω in firm Y now and the rest of the firm after T periods. When X acquires a minority stake in Y, firm X still has to pay a premium, however, now with a discount ζ. Hence, the price of the minority stake is

$$\Omega_0 = \omega\zeta(1+\gamma)V_0^Y. \tag{4.24}$$

The firm values V_t^X, V_t^Y evolve over time per period Δt with up-factors $u_X = e^{\sigma_X\sqrt{\Delta t}}$, $u_Y = e^{\sigma_Y\sqrt{\Delta t}}$; and down-factors $d_X = 1/u_X$, $d_Y = 1/u_Y$ respectively, where σ_X and σ_Y represent the volatilities of the firm-values. The movements of the firm values V_t^X and V_t^Y can furthermore also be correlated with each other with correlation factor ρ. Hence, we can deduct that the volatility of the combined firm value $V_t^{XY} = (V_t^X + V_t^Y)(1+\gamma)$

is equal to:

$$\sigma_{XY} = \sqrt{(1+\gamma)^2\left((\sigma^X)^2 + (\sigma^Y)^2 + 2\rho\sigma^X\sigma^Y\right)}. \qquad (4.25)$$

Such that V_t^{XY} moves up or down per period with factors $u_{XY} = e^{\sigma_{XY}\sqrt{\Delta t}}, d_{XY} = 1/u_{XY}$. Firm X can, however, not (fully) realize synergies as long as it has not acquired a controlling stake in firm Y. Therefore, every period without a controlling stake is considered as a period with 'lost dividends' by firm X, where the dividend yield in this case is proportional to the synergy factor. That means that the combined firm value decreases in every period with factor $e^{-\eta\gamma\Delta t}$, where $\eta \geq 0$ represents the proportion. Firm X decides at time $t = T$ again whether it wants to exercise the acquisition option (extend the minority stake from the equity alliance to a controlling stake).

Suppose the decision-maker at firm X, say the CEO, has PT preferences as described in Section 4.3.1. Furthermore, suppose that firm X eventually wants to acquire 100% of firm Y. Having a minority stake of size ω then gives the following price K for the remaining stake at $t = T$:

$$K_T = (1-\omega)(1+\gamma)V_T^Y \qquad (4.26)$$

The reference point of the CEO depends on the minority stake investment and the exercise price (of obtaining a controlling stake). Suppose that the CEO only considers the sequential acquisition strategy worthwhile if (s)he can realize a return which is at least equal to the return of the direct acquisition strategy. The CEO can even require to obtain a return on the sequential strategy which exceeds the return of the direct strategy with a certain percentage, before (s)he considers the sequential strategy worth the effort.

Then the reference point becomes:

$$\frac{e^{-rT}\left(V_T^{XY}-K_T\right)-\Omega_0}{V_0^X} > (1+\xi)\frac{V_0^{XY}-(1+\phi)V_0^Y}{V_0^X}$$
$$\Longleftrightarrow V_T^{XY}-K_T > \left((1+\xi)(V_0^{XY}-(1+\phi)V_0^Y)+\Omega_0\right)e^{rT}$$
$$RP = \left((1+\xi)(V_0^{XY}-(1+\phi)V_0^Y)+\Omega_0\right)e^{rT}. \tag{4.27}$$

This type of sequential acquisition option is analogous to an European-style real option to invest with lost dividends. The calculation is therefore straightforward with the help of Sections 4.3.2 and 4.3.3.

Consider an acquiring firm with firm value $V_0^X = 65$ and volatility $\sigma_X = 0.3$. The PT-RO framework is especially intended for real options that relate to underlying values that are not replicable. Therefore, we consider as target firm a private firm (or start-up) with firm value $V_0^Y = 35$. Start-ups are private firms, hence their stocks are not traded; furthermore, since it can be a company which offers new services, the company value may not be replicable by existing (traded) assets. For these types of companies, it is characteristic that the volatility is high because of the unpredictable and new nature. We assume the target value's volatility to be $\sigma_Y = 0.7$. Investment opportunities with high risk (uncertainty) are especially suited to look at from a real options point of view. Finally, we assume that the two firm values are uncorrelated, $\rho_{XY} = 0$.

We consider a possible minority stake of $\omega = 25\%$ and look at two different cases for the synergy factor: Low $\gamma = 0.1$ and high $\gamma = 0.4$. We set the premium equal to the synergy factor $\phi = \gamma$, as target management (or owners) often demand(s) the value of the improvement (synergies) in return for their control (e.g. Shleifer & Vishny, 1986; Tirole, 2010). Furthermore, we set the discount for the equity alliance premium at $\zeta = 1/(1+\phi)$, which means that the minority equity stake can be acquired at firm value without additional premium. The risk-free rate r is again 2%. The probability of an up-movement is $p = 0.5$ and the time to maturity is $T = 1$. Furthermore, we employ PT-parameters as in Section 4.3.1 and consider reference points as in Equation (4.3.5) with $\xi = \{0, r, 0.1, 0.25\}$.

The PT-RO values are displayed in Figure 4.7 for the two synergy cases as a function of η, the proportion of synergies which is considered lost dividends. Furthermore, we have also displayed the risk-neutral value of the real option and the static net present value (NPV) of the direct acquisition strategy. First, we observe by looking at the left panel with synergy factor $\gamma = 0.1$ that depending on the reference point, a decision-maker with a high reference point $\xi = 0.25$ always employs a sequential acquisition strategy as it gives higher value than the static NPV. On the other hand, a decision-maker with low RPs ($\xi = \{0, r\}$ never prefers the sequential acquisition strategy over the direct acquisition. For a decision-maker with moderate reference point $\xi = 0.1$ the choice between a sequential strategy or direct acquisition depends on the magnitude of what are considered lost dividends: For a low (high) amount of lost dividends, a sequential strategy (direct acquisition) is preferred. This again illustrates the importance of the reference point in decision making.

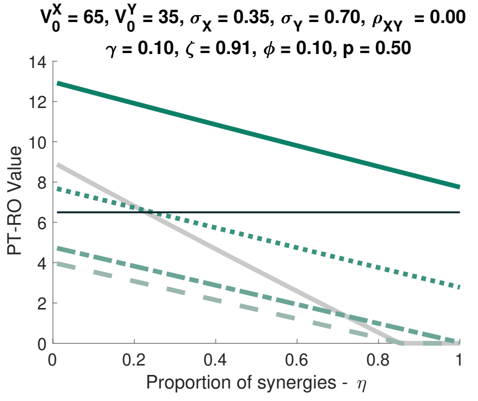
Furthermore, we see that for a higher synergy factor $\gamma = 0.4$, the decision maker is inclined to choose the direct acquisition for lower levels of lost dividends[22]. Higher synergies do not only affect the magnitude of the option values, but also the slope, such that now for lower reference points it is also possible to prefer the sequential strategy[23].

[22] Also the correlation matters, for positive correlation $\rho_{XY} = 1$ the PT-RO and RNV option values increase, as σ_{XY} increases. The cut-off point between RNV and NPV for $\gamma = 0.1$ is at $\eta \approx 0.5$ for $\rho_{XY} = 1$ whereas it is at $\eta \approx 0.22$ for $\rho_{XY} = 0$.

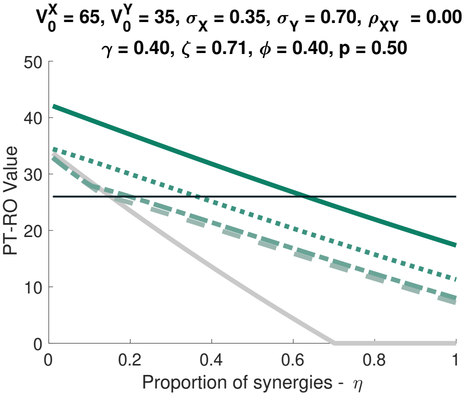
[23] It is interesting to link this observation to a difference in optimism in a PT context and

Figure 4.7: PT-RO Values $\mathcal{R}$ for the sequential acquisition option

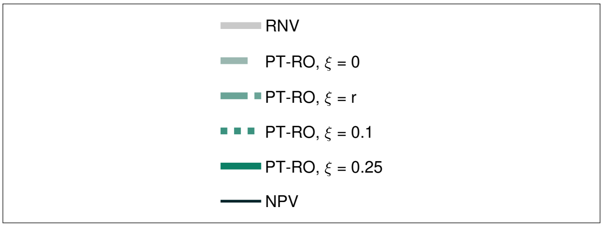
This figure shows the prospect theory real option (PT-RO) values $\mathcal{R}$ for a sequential acquisition option with maturity $T = 1$ and number of evaluation periods $n = T$. The values are plotted as a function of the proportion of synergies η which is considered as lost dividends by the decision-maker. The firm value of the acquirer and target are $V_0^X = 65$ and $V_0^Y = 35$ respectively. The volatility of firm values are $\sigma_X = 0.35$ and $\sigma_Y = 0.7$ for the acquirer and target respectively, we assume zero correlation $\rho_{XY} = 0$. The size of the minority stake is $\omega = 25\%$, the premium is equal to the synergy factor $\phi = \gamma$ and the discount ζ on this premium for acquiring the minority stake is $\zeta = 1/(1 + \phi)$. We consider two cases for the synergy factors: $\gamma = 10\%$ and $\gamma = 40\%$. The probability weighting function (PWF) has parameterset from Abdellaoui (2000): $(a^+ = 0.6, b^+ = 0.65, a^- = 0.65, b^- = 0.84)$. The parameter of the power utility function is $\alpha = 0.9$ The loss-aversion parameters is $\lambda = 2.25$. The PT-RO values are plotted for several reference points (RP) which are $\{0, rI, 0.10I, 0.25I\}$. For the purpose of comparison the risk neutral value (RNV) of the real option is also plotted for all settings along with the static net present value (NPV) of the acquisition. Finally, the probability of an up-movement and down-movement of the underlying value V_t are both 0.5.



(a) Synergies - $\gamma = 10\%$



(b) Synergies - $\gamma = 40\%$



4.4 Discussion

We integrated prospect theory and real options theory (PT-RO) in a binomial tree framework and used this framework to analyze several real-option-like investment decisions in finite and discrete contexts.

Whereas probability weighting drives value in a general way, with optimistic (pessimistic) probability weighting leading to higher (lower) PT-RO values overall, the reference point can partly explain value differences such as over- or underinvestment as well. Probability weighting affects the PT-RO values over the whole range, shifting the curve of PT-RO values upwards or downwards. The reference point, on the other hand, may explain value differences within the same type of probability weighting.

For instance, with an inverse-S type probability weighting function (PWF) as in Abdellaoui (2000), a RP equal to the risk-free rate times the investment amount ($RP = rI$), results in lower values overall compared to values for a RP of 0. However, especially for in-the-money (ITM) and out-the-money (OTM) real options, a much higher RP of 25% times the investment amount ($RP = 0.25I$), actually results in higher PT-RO values in monetary terms compared to RP of 0 for low volatility . For low levels of volatility, $RP = 0.25I$ results even in higher values compared to the risk-neutral values for ITM and OTM options. However, higher monetary values for the real option do not necessarily correspond with higher utilities for higher RP agents.

Furthermore, the reference point influences exercise moments (timing) and exercise

overconfidence as behavioural bias. We have seen that optimism increases PT-RO values, since favourable outcomes are overweighted. This would mean that optimism would increase the likelihood of choosing a sequential strategy as it results in higher PT-RO values compared to the static NPV. On the other hand, overconfidence with respect to the synergy factor for a non-PT decision maker (NPV versus RNV) can increase the likelihood of not choosing for a sequential strategy.

behaviour (state-dependent). The magnitude of the reference point determines whether a decision-maker does not exercises the option in only the down-state or in both states of the following period, where lower reference point agents more often exit in both states. The exercise moments show that agents with higher reference points, especially very high reference points, hold on longer to real options without exercising compared to lower reference points; this holds for all levels of volatility. Therefore, the difference in RPs may help to explain a bias known as escalation of commitment (Staw, 1981; Smit & Moraitis, 2015). The escalation of commitment, a decision-making fallacy described as "throwing good money after bad or committing new resources to a losing course of action" (Staw, 1981), has been a particularly well-examined example of sub-optimal investment behavior and has been confirmed with robust empirical findings. Failing to terminate projects even when these projects underperform can thus be due to a high reference point.

Moreover, the impact of the reference point may also put option-based overconfidence measures in a different light. Malmendier & Tate (2005a) classify CEOs as overconfident when they hold on to their options on their own firm's stock, when the options are already substantially in the money. Our analysis shows that not only overconfidence, but also a high reference point can cause an individual to hold on to options longer too if these are evaluated through the PT-RO framework. Of course, stock options are priced in complete markets, but still exercise behaviour (which is choice-making) can be based on reference-dependent utility. A high reference point in general decision-making would be reflected in exercise behaviour of options on all kinds of stocks and not only the own firm's, whereas the overconfidence effect would be only with respect to own firm options; examining this would contribute to disentangle the effects of overconfidence and reference points (and to investigate whether these affect each other).

4.4.1 Limitations and Future Research

Our PT-RO model has some limitations. First, whereas the risk-neutral binomial tree model converges for small time steps Δt to the Black-Scholes model, which is its continuous counterpart, this is not the case for our PT-RO model. Risk-neutral probabilities are adjusted for Δt and go to 0.5 when the time steps become very small. Within the PT-RO framework, weighted probabilities remain constant. Hence, in the case of small time steps, the backward induction is quite long and this results in very small (large) PT-RO values, due to the overweighting (underweighting) of small down-state payoffs. Small time steps are however more required for continuous contexts with continuous monitoring as with oil prices, for instance. Hence, this does not necessarily posit a problem as the focus of our PT-RO framework is at discrete contexts.

Secondly, for long maturity (large T), the PT-RO values become very large for high levels of volatility. For very large T, the end-node values in the upper states can become quite large, with constant weighted probabilities (instead of adjustment as with RNV) this leads to very large PT-RO values. For high level of volatility the risk-neutral probabilities are adjusted such that they are often lower than weighted probabilities, whereas this is the other way around for lower volatility. The PT-RO framework is flexible enough though to make an adjustment, based on economic and behavioural theory, such that the weighting of the probabilities is dependent on volatility and time steps.

It is imaginable that the perception of probabilities is different when the spectrum of outcomes is larger (larger spacing of outcomes due to higher volatility) and the evaluation of probabilities is more frequent (smaller time steps). Etchart-Vincent (2009) find experimental evidence that spacing and level of outcomes indeed affect probability weighting for moderate and high probabilities. Formal theory about the effect of spacing and frequency on probability weighting has however not been formulated yet.

Additionally, regarding the effect of time in probability weighting, Polkovnichenko & Zhao (2013) show with empirical non-experimental evidence that even in complete financial markets[24] the empirical pricing kernels of index options are in accordance with rank-dependant utility and probability weighting with an inverse S shape for the PWF. They also stress that empirical probability weighting is time varying and at times implies underweighted tails.

Nau & McCardle (1991) argue that risk-neutral probabilities $\hat{p}$ in an expected utility framework can be interpreted as

$$\hat{p}(\theta) \propto p(\theta)U'(W(\theta)),$$

normalized such that the risk-neutral probabilities integrate to 1, where $p(\theta)$ represents the subjective probability of state θ and $W(\theta)$ denotes the level of wealth associated with state θ, $U'(\cdot)$ gives the marginal utility[25]. In this way, the risk neutral probabilities encode both the agent's risk preferences as well as beliefs. For our PT-RO framework where we consider solely prospects with two outcomes, this may translate to

$$\begin{aligned} \hat{p}(x_u) &\propto \pi_u U'(x_u|RP) \\ \hat{p}(x_d) &\propto \pi_d U'(x_d|RP) \end{aligned} \tag{4.28}$$

[24] Kliger & Levy (2009) and Gurevich et al. (2009) also used data from complete financial markets, in particular S&P500 index options and options on stocks of 30 leading firms of the S&P100 respectively, to estimate prospect theory parameters and found parameters consistent with prospect theory.

[25] Knight & Singer (2014) argue that the approach proposed by Nau & McCardle (1991), compares to probability weighting in PT.

where π_u and π_d are the weighted probabilities as in (4.6) and the marginal utility is relative to the reference point RP. Whereas this indeed produces a variety of probability weighting functions for outcomes further away from the RPs, the problem however with this formulation is that the marginal utilities for outcomes close to the reference point are extremely high. Outcomes close to the RP are therefore extremely overweighted, resulting in a weighted probability close to 1 if the other outcome is further away from the reference point. Especially with a RP of 0 this results in almost all PT-RO values close to 0, as many down-state outcomes in the PT-RO are equal to 0.

A possible suggestion, specifically for this PT-RO framework, would be to relate the degree of probability weighting to the difference in utilities resulting from the two outcomes. This would imply that probability weighting is more dominant when the difference in outcomes is large than when outcomes are very close to each other. In this way, the probabilities used in the PT-RO framework, say p^*, are more close towards weighted probabilities π if the difference in utilities is large and close to other probabilities χ (whether that are objective probabilities, risk-neutral probabilities or just a probability of $1/2$) if the difference in utilities is small. Formally, with $x_u \geq x_d$ this implies:

$$\begin{aligned} p^*(x_u) &\propto \pi_u \Big[U(x_u|RP) - U(x_d|RP) \Big] + \chi(u) \\ p^*(x_d) &\propto \pi_d \Big[U(x_d|RP) - U(x_d|RP) \Big] + \chi(d), \end{aligned} \tag{4.29}$$

normalized such that the probabilities p^* are between 0 and 1.

In principle, making the probability weighting function dependent on outcomes is not ideal as it leads to a too general model. However, for the PT-RO framework, it can provide additional insights. It also enables the inclusion of time steps or frequency in such a way that probability weighting is, for instance, less present when the time-steps between subsequent probability weightings are small:

$$
\begin{aligned}
p^*(x_u) &\propto \pi_u \Big[U(x_u|RP) - U(x_d|RP) \Big] \Delta t + \chi(u) \\
p^*(x_d) &\propto \pi_d \Big[U(x_d|RP) - U(x_d|RP) \Big] \Delta t + \chi(d).
\end{aligned}
\tag{4.30}
$$

As a trial, we incorporated probability weighting as in (4.30) with $\chi = 1/2$ into the PT-RO framework and found that this does even enable continuous evaluation of PT-RO values, in contrast with regular probability weighting. We have displayed this as an illustration in Figure C.1 in Appendix C. As explained above, with regular probability weighting, we find for very small time-steps $\delta t = T/n$ that PT-RO values either explode or go to zero, dependent on over- or underweighting of the probabilities. With alternative probability weighting for $T = 1$ and $n = 250$ we find PT-RO values which converge to values that are either slightly above or below risk-neutral values, dependent on the PWF and χ. Probability weighting as in (4.30) is however just an idea and not based on formal theory. Further research will have to determine how the dependence of probability weighting on outcomes, time and frequency can be pinned down.

A final remark on changing probability weighting functions would be that we have focused our efforts on investment under risk (known probabilities), whereas the PT-RO framework is extendable to deal with uncertainty (unknown probabilities). Abdellaoui et al. (2011) formalize a theory called the source method, where they distinguish between different sources S of uncertainty. A source function $w_S(\cdot)$ assigns weight to (subjective) probabilities per source. Considering different periods t over longer $T > 1$ as different sources of uncertainty would justify the use of different probability weighting functions.

This would be a plausible assumption as the volatilities and probababilities in different time periods can be different and uncertain. The specification in (4.30) implies that an agent applies more probability weighting when uncertainty is higher as higher volatility (which results in larger differences of utility due to larger spacing of outcomes) and longer time-frames are often associated with more uncertainty. This again offers a suggestion for future research.

As mentioned in Section 4.1.2, the prospect theory framework enables us to consider real option type of investments in isolation without taking portfolio considerations (personal financial investments, consumption) into account, while this is precisely a feature of utility based approaches for real option models in incomplete markets (e.g., Henderson, 2007; Miao & Wang, 2007). Leaving out portfolio considerations may be seen as a potential downside of the framework. However, PT-RO values can still be determined in a prospect theory framework with portfolio considerations: Let X_t denote wealth, first determine the PT-value of discounted wealth from X_T at time $t = T$, where a proportion κ of current wealth κX_0 is invested in the stock market S and the remaining proportion $(1 - \kappa)$ earns the risk-free rate[26]. Next, again determine the PT-value of wealth at time T, where now a proportion of wealth $\delta(X_0 - \nu)$ is invested in the stock market and $(1 - \delta)(X_0 - \nu)$ earns the risk-free rate, but where now there additionally is the real option payoff F_T (giving the pay-off F_u and F_d in up- and down-state respectively at $t = T$). The ν for which holds

$$PT([X_0 - \nu]_{t=T} + F_T) \geq PT(X_T), \qquad (4.31)$$

[26] The stock value S can move up to S_h or down to S_l in the next period with certain probabilities, independent from, or partially correlated with the underlying project value of the real option V, which moves to V_u and V_d in the next period.

determines the price ν which a PT agent is willing to (maximally) pay to acquire this real option. This methodology can also be extended by taking consumption in account. In many cases to find ν we have to rely on numerical methods, especially with non-plain non-European style real options, and when the reference point depends on ν.

Lastly, investment decisions such as an acquisition are often not taken in isolation; strategic considerations have to be taken into account as well. Whereas waiting can create value, the treat of competitors acting first, erodes this option value (Smit & Trigeorgis, 2004). We have shed some light on investment behaviour of a PT agent and how this behaviour can differ from an agent relying on risk-neutral valuation (whereas risk-neutral valuation may not be justified). Additionally, it would be interesting to extend the PT-RO framework with game theory such that also strategic considerations are taken into account and investment behaviour in competitive contexts can be analyzed.

4.5 Conclusion

We investigated how the investment behaviour of agents in a real options (RO) context may be explainable by elements of prospect theory (PT). Real options theory is widely used to model investment decisions under risk; thereby making the crucial assumption that the underlying value of the real option is replicable by traded assets and bonds. This is denoted as the complete markets setting, and then financial option theory is used to value the investment opportunity.

The replicability condition is often deemed "the Achilles' heel" of real options theory, since this assumption is not plausible to hold for a large number of settings, such as investments in start-ups or R&D. Because of the prospect-like nature of real options, we created an integrated RO and PT framework for the valuation of real options in incomplete markets. Since decision-makers tend to break up complex reality into simple algorithms, we chose to develop a PT-RO integrated binomial tree model, in order to create a simple, intuitive, and tractable tool for the valuation of real options in incomplete markets and discrete contexts.

We find that optimism (pessimism) with respect to probabilities, increases (decreases) PT-RO values. Furthermore, we find that the reference point plays an important role in determining the monetary value of a real option. Agents with high reference points are sometimes willing to invest relatively higher amounts compared to lower reference points, which may feel counter-intuitive. However, a higher monetary amount can still feel as a greater loss compared to someone with a lower reference point. Additionally, the magnitude of the reference point also affects the investment timing and investment sensitivity. An agent with a higher reference point holds on to a real option to invest with dividends longer without exercising compared to an agent with a lower reference point. An agent with a lower reference point exits more often in both states, whereas an agent with a higher reference point only exits in the down-state.

Furthermore, we examined how optimism and the magnitude of the reference point play a role in choosing between acquisition strategies. Optimism increases the likelihood of preferring a sequential acquisition strategy over a direct acquisition. The magnitude of the reference point also determines whether an agent always, never, or under certain conditions chooses a sequential strategy over a direct acquisition. Whereas most studies focus on the S-type utility function within prospect theory, we confirm that the probability weighting function and reference point are as important elements of prospect theory and that these heavily influence decision-making.

Prospect theory is not normative but rather descriptive. Polkovnichenko & Zhao (2013) however, state that probability weighting and rank-dependent utility (of which PT is a generalization) are important and empirically relevant elements for understanding asset prices, even in complete markets, and have implications for the assumptions of investor behaviour. Our findings therefore may help to explain some common investment behaviour anomalies such as escalation of commitment and overinvestment. With our model, we do not aim to create a framework which can be used as a sophisticated valuation model, but we hope to raise awareness about how PT preferences can affect real option investment decisions.

If agents learn about their own behavioural traits such as optimism or a high reference point and pay attention to the effects of these in their personal valuation and decision making, they may correct their valuations and judgements for these (possibly undesirable) traits. Insights in these traits may help investors, managers and policy makers to make their decisions less subjective. After all, Abdellaoui et al. (2013) find clear support in a sample of private bankers and fund managers that financial professionals behave according to prospect theory and violate expected utility maximisation.

Altogether, we hope to have contributed to paving the way for more future research focused on integrating valuation theory, such as real options, with behavioural theory, in particular prospect theory.

A Risk Neutral Valuation

Consider a simple call option on a stock S_t with strike price K. This financial derivative gives the holder the right, but not the obligation, to buy the stock at maturity of the option, say time $t = T$ for the agreed strike price K. Hence, the payoff of this option at T is $\max[S_T - K, 0]$. How can we determine the fair price (value) of such an option? Can this be done through expected values? Moreover how do we discount over time, with which rate?

The most common method to determine the value of an option is via the non-arbitrage argument, that is, create a portfolio which exactly replicates the payoffs of the option. The option should then have the same price as the portfolio. Let B denote a bond with normalized price 1. Furthermore r denotes the risk-free rate and σ^2 is the variance of the natural logarithm of the stock (often a log-normal distribution for stock prices is assumed). Hence, $\ln(S)$ can move to $\ln(S) + \sigma\sqrt{\Delta t}$ or $\ln(S) - \sigma\sqrt{\Delta t}$. That means that S can move to $Se^{\sigma\sqrt{t}}$ or $Se^{-\sigma\sqrt{t}}$. Denote $u = e^{\sigma\sqrt{\Delta t}}$ and $d = e^{-\sigma\sqrt{\Delta t}} = \frac{1}{u}$.

For simplicity and the purpose of illustration, we only consider two periods $t = 0$ and $t = 1$. At $t = 1$ the stock can take values $S_u = S \cdot u$ with probability p and $S_d = S \cdot d$ with probability $1 - p$. At $t = 1$ the bond takes value $e^r B$. Now we construct a portfolio Ξ of stocks and bonds. Denote by δ the amount of stocks and Ψ the amount of bonds in the portfolio. At $t = 0$ the portfolio has value $\Xi_0 = \delta S + \Psi B$ and at $t = 1$ the portfolio can have either the following values:

$$\Xi_1 = \begin{cases} \delta S_u + \Psi e^r B & \text{in the up-state} \\ \delta S_d + \Psi e^r B & \text{in the down-state} \end{cases}$$

Denote by F the value of the option. The payoffs in the up and down state are F_u and F_d respectively with $F_i = \max[S_i - K, 0], i = \{u, d\}$. Then we want to match these payoffs with our portfolio, hence, it should hold that:

$$\delta S_u + \Psi e^r B = F_u$$
$$\delta S_d + \Psi e^r B = F_d$$

Solving for δ and Ψ gives:

$$\delta = \frac{F_u - F_d}{S_u - S_d}$$
$$\Psi = \frac{1}{e^r B}\left[F_u - \left(\frac{F_u - F_d}{S_u - S_d}\right) S_u\right] = \frac{F_u - \delta S_u}{e^r B}$$

Hence, the price of the option at $t = 0$ should be $F = \delta S + \Psi B$. The derivation above is solely based on arbitrage. What about expectations? We can rewrite:

$$F_0 = \delta S_0 + \Psi B_0$$
$$= \underbrace{\left(\frac{F_u - F_d}{S_u - S_d}\right)}_{\delta} S_0 + \underbrace{\frac{1}{e^r B_0}\left(F_u - \left(\frac{F_u - F_d}{S_u - S_d}\right) S_u\right)}_{\Psi} B_0$$
$$= \left[\underbrace{\left(\frac{e^r S_0 - S_d}{S_u - S_d}\right)}_{\hat{p}} F_u + \underbrace{\left(\frac{S_u - e^r S_0}{S_u - S_d}\right)}_{(1-\hat{p})} F_d\right]\frac{1}{e^r}$$
$$= \frac{[\hat{p} F_u + (1 - \hat{p}) F_d]}{e^r}$$

The 'probability' $\hat{p}$ is known as the *risk-neutral probability*:

$$\hat{p} = \frac{e^r S - S_d}{S_u - S_d} = \frac{e^r - d}{u - d}$$

Under the risk-neutral probability all underlying assets S, V, etc. earn the risk-free rate. For the stocks for example, by plugging in $\hat{p}$:

$$\mathbb{E}^{\hat{p}}(S_{next\ period}) = \hat{p}S_u + (1 - \hat{p})S_d = e^r S$$

Real options are often valued in the same way as financial options through the non-arbitrage argument, relying thereby on the (sometimes less plausible) assumption that it is possible to construct a portfolio of bonds and a perfectly correlated asset, such that the real option payoffs can be exactly replicated.

B Prospect Theory for Multiple Outcomes

Consider several outcomes (gains/losses) x_i with corresponding probabilities p_i, that is consider the prospect:

$$\mathcal{X} = (p_1, x_1; \dots; p_n, x_n), \tag{32}$$

where we have

$$x_1 \geq \dots \geq x_k \geq 0 \geq x_{k+1} \geq \dots \geq x_n, \tag{33}$$

and $\sum_{i=1}^{n} p_i = 1$. The 'regular' expected value of (32) is simply computed as $\mathbb{E}(\mathcal{X}) = \sum_{i=1}^{n} p_i x_i$. An agent in the expected utility framework with utility function $u(\cdot)$ bases decisions on the expected utility, which is computed as

$$EU(\mathcal{X}) = \sum_{i=1}^{n} p_i u(W + x_i), \tag{34}$$

where W is the current level of wealth. A prospect theory agent evaluates the outcomes with corresponding probabilities (lotery) in (32) by computing the following PT-value

$$PT(\mathcal{X}) = \sum_{i=1}^{n} \pi_i U(x_i; RP) \tag{35}$$

where

$$\pi_i = \begin{cases} w^+(p_i + \dots + p_1) - w^+(p_{i+1} + \dots + p_1) & \text{for } i \leq k, \\ w^-(p_i + \dots + p_n) - w^-(p_{i+1} + \dots + p_n) & \text{for } i \geq k+1. \end{cases} \tag{36}$$

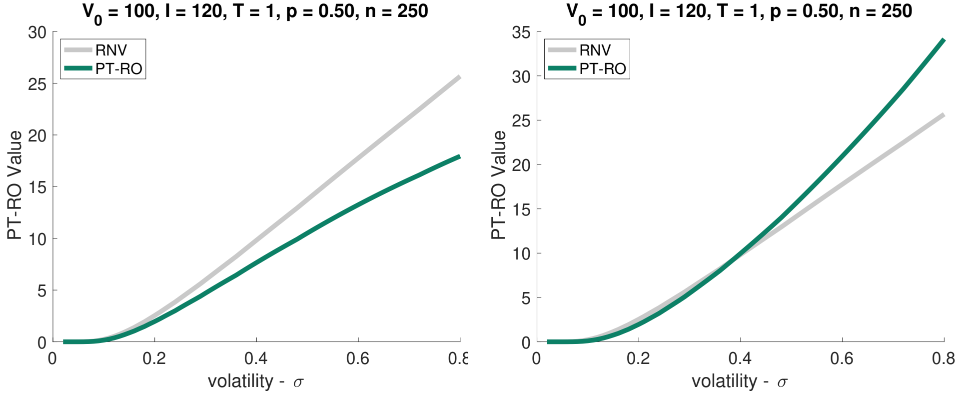
Here $U(\cdot; RP)$ is the utility or value function and $w^+(\cdot)$ and $w^-(\cdot)$ are the probability weighting functions. The formula in (35) can be generalized for a gamble $\mathcal{Y}$ with continuous outcomes y which follow a continuous cumulative distribution function $F(y)$ and probability distribution function $f(y) = F'(y)$ as (Wakker, 2010):

$$PT(\mathcal{Y}) = \int_{\mathbb{R}^-} U(y) {w^-}'(F(y)) f(y) dy + \int_{\mathbb{R}^+} U(y) {w^+}'(1 - F(y)) f(y) dy. \quad (37)$$

$$= \int_{-\infty}^{0} U(y) \frac{d}{dy}\Big(w^-(F(y))\Big) dy + \int_{0}^{\infty} U(y) \frac{d}{dy}\Big(-w^+(1 - F(y))\Big) dy. \quad (38)$$

C Additional Figures

Figure C.1: The real option to invest - alternative weighting
This figure demonstrates how alternative probability weighting as suggested in Equation (4.30) enables PT-RO values calculation for large number of time steps n. This figure shows the prospect theory real option (PT-RO) values $\mathcal{R}$ for a OTM real option to invest with maturity $T = 1$ and number of evaluation periods $n = 250$. The values are plotted as a function of the volatility of the underlying project-value σ for OTM moneyness level with $I = 120$ and and probability weighting function (PWF) parameterset from Abdellaoui (2000): $(a^+ = 0.6, b^+ = 0.65, a^- = 0.65, b^- = 0.84)$. The parameter of the power utility function is $\alpha = 0.9$ The loss-aversion parameters is $\lambda = 2.25$. The PT-RO values are plotted for reference point 0. The risk neutral value (RNV) of the real option is also plotted. The true probability of an up-movement and down-movement of the underlying value V_t are both 0.5. Panel (a) uses alternative probability weighting as in (4.30) with χ equal to the risk neutral probabilities $\hat{p}$, panel (b) uses χ equal to $1/2$.



(a) $\chi = \hat{p}$ (b) $\chi = 1/2$

5

Summary

This dissertation consists of three (mainly) theoretical essays on the impact of behavioural traits on (corporate) financial decisions. Every essay presents a theory based on mathematical and financial foundations that combines rational theory with behavioural elements. Furthermore I present empirical evidence supporting the theories.

Chapter 2 investigates whether CEO overconfidence affects the choice of an acquisition strategy. Besides a direct control acquisition, a CEO of an acquiring firm can follow a toehold strategy. In a toehold strategy, a minority stake in the firm is acquired first and only extended to a controlling stake if circumstances develop favourably. Previous research has expressed and illustrated the advantages associated with a toehold strategy. Despite these advantages, however, the toehold strategy is only rarely executed.

I develop a continuous time real options model, where I model the toehold strategy as a call option on the control acquisition. I show that overconfident CEOs have a higher likelihood of preferring the immediate control acquisitions over the toehold real option. I empirically investigate the claims of the theoretic model about the impact of CEO overconfidence on the use of toeholds in acquisition strategies. I find that, given an acquisition, overconfident CEOs are more likely to execute direct control acquisitions instead of minority stake acquisitions. The implications of this study for contracting and deal execution practices, is that CEOs should focus attention on toehold acquisition strategies as a potential way to improve acquisition performance. Acknowledging the existence of overconfidence in acquisition strategies can offer executives the insights and new organisational processes that could be helpful in efforts to de-bias acquisition strategies.

Chapter 3 investigates how behavioural theory can explain why sellers choose a particular selling mechanism. Classical economic theory dictates that a seller should always opt for an auction to sell an object, since the bidding among competitors will maximize expected revenues for the seller. Still, we observe many sales through negotiations. Often these negotiations precede subsequent auctions, which only take place in case of a failed negotiation. The choice for such a sequential selling mechanism, where the negotiation is first tried before an auction, is not explainable from a rational point of view.

I first model the choice between a direct auction and the sequential selling mechanism from a rational perspective with auction theory[1]. In the model, it is costly to organize an

[1] The Nobel prize in economic sciences of 2020 was awarded to P. Milgrom and R. Wilson, for their contributions to auction theory.

auction. I show that there exists a 'negotiation penalty', which means that the expected pay-offs for the seller from the sequential mechanism are always lower than the expected pay-offs from the direct auction. In addition, the expected pay-offs from a sequential auction are always (much) lower than its simultaneous counterpart. This confirms that sellers should opt for the direct auction in order to maximize expected value. Past research has shown, however, that agents do often not act as rational expected value maximizers. I show that the choice for a sequential selling mechanism can be explained with behavioural decision theory. I integrate prospect theory[2] with auction theory and show that for a prospect theory decision-maker it is possible to prefer the sequential mechanism.

By using a dataset of corporate acquisitions, I empirically confirm the existence of a negotiation penalty in takeover-premiums between direct and sequential auctions. Furthermore, I find that higher auction costs lead to a lower likelihood of choosing the sequential mechanism, which is not predicted by the rational model, but can be explained by the prospect theory model. These findings provide insights for sellers choosing between selling procedures and may have implications for deal and contracting procedures. All in all, this study shows that outcomes of selling mechanisms are in line with a rational model, but choice-making between selling mechanisms is in line with a behavioural model.

Chapter 4 develops a theory of real options integrated with prospect theory. Many investment opportunities can be modelled with real options theory. However, the valuation of real options through the financial options paradigm relies on the crucial assumption of complete financial markets. For investments or projects, this means that the pay-offs should be replicable by traded assets. This strong assumption is not plausible in many

[2] Prospect theory is a prominent behavioural decision theory which incorporates several behavioural elements such as reference dependence, loss aversion, probability weighting and risk seeking (averse) attitude over losses (gains).

cases. Investments in R&D or angel investments in start-ups are examples of incomplete markets settings.

The dynamics of the investment outcomes in discrete and finite contexts, represented as a real option tree, resemble compound prospects of obtaining outcomes with particular probabilities. By integrating prospect theory and real option theory in a binomial tree framework, I can analyze investment behaviour in incomplete markets settings and explain some anomalies. I analyze several discrete investment settings represented through (compound) real options and examine the investment behaviour of PT agents. I find that anomalies regarding project investments, such as overinvestment and escalation of commitment, are explainable through the combination of real option theory and prospect theory. In general, I find that behavioural traits as optimism or high reference points clearly affect the value of investments and investment decisions, such as timing of exit, within the real options context. This encourages more future research on the integration of valuation theory with behavioural theory.

All in all, this dissertation examines the impact of behavioural traits on financial decision making. It shows that behavioural biases such as overconfidence affect decision making such that it can alter choices. By considering behavioural traits through behavioural decision theory, it is possible to explain several anomalies in financial decisions. These findings do not only contribute to academic literature and our understanding of decision processes, but also have relevant implications for executives, policy makers, and all financial decision-making individuals. This dissertation contributes to the ongoing discussion of the plausibility of the rationality assumption of individuals and contributes to illustrate the relevance of the behavioural side of economics and management.

6

Samenvatting in het Nederlands

Dit proefschrift bevat drie (voornamelijk) theoretische essays over de impact van gedragskenmerken op financiële beslissingen. Elk essay presenteert een theorie die is gebaseerd op wiskundige en financiële grondslagen en die rationele theorie combineert met gedragselementen. Verder presenteer ik ook de resultaten uit het empirische onderzoek (d.w.z. met data en wiskundig-statistische analyses) dat ik uitgevoerd heb. Deze empirische resultaten leveren ondersteuning voor de theorieën die ik ontwikkeld heb. Hieronder beschrijf ik per hoofdstuk welke vraagstukken ik onderzocht heb en wat mijn bevindingen zijn.

Hoofdstuk 2 onderzoekt of overmoedigheid van CEO's invloed heeft op de keuze van een overnamestrategie. Naast een directe overname van de zeggenschap, kan de CEO van een overnemende onderneming een toehold-strategie volgen. In een toehold-strategie wordt eerst een minderheidsbelang in het doelwit bedrijf verworven en wordt dit minderheidsbelang pas uitgebreid naar een controlerend belang als de omstandigheden zich gunstig ontwikkelen. Eerder onderzoek heeft de voordelen van een toehold-strategie benoemd en aangetoond. Ondanks deze voordelen wordt de toehold-strategie echter maar weinig uitgevoerd, hetgeen puzzelend is. Ik stel de hypothese dat het lage gebruik van toehold-strategieën mogelijk deels te verklaren is door overmoedigheid van een CEO.

Om dit te onderzoeken, ontwikkel ik een wiskundig reële opties model in continue tijd, waarbij ik de toehold-strategie modelleer als een call-optie[1] op de controle-acquisitie. Ik laat zien dat overmoedige CEO's eerder geneigd zijn (dat er een grotere kans is) om de directe overname te verkiezen boven de toehold-strategie. Ik onderzoek daarnaast ook op empirische wijze of de beweringen kloppen die volgen uit mijn theoretische model over de impact van overmoedigheid van CEO's op het gebruik van toeholds in acquisitiestrategieën. Daarbij is het nodig om overmoedigheid van CEO's te meten.

Voor het kwantificeren van overmoedigheid bij CEO's gebruik ik een empirische maatstaf die gebaseerd is op het persoonlijke optie-uitoefen gedrag van CEO's. De CEO en andere leden van het (hogere) management ontvangen vaak opties op de aandelen van het bedrijf waar ze werkzaam zijn als onderdeel van hun compensatiepakket. De maatstaf voor CEO-overmoedigheid die ik gebruik is gebaseerd op de gedachte dat een CEO die niet overmoedig is, zijn/haar opties meteen zou uitoefenen wanneer de prijs van het aan-

[1] Een call optie is een financieel instrument waarbij de houder het recht (niet de verplichting) heeft om een aandeel in de toekomst tegen een vastgestelde prijs te kopen. Een reële optie is vergelijkbaar met een financiële optie, alleen heeft de optie dan betrekking op een reële investering zoals bijvoorbeeld een nieuw project, nieuw gebouw of nieuw product.

deel hoger is dan de uitoefenprijs, aangezien de CEO met de opties op zijn/haar 'eigen aandelen' onder-gedifferentieerd is. Echter, CEO's die denken dat onder hun leiding het bedrijf zal floreren, houden hun opties langer aan, zelfs als de prijs van het aandeel al ver boven die uitoefenprijs ligt. Dergelijk gedrag wijst (gemiddeld genomen) op overmoedigheid. Als alternatieve maatstaf gebruik ik data van nieuwsartikelen in kwaliteitskranten om te bepalen of een CEO door de media als overmoedig gezien wordt. Tenslotte gebruik ik maatstaven die gebaseerd zijn op de salarissen van CEO's ten opzichte van andere leden van het management.

Met deze empirische maatstaven voor overmoedigheid en een dataset van ongeveer 10.000 overnames, constateer ik dat, gegeven een overname, overmoedige CEO's eerder geneigd zijn om directe acquisities van volledig zeggenschap te doen in plaats van een minderheidsbelang in te nemen. De implicaties van deze studie voor het doen van overnames, is dat CEO's toehold acquisitiestrategieën serieuzer moeten overwegen als een mogelijke manier om de acquisitieprestaties te verbeteren. Het erkennen van het bestaan van overmoedigheid in acquisitiestrategieën kan leidinggevenden de inzichten en nieuwe organisatieprocessen bieden die nuttig zouden kunnen zijn bij pogingen om gedragsafwijkingen in acquisitiestrategieën weg te nemen.

Hoofdstuk 3 onderzoekt hoe gedragstheorie kan verklaren waarom verkopers voor een bepaald verkoopmechanisme kiezen. De klassieke economische theorie schrijft voor dat een verkoper altijd moet kiezen voor een veiling om een object te verkopen, aangezien het opbieden tussen concurrenten de verkoopprijs zal opdrijven en daardoor de verwachte inkomsten voor de verkoper zal maximaliseren. Toch zien we veel verkopen via onderhandelingen. Vaak gaat zo een onderhandeling vooraf aan een opeenvolgende veiling, welke alleen plaatsvindt als de onderhandeling mislukt. De keuze voor een dergelijk sequentieel verkoopmechanisme, waarbij de onderhandeling eerst wordt geprobeerd voordat er een veiling plaatsvindt, is vanuit rationeel oogpunt niet verklaarbaar.

Ik modelleer eerst de keuze tussen een directe veiling en het sequentiële verkoopmechanisme (onderhandeling met een daaropvolgende veiling in geval van mislukte onderhandeling) vanuit een rationeel perspectief met behulp van veilingtheorie. Toevalligerwijs werd de Nobel prijs voor de economie van dit jaar (2020) uitgereikt aan Paul Milgrom en Robert Wilson (beiden van Stanford University), voor hun verbeteringen in de veilingtheorie en uitvindingen van nieuwe veilingformats.

In het model dat ik ontwikkel is het organiseren van een veiling niet kosteloos. Ik laat zien dat er een 'onderhandelingsboete' bestaat, wat betekent dat de verwachte opbrengsten voor de verkoper uit het sequentiële mechanisme altijd lager zijn dan de verwachte opbrengsten uit de directe veiling. Bovendien zijn de verwachte opbrengsten van een opeenvolgende veiling altijd (veel) lager dan de directe veiling. Dit bevestigt dat verkopers eigenlijk moeten kiezen voor de directe veiling om hun verwachte waarde te maximaliseren. Uit eerder onderzoek is echter gebleken dat agenten vaak niet opereren als rationele verwachtingswaarde-maximaliseerders. Ik laat zien dat de keuze voor een sequentieel verkoopmechanisme wel verklaard kan worden met gedragstheorie en niet met rationele theorie. Ik integreer prospect theorie [2] met veilingtheorie en laat zien dat het voor een prospect theorie beslisser wel mogelijk is om de voorkeur te geven aan het sequentiële mechanisme.

Met een dataset van bedrijfsovernames bevestig ik het bestaan van een onderhandelingsboete bij overname premies tussen directe en opeenvolgende veilingen. Verder vind ik dat hogere veilingkosten leiden tot een kleinere kans om het sequentiële mechanisme te

[2] Prospect theorie is een prominente gedragsbeslissingstheorie die verschillende gedragselementen zoals referentieafhankelijkheid, verliesaversie, kansweging en risicozoekende (afkerige) houding ten opzichte van verliezen (winsten) incorporeert. Prospect theorie verklaart bijvoorbeeld waarom over het algemeen verliezen meer pijn doen dan dat even grote winsten voldoening opleveren.

kiezen, wat niet voorspeld wordt door het rationele model, maar wel verklaard kan worden door het prospect theorie model. Het lijkt misschien voor de hand liggend om de gratis onderhandeling te 'proberen' wanneer de kosten voor een veiling hoog zijn, maar de verwachte opbrengst van het totale mechanisme is lager dan voor een directe veiling: mocht immers de onderhandeling mislukken, dan ben je veel slechter af met een opeenvolgende veiling dan met een directe veiling zonder onderhandeling. Deze bevindingen bieden inzichten voor verkopers die kiezen tussen verkoopprocedures en kunnen gevolgen hebben voor deal- en contractprocedures. Al met al laat dit onderzoek zien dat uitkomsten van verkoopmechanismen in lijn zijn met een rationeel model, maar dat het maken van keuzes tussen verkoopmechanismen in lijn is met een gedragsmodel.

Hoofdstuk 4 ontwikkelt een theorie van reële opties geïntegreerd met prospect theorie. Veel investeringsmogelijkheden kunnen worden gemodelleerd met de theorie van reële opties[3]. De waardering van reële opties door middel van het financiële optie-paradigma berust echter op de cruciale veronderstelling van complete financiële markten. Voor investeringen of projecten betekent dit dat de pay-offs (opbrengsten) repliceerbaar moeten zijn door verhandelde financiële instrumenten. Deze sterke aanname is in veel gevallen niet plausibel. Investeringen in R&D (onderzoek en ontwikkeling) of investeringen van durfkapitaalverstrekkers in start-ups zijn voorbeelden van incomplete markt omstandigheden.

De dynamiek van de investeringsuitkomsten in discrete en eindige contexten, gepresenteerd als een reële optie boom, lijkt sterk op een samengestelde prospect met bepaalde kansen op resultaten. Door prospect theorie (PT) en reële optie theorie te integreren in een binominale boom model, kan ik investeringsgedrag in incomplete markten analyseren en

[3] Een investeringsbeslissing is te presenteren als een optie, de beslissing kan immers uitgesteld worden en later genomen worden wanneer onzekerheid opgehelderd is over de tijd. Deze flexibiliteit om later te beslissen heeft waarde die gekwantificeerd kan worden.

enkele anomalieën verklaren. Ik analyseer verschillende investeringsmogelijkheden in discrete contexten gerepresenteerd door (samengestelde) reële opties en onderzoek daarbij het investeringsgedrag van PT-agenten. Ik vind dat anomalieën met betrekking tot projectinvesteringen, zoals overinvesteringen en escalatie van toewijding[4], verklaarbaar zijn door de combinatie van reële optie theorie en prospect theorie. In het algemeen, is mijn bevinding dat gedragskenmerken als optimisme of het hebben van hoge referentiepunten een duidelijke invloed hebben op de waarde die toegekend wordt aan investeringen en op investeringsbeslissingen, zoals het moment van uitstappen, binnen de context van reële opties. Deze bevindingen nodigen uit tot meer toekomstig onderzoek naar de integratie van waarderingstheorie met gedragstheorie.

Al met al onderzoekt dit proefschrift de impact van gedragskenmerken op financiële besluitvorming. Het laat zien dat gedragskenmerken, zoals overmoedigheid, de besluitvorming zodanig beïnvloeden dat het keuzes kan veranderen. Door gedragskenmerken te beschouwen door middel van gedragstheorie, is het mogelijk om verschillende anomalieën in financiële (bedrijfs)beslissingen te verklaren. Deze bevindingen dragen niet alleen bij aan de academische literatuur en ons begrip van besluitvormingsprocessen, maar hebben ook relevante implicaties voor leidinggevenden, beleidsmakers en alle financiële besluitvormers. Dit proefschrift draagt bij aan de voortdurende discussie over de plausibiliteit van de aanname van rationaliteit bij individuen en illustreert de relevantie van de gedragsmatige kant binnen economie en management.

[4]De escalatie van toewijding (escalation of commitment) is een fenomeen waarbij iemand die geconfronteerd wordt met steeds negatiever wordende resultaten van een beslissing, actie of investering, toch het gedrag voortzet in plaats van de koers te wijzigen.

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About the Author

Nishad Matawlie was born on April 4th, 1993 in The Hague, The Netherlands. After finishing the Gymnasium, cum laude, at Hofstad Lyceum in the Hague, he obtained his Bachelor's degree in Econometrics and Operations Research, cum laude, from the Erasmus University Rotterdam in 2014. In 2015, Nishad obtained his Master's degree in Econometrics and Management Science, with a specialisation in Quantitative Finance, cum laude, from the Erasmus University as well. During study, Nishad was a teaching assistant for several mathematics and statistics courses, participated in the ESE Research Traineeship, and did a full-time summer internship at Barclays Investment Bank in London. For his Master's thesis, Nishad received the *Best Econometric Thesis Award* from the Econometric Institute and Veneficus. Nishad started his PhD in Finance in September 2015 at the Erasmus School of Economics and Erasmus Research Institute of Management. His research interests lie at the intersection of dynamic corporate finance, real options and behavioural decision theory. Nishad has presented his work on several international conferences, including the Real Options Conference 2017 in Boston, USA, where he received the *Best PhD Paper Award* for his working paper. At the Erasmus University, Nishad lectured many tutorial groups and supervised multiple master's theses. He is an instructor and co-developer of the massive online open course (MOOC) *Advanced Valuation and Strategy - M&A, Private Equity, and Venture Capital*, which has over 40.000 learners at the moment. Moreover he helped to intensify and digitize the Master's course *Advanced Corporate Finance and Strategy*, for which he received together with the team, the *Educational Innovation Award* of 2018 by the Erasmus School of Economics.

Portfolio

Working Papers

- *Do Overconfident CEOs Ignore Toehold Strategies*, with J.T.J. Smit
- *To Auction Directly or Sequentially?*
- *Real Options in Incomplete Markets: A Simplified Prospect Theory Approach*, with J.T.J. Smit

Conference Presentations

- 2019: European Financial Management Conference (The Azores, Portugal)
- 2018: Portuguese Finance Network Conference (Porto, Portugal)
- 2017: Real Options Conference (Boston, USA)
- 2016: Research in Behavioural Finance Conference (Amsterdam, The Netherlands)

Teaching

- **Advanced Corporate Finance and Strategy**:
  Teaching multiple tutorial classes (∼60 MSc. students each) per period, grading exams, co-composing the exam, organizing the exam review sessions. Conducting the digitization and intensification of the course with the team. This course is part of the Financial Economics program of the MSc. Economics and Business at Erasmus School of Economics.

- **Co-developer and instructor of Coursera MOOC - Advanced Valuation and Strategy - M&A, Private Equity, and Venture Capital**:
  ∼40.000 learners (per September 2020). Co-created multiple review videos, 2D animated videos, reading material, quizzes, and cases.

- **Master's theses**:
  Supervising multiple MSc. students in writing their thesis for graduation, leading the defense ceremonies, examining and grading the theses.

Awards

- **Best PhD Paper Award**, Real Options Conference 2017, Boston, USA

- **Educational Innovation Award 2018-2019**, Erasmus School of Economics
  For the development of the MOOC and digitization and intensification of the course Advanced Corporate Finance and Strategy using the MOOC.

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This thesis contains three (mainly) theoretical essays on the impact of behavioural traits on (corporate) financial decisions. Every essay presents a theory based on mathematical and financial foundations that combines rational theory with behavioural elements. The first study investigates whether CEO overconfidence affects the choice of an acquisition strategy. I develop a continuous time real options model and show that an overconfident CEO is more likely to prefer a direct control acquisition over a toehold strategy; moreover, I find empirical support for the theoretical claims. The second study investigates how behavioural theory can explain why sellers choose a particular selling mechanism. I model the choice between a direct auction and a sequential selling mechanism from both a rational and behavioural perspective using auction theory integrated with prospect theory. I find that where rational theory cannot explain the choice for a sequential mechanism and the effect of auction costs, prospect theory can. Furthermore, I show theoretically, and confirm empirically, that the expected payoffs from a direct auction are higher than from an auction after a failed negotiation. The final essay integrates real option theory with prospect theory for discrete investment contexts, where the investment pay-offs are not replicable by traded assets. I find that behavioural traits as optimism or high reference points clearly affect the value of investments and investment decisions, such as timing of exit, within the (compound) real options context. These findings contribute to our understanding of decision processes and have relevant implications for all corporate financial decision-making individuals.

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