Decision Making under Uncertainty in Developed and Developing Countries: An Experimental Analysis of Farmers' Risk Attitude and Investment Behavior

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Table of Contents

I.   General Introduction

1   Introduction

Globally, decision makers are faced with an ongoing uncertainty within the economic environment in which entrepreneurial decisions must be made (Dixit and Pindyck 1994). Specifically, that means that the factors relevant for success are random variables, which can have various future values. Due to the uncertainty of these factors, even the success of an entrepreneurial action becomes a random variable and it is not possible to predict the outcome of this variable with certainty. In the agricultural sector, almost every entrepreneurial decision is constrained by uncertainty, such as uncertainty over changes in the climate, uncertainty over future product prices and operating costs that determine cash flows or uncertainty over price fluctuations due to the increasing liberalization on domestic agricultural markets (Fafchamps and Hill 2008; Hill 2010a; Hill and Viceisza 2012; Ragasa et al. 2013). Therefore, it is of great relevance in the field of agricultural economics research to analyze and assess decision problems under uncertainty in the context of both developed and developing countries. In this regard, elaborate research is required to better understand what exactly drives individuals' decision making under uncertainty and to predict this behavior in the future for a meaningful policy impact assessment. The consideration of decision problems of individuals in developed and developing countries may also allow identifying potential differences in the decision behavior of individuals, which might be valuable in order to tailor policy instruments in the agricultural sector in the respective countries. This doctoral thesis consists of three papers, which specifically focus on decision making under uncertainty of farmers in developed and developing countries and applying experimental approaches in order to investigate farmers' risk attitude, investment and disinvestment behavior. In the following section, the topics are briefly described.

2   Problem statement and objectives of the study

2.1   Analysis of the investment and disinvestment behavior

Investment and disinvestment, in the sense of long-term acquisition and abandonment of assets, usually represent fundamental decisions, which often involve uncertainty regarding future returns and tradeoffs between current and future realization of the investment or disinvestment for both decision makers in developed and developing countries (Hill 2010b;

Sandri et al. 2010). The classical investment theory that is based on the net present value (NPV) criterion implies that a decision maker undertakes an investment if its expected present value exceeds the expected costs and if its NPV is positive (Jorgenson 1963; Tobin 1969). However, the weakness of the NPV criterion is that it often is not suitable for analyzing agro-economic investment and disinvestment decisions, which are regularly characterized by uncertainty, temporal flexibility, and irreversibility (Dixit and Pindyck 1994; Trigeorgis 1996). The real options approach (ROA), also referred to as the new investment theory, extends the classical NPV approach to explicitly account for uncertainty, flexibility, and irreversibility in investment decision making (Dixit and Pindyck 1994). Specifically, the ROA asserts that an investor may increase its profits by postponing an irreversible investment decision, even if the expected net present value of the returns exceeds the investment costs. Similarly, it may be optimal to postpone an irreversible disinvestment decision, even if the expected present value of the returns falls below the salvage value. According to the ROA, the value of an investment is referred to as 'options value' and consists of the intrinsic value, which is equal to the NPV, and the value of waiting (Trigeorgis 1996, p. 124). The idea of the 'options value' has been widely accepted in the investment literature since the seminal work of Dixit and Pindyck (1994). That is, deferring the decision to invest and disinvest has a positive value because new information about the expected present value of the returns arrives in subsequent periods. In contrast to the NPV criterion, the optimal investment trigger is shifted upwards and the optimal disinvestment trigger is shifted downwards in the case of the ROA. The reason is that the opportunity to postpone the investment and disinvestment decision causes opportunity costs that have to be covered by the expected returns. Hence, the ROA has been discussed as a possible alternative or an additional explanation for economic inertia (Abel and Eberly 1994; Dixit and Pindyck 1994). In this context, the ROA also has been examined with regard to the effect of policy interventions, in particular the effect of a price floor policy, which is often used to stimulate investment, on the investment behavior (Dixit and Pindyck 1994).

A rich literature exists on normative and econometric analyses of investment and disinvestment problems in an agricultural context using the ROA. Some normative applications include Purvis et al. (1995), Winter-Nelson and Amegbeto (1998), and Luong and Tauer (2006), but these applications merely indicate the explanatory potential of the ROA for observed economic inertia. Some studies provide empirical evidence for the

validity of the ROA using econometric approaches based on field data (e.g., Richards and Green 2003; Wossink and Gardebroek 2006; Hill 2010b). However, an empirical validation of real options models explaining investment and disinvestment behavior is difficult for several reasons. For example, predictions of the ROA usually refer to investment and disinvestment triggers, which are not directly observable (Odening et al. 2005). Furthermore, besides options effects, multiple investment options may coexist or financial constraints and risk aversion may affect the decision behavior (Huettel et al. 2010). In regard to these difficulties, it seems reasonable to use experimental methods for the validation of the ROA. The advantage of using experiments is that it allows observing individuals' actual decision behavior in a controlled environment and the elicitation of otherwise unobservable variables, which improves the internal validity (Harrison and List 2004; Roe and Just 2009). The experimental investigation of the ROA is still in its early stages. There are few studies that use experimental methods in examining the ROA in the field of economics, which have been conducted with convenience samples of students or entrepreneurs in developed countries (Rauchs and Willinger 1996; Yavas and Sirmans 2005; Oprea et al. 2009; Sandri et al. 2010). However, there are only few experimental studies on the ROA in the field of agricultural economics, which have been conducted with agricultural entrepreneurs in a developed country (Maart-Noelck and Musshoff 2013; Musshoff et al. 2013). These studies often come to different conclusions regarding the explanatory power of the ROA and thus, require further investigation. Furthermore, to the best of our knowledge, there are no experimental studies examining the ROA and the effect of policy measures, such as price floors on the investment behavior of decision makers in developing countries. A few attempts have been made to examine the impact of price support systems on investment in theoretical and empirical applications, but these studies provide conflicting results (Chavas 1994; Dixit and Pindyck 1994; Chavas and Kim 2004; Sckokai and Moro 2009; Patlolla et al. 2012). Thus, it is crucial to investigate if or under which conditions price support systems have an effect on the investment behavior.

In the light of the above, the first paper titled '*Does Timing Matters? A Real Options Experiment to Farmers' Investment and Disinvestment Behaviours*' and the second paper titled '*Investment Behavior of Ugandan Smallholder Farmers: An Experimental Analysis*' of the dissertation seek to analyze the predictive potential of the ROA and the NPV approach to account for farmers' investment and disinvestment behavior. In both papers, the experimental setting simulates a problem of optimal stopping, stylizing an option to

invest and disinvest in a project. The observed investment and disinvestment decisions during the incentive-compatible experiments are contrasted with normative benchmarks from the ROA and the NPV. The analysis of the two papers is similar, which may allow for a comparison of the studies. The two papers specifically differ in the framing of the experiment, the pool of subjects and sample size, the design and implementation of the experiment, as well as in the selected parameter values. For example, the first paper focuses on investment and disinvestment decisions in an agricultural context, whereas the second paper deals with investment decisions in a non-agricultural context with and without the presence of a price floor. Furthermore, in the first paper, the experiment was computer-based and conducted with a sample of German farmers, while in the second paper, the experiment was paper-based and conducted with a sample of Ugandan smallholder farmers.

2.2 Elicitation of the individual risk attitude

Risk is ubiquitous in entrepreneurial decision making, particularly for smallholder farmers in developing countries. Almost every important economic decision, such as crop selection (Price and Wetzstein 1999), technology adoption (Purvis et al. 1995), conservation intervention (Winter-Nelson and Amegbeto 1998), and crop insurance markets (Hill and Viceisza 2012), is associated with risk. Consequently, it is crucial that individual risk attitudes, their influencing factors, and different risk elicitation methods are assessed and better understood in order to design effective policy instruments in the agricultural sector as well as to offer an adequate single-farm decision support (Harrison et al. 2010; Nielsen et al. 2013).

A variety of methods has evolved to elicit and asses individual risk attitudes, which can be broadly divided into econometric and experimental approaches. Some researchers have applied econometric approaches for the estimation of individual risk attitudes (Just 1974; Antle 1989; Chavas and Holt 1996; Gardebroek 2006), whereas other researchers have used experimental approaches to elicit risk attitudes (Binswanger 1980; Holt and Laury 2002; Harrison et al. 2010; Tanaka et al. 2010; Liu 2013). One advantage of experimental to econometrical approaches is that they allow for data collection under controlled conditions and the elicitation of otherwise unobservable characteristics such as preferences and beliefs.

However, previous investigations eliciting individual risk attitudes using different experimental methods show that results may lead to diverging measures of risk attitudes (Isaac and James 2000; Andersen et al. 2006; Dave et al. 2010; Reynaud and Couture 2012). Furthermore, the problem of inconsistent response behavior has been noted in many studies, especially in a developing country context (Galarza 2009; Jacobson and Petrie 2009; Doerr et al. 2011; Engle-Warnick et al. 2011). These problems show that there is a danger that risk attitudes are not estimated correctly. Although the existing literature suggests various methods to elicit risk attitudes, a research gap persists in the comparison of different elicitation methods and in the assessment of the relative effectiveness in reducing inconsistent response behavior, in particular for data collected in developing countries among smallholder farmers.

With this in mind, the third paper of the dissertation titled '*Do Changing Probabilities or Payoffs in Lottery-Choice Experiments Affect the Results? Evidence from Rural Uganda*' analyzes two different methods for eliciting the individual risk attitude regarding the consistency of risk measures and inconsistency rates in the response behavior to answer the question of how the choice of method affects the results. Furthermore, the effect of specific socio-demographic and socio-economic factors on farmers' risk attitudes across the two elicitation methods is examined and compared with each other.

3   Outline of the dissertation

The dissertation is structured as follows: Following this introductory part, Chapter II presents the paper titled '*Does Timing Matters? A Real Options Experiment to Farmers' Investment and Disinvestment Behaviours*', which was published in the Australian Journal of Agricultural and Resource Economics. The main focus of this paper is the experimental investigation of the investment and disinvestment behavior of German farmers using an investment situation in an agricultural context.

Chapter III presents the paper titled '*Investment Behavior of Ugandan Smallholder Farmers: An Experimental Analysis*', which was published in the GlobalFood Discussion Paper Series and, which is currently under review. This paper experimentally analyzes the investment behavior of Ugandan smallholder farmers using an investment situation in a non-agricultural framing with and without the presence of a price floor.

Chapter IV presents the paper titled '*Do Changing Probabilities or Payoffs in Lottery-Choice Experiments Affect the Results? Evidence from Rural Uganda*', which was

published in the GlobalFood Discussion Paper Series and, which is currently under review as well. In this paper, two different methods for eliciting the individual risk attitude are compared regarding the consistency of risk measures and inconsistency rates in the response behavior to answer the question of how the choice of method affects the results.

Finally, Chapter V contains a summary as well as a discussion of the validity of theoretical investment models and prospects for future research on the issue of experimental investigation of investment behavior.

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Chapter II: Does Timing Matter? A Real Options Experiment to Farmers'
Investment and Disinvestment Behaviours

10

II. Does Timing Matter? A Real Options Experiment to Farmers' Investment and Disinvestment Behaviours

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Abstract

In this article, we analyse the (dis)investment behaviour of farmers in a within-subject designed experiment. We ascertain whether, and to what extent, the real options approach and the classical investment theory can predict farmers' (dis)investment behaviour. We consider a problem of optimal stopping, stylizing an option to (dis)invest in agricultural technology. Our results show that both theories do not explain exactly the observed (dis)investment behaviour. However, some evidence was found that the real options approach predicted the decision behaviour of farmers better than the classical investment theory. Moreover, we found that farmers learn from repeated investment decisions and consider the value of waiting over time. Socio-demographic and farm-specific variables also affect the (dis)investment behaviour of farmers.

Key words

Disinvestment, experimental economics, inertia, investment, real options.

1   Introduction

Globally, farmers are faced with an ever-changing environment, including changes in the climate or market prices, as well as institutional changes, leading to the need for farmers to implement strategies in order to remain viable. However, farmers' adaptations to a dynamic environment are often characterized by some kind of inertia in which farmers respond surprisingly slow to changes. Examples of such inertia have been reported in (dis)adoption studies that focused on a range of agricultural technologies, such as irrigation technology (Carey and Zilberman 2002; Seo et al. 2008), conservation intervention (Winter-Nelson and Amegbeto 1998), investment in new perennial crop varieties (Richards and Green 2003), and land conversion (Frey et al. 2013). Several reasons have been offered to explain farmers' slow response, including economic and sociological factors, such as financial constraints (Huettel et al. 2010), risk aversion (Knight et al. 2003), and non-monetary goals of the decision maker (Musshoff and Hirschauer 2008). In this context, the real options approach (ROA) – also known as the new investment theory – has been discussed as a possible alternative or an additional explanation for economic inertia (Abel and Eberly 1994; Dixit and Pindyck 1994).

The ROA evaluates uncertainty, temporal flexibility, and irreversibility in (dis)investment decision-making and generates results that can be different from the classical investment theory. The ROA states that an investor may increase profits by deferring an irreversible (dis)investment decision rather than realizing the (dis)investment immediately, even if the expected net present value (NPV) is positive. The option to postpone a decision in order to adapt to changing conditions may become quite valuable for an investor, especially when future returns of the (dis)investment are uncertain. The value of a (dis)investment is called 'options value' and consists of the intrinsic value and the value of waiting (Trigeorgis 1996, p. 124).

From the policymaker's perspective, it is imperative to understand farmers' (dis)investment behaviour in order to gain insight into the dynamics of how uncertainty affects their decision behaviour and to predict this behaviour in the future. Such understanding can contribute to an environment in which the (dis)adoption of specific agricultural technology is encouraged. Specifically, this study focuses on irrigation technology, since investment in new irrigation systems and water-saving technologies has gained increasing importance over the past decade (Brennan 2007; Seo et al. 2008).

This study is inspired by previous and current research on normative and econometric analyses of (dis)investment problems using the ROA based on field data (e.g., Luong and Tauer 2006; Hill 2010). Unfortunately, an econometric validation of the ROA is difficult for several reasons. For instance, the results of the ROA usually refer to (dis)investment triggers, which are not directly observable. Furthermore, risk aversion or financial constraints may cause farmers' reluctance to (dis)invest.

Experimental methods are a natural way to overcome these difficulties. A fundamental difference of experimental methods to econometrical analyses is that investigators can observe the decision behaviour of individuals in a controlled environment. Experimental methods allow them to study the question of interest more precisely by controlling extraneous factors which may affect individual behaviour, and thus improves internal validity (Roe and Just 2009). Studies that use experimental methods in examining the ROA to (dis)investment decisions include Yavas and Sirmans (2005), Oprea et al. (2009), Sandri et al. (2010), Musshoff et al. (2013), and Maart-Noelck and Musshoff (2013). However, these studies come to different conclusions regarding the explanatory power of the ROA. Different findings observed in (dis)investment experiments might result from the involvement of different groups of participants, in particular, as the number of participants is relatively small in each of these experiments. The question arises whether the different decision behaviour observed in previous experiments can be validated in a within-subject design. In contrast to a between-subject design, where each participant is engaged in only one treatment, in a within-subject design, each participant is exposed to more than one treatment. Thus, we obtain observations from each participant that facilitate the comparison of the different behaviour an individual shows in the different treatments and therefore results in a stronger statistical power of the research findings (Charness et al. 2012).

The main objective of this paper is to investigate the (dis)investment behaviour of farmers in a within-subject designed experiment. We ascertain whether, and to what extent, the ROA and the NPV criterion can predict farmers' (dis)investment behaviour. Moreover, we examine the effect of personal experience during the experiment and specific socio-demographic and farm-specific variables on farmers' decision behaviour. In addition, we carry out a lottery-choice experiment based on Holt and Laury (2002) to elicit farmers' risk attitudes, since risk aversion has been recognized as a major influencing factor of (dis)investment behaviour (Koundouri et al. 2006).

Our paper contributes to the extant literature by addressing the following two aspects: First, we combine investment and disinvestment decisions in one experiment using a within-subject design. (Dis)Investments represent fundamental decisions in agricultural businesses and individuals are likely to face both types of decisions, thus, a within-subject design might have more external validity. Second, to our knowledge, this is the first experimental contribution incorporating an optimal stopping framework in analyzing the timing of (dis)investment in agricultural technology and irrigation technology, in particular. This allows us to observe the effects of uncertainty and irreversibility, as well as the option to wait on an individual's (dis)investment strategy under controlled conditions compared to an econometric analysis of field data. Moreover, our paper differs from the papers by Yavas and Sirmans (2005), Oprea et al. (2009), and Sandri et al. (2010) in that a convenience sample of farmers was chosen as participants instead of students. Furthermore, their individual risk propensity was measured to determine the normative benchmark for the (dis)investment decision.

The paper is structured as follows: In section 2, the research hypotheses from the relevant literature are derived. In section 3, the design of the experiment is presented. The section 4 briefly describes the calculation of the normative benchmarks. The main experimental results are presented and discussed in section 5. The paper ends with conclusions in section 6.

2   Theory and hypotheses

The ROA considers the value of timing of the investment, while the NPV decision rule rather implies an 'either now-or-never' investment decision. According to the ROA, the expected investment returns not only have to cover the investment costs but also the opportunity costs or the profit that could be realized if the investment is postponed; that is, the investment trigger is shifted upwards (Abel and Eberly 1994; Dixit and Pindyck 1994). Similarly, the salvage value not only has to cover the project's returns, but also the opportunity costs or the profit that could be realized if the disinvestment is postponed; that is the disinvestment trigger is shifted downwards. Figure 1 stylizes (dis)investment choices derived from experimental results of various studies in relation to normative benchmarks.
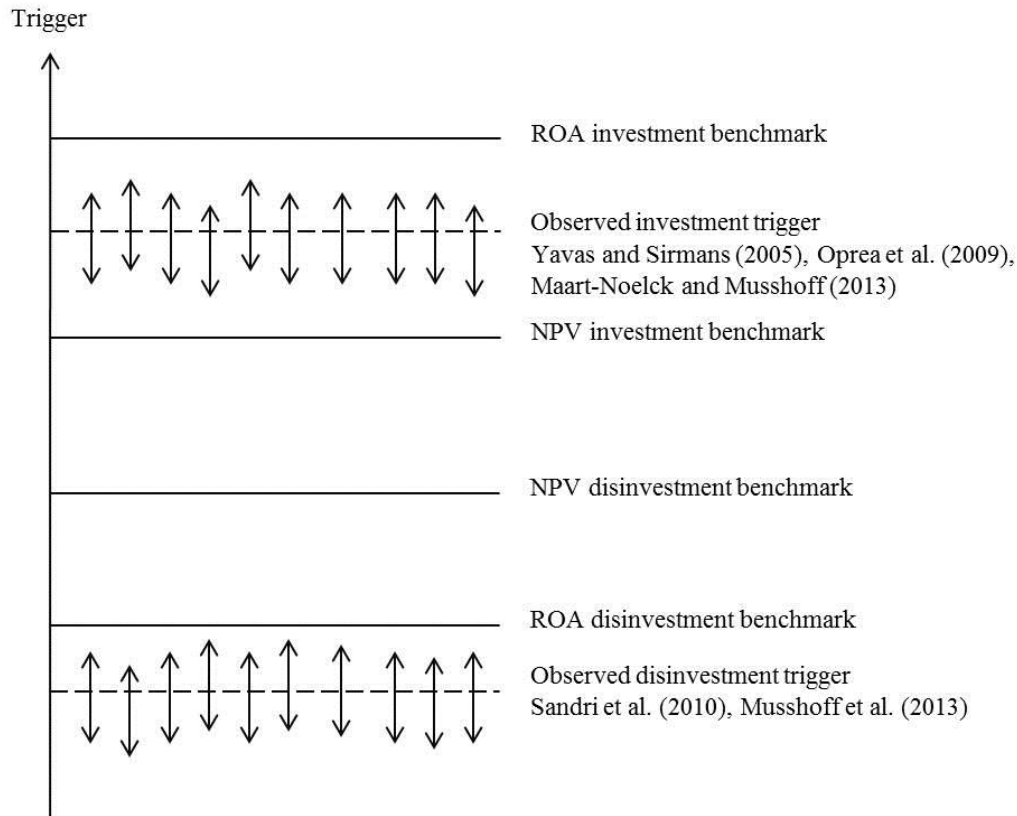
Figure 1 Stylized representation of (dis)investment choices in other experimental (dis)investment studies in relation to normative benchmarks.

Yavas and Sirmans (2005) carried out an investment experiment with 114 students and found that participants invested earlier than predicted by the ROA and thus failed to recognize the benefit of the option to wait. However, their willingness to pay for an investment included an options value when they had to compete with other investors. Another real options laboratory investment experiment with 69 students was conducted by Oprea et al. (2009) and focused on learning effects of participants. Their research revealed that participants can learn from personal experience to closely approximate optimal exercise of wait options. Maart-Noelck and Musshoff (2013) carried out an experiment with 106 farmers on the decision behaviour in a (non)-agricultural investment situation. They found that the timing of investments was not exactly predictable with the ROA or with the NPV but lied between both benchmarks. Sandri et al. (2010) experimentally compared the disinvestment behaviour of 15 high-tech entrepreneurs and 84 non-entrepreneurs (mainly students) and showed that both groups of decision makers postponed irreversible decisions, such as project termination, even if the present value of the project cash flow fell below the liquidation value and therefore rejected the NPV criterion. Decision makers tended to wait even longer than indicated by the ROA. In a recent study, Musshoff et al. (2013) experimentally analyzed the exit decision of 63 farmers using the

ROA. Their results showed that the ROA predicted the actual disinvestment decisions better than the classical investment theory. Nevertheless, the reluctance to disinvest observed in the experiment was even more pronounced than it was predicted by the theory.

These studies show that participants seem to intuitively understand the value of waiting. The actual behaviour of individuals may not be fully consistent with the predictions of investment theory, but this does not imply that theoretical investment models do not have any explanatory power to predict the decision behaviour. It is therefore pertinent to assess the performance of the ROA compared to the NPV criterion that is addressed in the following hypothesis:

H1 'ROA superiority to NPV for (dis)investment decisions': The ROA outperforms the NPV in explaining the (dis)investment behaviour of farmers.

In reality, decision makers are repeatedly faced with similar decision situations. Moreover, previous decisions can influence the decision-making process and potential future decisions. Essentially, this means that the decision behaviour is influenced by previous experiences. It stands to reason that a decision maker tends to avoid repeating past mistakes, and in the case that something positive results from a decision, the individual is more likely to reach their decision in a comparable way, given a similar situation (Camerer 2003). This phenomenon is referred to as the 'learning effect'. A series of studies using econometric approaches based on field data showed that learning can affect the behaviour of decision makers in technology adoption decisions (Cameron 1999; Baerenklau 2005). Oprea et al. (2009) carried out a laboratory experiment with students who faced multiple investment opportunities and found that subjects responded to *ex-post* errors. They tended to exercise the wait option prematurely, but over time their average investment behaviour converged close to optimum. Loewenstein (1999) pointed out that 'stationary replication' in an experiment is a useful tool to observe how people learn in repetitive situations. Furthermore, people usually face several opportunities for learning in real life. These opportunities are then recreated, to some extent, in laboratories, with replications of the task. We expect that with each repetition farmers better understand the dynamic of the development of (dis)investment returns. Thus, we formulate the following hypothesis:

H2 'learning effect for (dis)investment decisions': Farmers approximate optimal exercise of the ROA if they are given a chance to learn from personal experience in (dis)investment decisions.

Socio-demographic and farm-specific variables might also have an impact on the (dis)investment timing. We focus on specific socio-demographic variables (risk attitude, age, gender, university degree, economic background in education, and household size) and farm-specific variables (farm size, farm income type, farm type, use of irrigation, and farm performance). The selected variables are known in the literature to possibly have an influence on the (dis)investment time and are therefore considered in our analysis. Table 1 provides a summary of the variables and their impact on the (dis)investment time derived from other econometric and experimental studies.

Therefore, our last hypothesis is:

H3 'farmer-specific effects for (dis)investment decisions': Socio-demographic and farm-specific variables have a significant effect on the (dis)investment behaviour of farmers.

Table 1 Overview of socio-demographic and farm-specific variables and their impact on (dis)investment time

Variable	Study	Impact	
Socio-demographic variables			
Risk attitude	Viscusi et al. (2011)	+	Higher level of risk aversion will lead to later investment
	Sandri et al. (2010)	-	Higher level of risk aversion will lead to earlier disinvestment
Age	Gardebroek and Oude Lansink (2004)	+	Older farmers will invest later
	Pushkarskaya and Vedenov (2009)	-	Older farmers will disinvest earlier
Gender	Jianakoplos and Bernasek (1998)	+	Female farmers will invest later
	Justo and DeTienne (2008)	-	Female farmers will disinvest earlier
University degree	Gardebroek and Oude Lansink (2004)	-	A higher level of education will lead to earlier investment
	Pushkarskaya and Vedenov (2009)	-	A higher level of education will lead to earlier disinvestment
Economic background in education	DeTienne and Cardon (2006)	+/-	Economic background in education has an impact on (dis)investment decisions
Household size	Lewellen et al. (1977)	+	Farmers with a large household size will invest later
	Justo and DeTienne (2008)	-	Farmers with a large household size will disinvest earlier
Farm-specific variables			
Farm size	Savastano and Scandizzo (2009)	+	A larger size of land will lead to later investment
	Foltz (2004)	+	A larger size of land will lead to later disinvestment
Farm income type (principal income or sideline)	Adesina et al. (2000)	+/-	Farm income type has an impact on (dis)investment decisions
Farm type (crop production or other)	O'Brien et al. (2003)	+/-	Farm type has an impact on (dis)investment decisions
Use of irrigation	Carey and Zilberman (2002)	+	Farmers with irrigation will invest later
	Seo et al. (2008)	+	Farmers with irrigation will disinvest later
Farm performance	Willebrands et al. (2012)	+/-	Farm performance has an impact on (dis)investment decisions

3   Experiment

In the following, we describe the design, setting and recruitment of the participants, and the incentive design of the experiment that was conducted. Our experiment consists of four parts. The first and second parts of the experiment include two randomized treatments. These two treatments stylize the option to invest (treatment A) and disinvest (treatment B) in irrigation technology. In the third part, we use a session of Holt and Laury (2002) lotteries (HLL) to elicit the risk attitudes of farmers. In addition, we gather socio-demographic and farm-specific information to complement the experimental data in the last part of the experiment.

3.1   (Dis)Investment experiment design

In treatment A, participants could hypothetically invest in irrigation technology, whereas in treatment B, participants could hypothetically disinvest in the technology. The order in which participants were faced with the two treatments was randomly determined. Each participant was faced with 10 repetitions of the respective treatment. Within each repetition, participants should decide to realize or to postpone a (dis)investment.

Within each repetition of treatment A, participants could decide to take an ongoing investment opportunity in one of 10 years. Every participant started the experiment with a deposit of 10,000 € for each repetition, the investment cost also was 10,000 €. We assumed that the investment costs were constant over time. Furthermore, the risk-free interest rate was fixed at 10 per cent per year. The gross margin in year 0 was always 1,200 €. The gross margins evolved stochastically and followed an arithmetic Brownian motion with no drift and a standard deviation of 200 € over 10 years. According to a state- and time-discrete approximation of an arithmetic Brownian motion (Dixit and Pindyck 1994, p. 68), the gross margin in year 1 would either increase to 1,400 € with a probability of 50 per cent or decrease to 1,000 € with a probability of 50 per cent.[1] The binomial tree of potential gross margins with their associated probabilities of occurrence was displayed on a screen as shown in figure 2.

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[1] The parameter values in the (dis)investment experiment (i.e. investment cost, salvage value, gross margin, standard deviation, interest rate per year, etc.) were selected based on the decision rules according to the NPV and ROA as well as for simplification reasons of the decision situation.

Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
										3200
									3000	0.10%
								2800	0.20%	2800
							2600	0.39%	2600	0.98%
						2400	0.78%	2400	1.76%	2400
					2200	1.56%	2200	3.12%	2200	4.39%
				2000	3.12%	2000	5.47%	2000	7.03%	2000
			1800	6.25%	1800	9.38%	1800	10.94%	1800	11.72%
		1600	12.50%	1600	15.62%	1600	16.41%	1600	16.41%	1600
	1400	25.00%	1400	25.00%	1400	23.44%	1400	21.88%	1400	20.51%
1200	50.00%	1200	37.50%	1200	31.25%	1200	27.34%	1200	24.61%	1200
	1000	50.00%	1000	37.50%	1000	31.25%	1000	27.34%	1000	24.61%
	50.00%	800	37.50%	800	31.25%	800	27.34%	800	24.61%	800
		25.00%	600	25.00%	600	23.44%	600	21.88%	600	20.51%
			12.50%	400	15.62%	400	16.41%	400	16.41%	400
				6.25%	200	9.38%	200	10.94%	200	11.72%
					3.12%	0	5.47%	0	7.03%	0
						1.56%	-200	3.12%	-200	4.39%
							0.78%	-400	1.76%	-400
								0.39%	-600	0.98%
									0.20%	-800
										0.10%

Figure 2 Binomial tree of potential gross margins and associated probabilities of occurrence (treatment A).

The present values of investment returns corresponded to the gross margins, which could be earned in the respective years assuming an infinite useful lifetime of the investment object. Moreover, it was assumed that the gross margin observed in the year after the investment realization was guaranteed during the entire useful lifetime (Dixit and Pindyck 1994, see chapter 2). Therefore, the risk-free interest rate is the appropriate discount rate for determining the present value of the investment returns. Hence, an annual gross margin of 1,400 € per year resulted in a present value of 14,000 €, while an annual gross margin of 1,000 € per year resulted in a present value of 10,000 €.

In treatment A, each participant had three options: First, a participant could invest immediately, i.e. he/she paid the investment cost of 10,000 € in year 0 and received 1,400 € (= present value of 14,000 €) or 1,000 € (= present value of 10,000 €) with a probability of 50 per cent in year 1. Second, a participant could decide to postpone the investment decision and could invest at any time between year 1 and year 9. In case a participant decided not to invest in year 0, he/she would be faced again with the investment decision in year 1. It was randomly determined if the gross margin in year 1 increased or decreased starting from the value of year 0. On the screen, potential gross margin developments, which were not relevant anymore, were suppressed, and the probabilities for

future gross margins were updated. Third, a participant could choose not to invest at any point throughout the 10 years, i.e. he/she saved the investment cost of 10,000 €. The deposit and the present value of the investment returns minus the investment cost realized before year 10 increased by the risk-free interest rate of 10 per cent for every year left in the tree.

Similar to treatment A, participants could decide to take an ongoing disinvestment opportunity in one of 10 years within each repetition of treatment B. Instead of investment cost, we have a salvage value of the irrigation system equal to 5,000 € (constant over time). The binomial tree of potential gross margins always started with 400 € in year 0. The other parameters were identical to treatment A. The binomial tree of potential gross margins with their associated probabilities of occurrence was displayed on a screen as shown in figure 3.

Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
										2400
									2200	0.10%
								2000	0.20%	2000
							1800	0.39%	1800	0.98%
						1600	0.78%	1600	1.76%	1600
					1400	1.56%	1400	3.12%	1400	4.39%
				1200	3.12%	1200	5.47%	1200	7.03%	1200
			1000	6.25%	1000	9.38%	1000	10.94%	1000	11.72%
		800	12.50%	800	15.62%	800	16.41%	800	16.41%	800
	600	25.00%	600	25.00%	600	23.44%	600	21.88%	600	20.51%
400	50.00%	400	37.50%	400	31.25%	400	27.34%	400	24.61%	400
	200	50.00%	200	37.50%	200	31.25%	200	27.34%	200	24.61%
	50.00%	0	37.50%	0	31.25%	0	27.34%	0	24.61%	0
		25.00%	-200	25.00%	-200	23.44%	-200	21.88%	-200	20.51%
			12.50%	-400	15.62%	-400	16.41%	-400	16.41%	-400
				6.25%	-600	9.38%	-600	10.94%	-600	11.72%
					3.12%	-800	5.47%	-800	7.03%	-800
						1.56%	-1000	3.12%	-1000	4.39%
							0.78%	-1200	1.76%	-1200
								0.39%	-1400	0.98%
									0.20%	-1600
										0.10%

Figure 3 Binomial tree of potential gross margins and associated probabilities of occurrence (treatment B).

In treatment B, each participant had three options: First, a participant could disinvest immediately in year 0, i.e. he/she received the initial gross margin of 400 € and the salvage value of 5,000 €. Second, a participant could decide to postpone the disinvestment decision and could disinvest at any time between year 1 and year 9, i.e. he/she received the gross margins of the respective years until the year he/she decided to disinvest as well as the salvage value in the disinvestment year. Third, a participant could choose not to disinvest

at any point throughout the 10 years, i.e. he/she received the gross margins of the respective years and the present value of future returns in year 10 assuming an infinite useful lifetime and an interest rate of 10 per cent. The realized gross margins and the realized salvage value increased by the risk-free interest rate of 10 per cent for every year left in the tree.

3.2 Lottery-choice experiment design

In the third part of the experiment, an HLL session was carried out in which participants made a series of 10 choices between two systematically varied alternatives (Holt and Laury 2002). Table 2 shows an extract of the choice situations the participants faced in this lottery. The earnings are held constant across the decision tasks, whereas the probabilities of the earnings vary in intervals of 10 per cent between the decision tasks. In the first row, alternative 1 (the safe alternative), offers the chance to either win 600 € with a probability of 10 per cent or 480 € with a probability of 90 per cent, while alternative 2 (the risky alternative) offers the chance to win 1,155 € or 30 € with the same probabilities as in alternative 1. In the second row, the probabilities raise to 20 per cent and 80 per cent, and so on. The last row is a test of whether the participants understand the experiment. Here obviously alternative 2 dominates over alternative 1 as it yields a secure earning of 1,155 €.

Table 2 Payoff matrix of the Holt and Laury lottery[*]

	Alternative 1 (A_1)	Alternative 2 (A_2)	Expected value		Critical constant relative risk aversion coefficient[†]
			A_1	A_2	
1	with 10% gain of 600 € with 90% gain of 480 €	with 10% gain of 1155 € with 90% gain of 30 €	492 €	142.5 €	-1.71
2	with 20% gain of 600 € with 80% gain of 480 €	with 20% gain of 1155 € with 80% gain of 30 €	504 €	255 €	-0.95
…	…	…	…	…	…
9	with 90% gain of 600 € with 10% gain of 480 €	with 90% gain of 1155 € with 10% gain of 30 €	588 €	1042.5 €	1.00
10	with 100% gain of 600 € with 0% gain of 480 €	with 100% gain of 1155 € with 0% gain of 30 €	600 €	1155 €	-

Notes: [*]The last three columns were not displayed in the experiment. [†]A power risk utility function is assumed.

The expected values of the alternatives change as participants move from one to the next decision task. The switching point from the safe to the risky alternative allows us to determine the individual risk attitude. A HLL-value (= number of safe choices) between one and three expresses risk preference, a HLL-value of four implies risk neutrality, and a HLL-value between five and 10 expresses risk aversion of the participant.

3.3 Experiment setting, recruitment and incentive design

The computer-based experiment was conducted at the leading German agricultural exhibition 'Agritechnica' in November 2011. In the course of five days, farmers could participate in our experiment which was carried out at a separate stand of the university equipped with tables, chairs and computers. Each experiment consisted of instruction, practice, decision-making, and payment. Participants had to silently read a set of instructions displayed on a computer screen. They were informed about all parameters and assumptions underlying the experiment. Before the experiment started, all participants had to answer some control questions to ensure that they completely understood the instructions. This required careful reading of the instructions for which participants spent a considerable amount of time. Participants also played a trial round to become familiar with the (dis)investment experiment. In the entire experiment, participants were not provided with the optimal (dis)investment strategy according to the NPV and ROA; they rather decided on an intuitive basis, however they were allowed to use a calculator. In each repetition of the game, a participant should try to collect as many € as possible because his/her potential earnings were proportional to the number of € he/she collected during the game. Our overall impression was that the formulation of the instructions was well understood by the participants, which was supported by the fact that no problems arose during the answering process of the control questions. In Appendix 1 (see supplementary material available at AJARE online), we present a translated English version of the instructions for the experiment which were originally submitted to the participants in German. The experiment was followed by a questionnaire that collected information on socio-demographic and farm-specific characteristics. The main variables collected through the questionnaire were age, gender, university degree, economic background in education, household size, farm size, farm income type, farm type, use of irrigation, and farm performance.

Participation in our experiment was voluntary. Farmers were recruited during the exhibition by personally asking for their participation in a (dis)investment game in which

they have to make hypothetical decisions on a computer and for which they have the chance to win money in addition to a fixed show-up payment. In total, we spoke to approximately 500 randomly selected farmers of which 135 participated in our experiment.[2] The overall aim was to recruit around 125 farmers with an acceptable deviation of 10 per cent. The entry criterion to participate in our experiment was being an agricultural entrepreneur or farmer at the time of the survey. Most of the participants in the experiment were decision makers within their own farm business, farm managers or supervisors. However, some younger participants were farm successors. These groups are those most likely to be faced with important economic decisions related to the farm business. In the experiment, choices made by participants were not time constrained. For the completion of the experiment, participants needed on average 45 minutes and ranged from 25 to 63 minutes. All participants received a show-up fee of 10 € as a compensation for their time. The hypothetical decisions in the (dis)investment treatment and in the HLL were related to real earnings to ensure incentive compatibility of the experiment and to motivate participants to take the tasks more seriously.

There is an ongoing controversial debate on the use of monetary incentives as rewards for participants in experiments and the practice of paying only some participants for only some of their decisions. Camerer and Hogarth (1999) found that using high financial incentives for a fraction of participants rather than providing small incentives for each of the participants often improved participants' performance during the experiment. We randomly chose one participant for payment for each of the experimental parts of our payment design; hence we had three winners in total. The earnings of two participants for the (dis)investment experiment were based on their individual scores attained on one randomly chosen repetition of the respective treatment. The winner received 100 € cash for each 2,500 € achieved in the selected repetition. The potential earnings varied between 270 € and 1,900 € for the investment treatment and between 0 € and 1,900 € for the disinvestment treatment. Following the optimal (dis)investment benchmarks ensured a maximum payoff. If a participant's decision behaviour deviated from the optimal benchmarks, he/she received a lower payoff. The earning of the participant from the lottery-choice experiment was based on his/her preference expressed between various mutually exclusive alternatives. We randomly chose one decision task for payment. The potential earning varied between 30 € and 1,155 €.

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[2] However, three participants were excluded from the analysis. They stopped the experiment and thus, did not complete it.

4   Normative benchmarks

For the evaluation of the observed (dis)investment behaviour in the experiment, we have to derive normative benchmarks which reflect the NPV and the ROA, respectively. We calculate the (dis)investment triggers of the NPV and the ROA, which mark the threshold levels on which it is optimal to (dis)invest. The (dis)investment triggers following the NPV can be directly determined respectively via annualizing the investment costs and the salvage value. In contrast, the (dis)investment triggers of the ROA have to be calculated by dynamic stochastic programming (Trigeorgis 1996, p. 312). Figure 4 illustrates the normative benchmarks of the (dis)investment for a risk neutral decision maker according to the NPV and the ROA. Appendix 2 analytically and numerically describes the derivation of the normative benchmark for the last two investment periods.
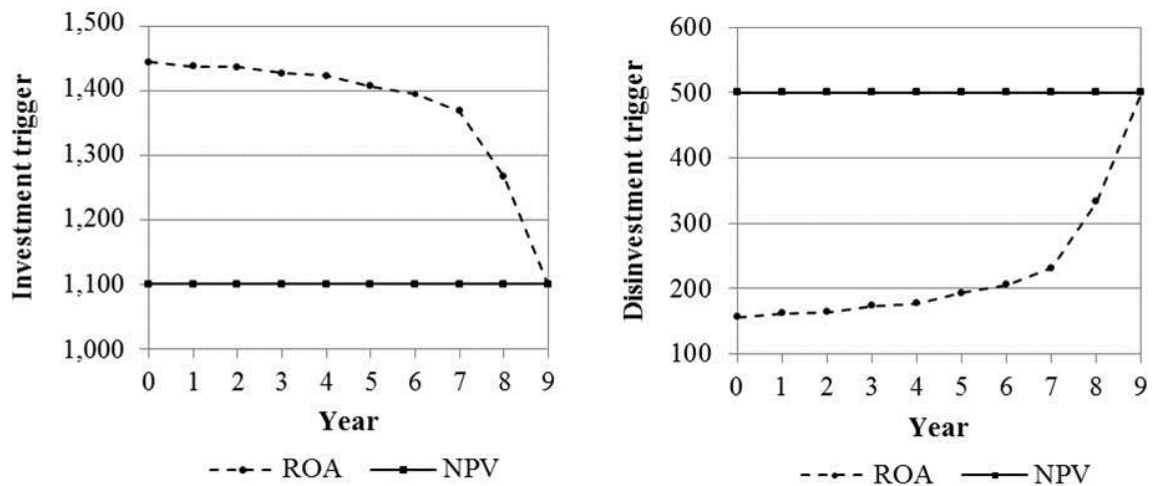
Figure 4 Investment (left figure) and disinvestment (right figure) triggers for a risk-neutral decision maker (in €).

The investment triggers of the ROA decrease exponentially reflecting the diminishing time value of the investment option. In turn, the disinvestment triggers of the ROA increase exponentially reflecting the diminishing time value of the disinvestment option. The trigger values start in year 0 at 1,444 € and 166 € for the investment and the disinvestment treatment, respectively. The curves coincide with the NPV at 1,100 € and 500 € at year 9, respectively. That means that the (dis)investment option expired in year 9, and thus there was no more time to postpone the decision. The (dis)investment triggers of the NPV are constant over time.

Moreover, we determine the normative benchmark for the (dis)investment decisions, while considering the individual risk attitude shown by the participants in the HLL. On the basis

of the results from the HLL, the respective risk-adjusted discount rates are determined. For each extent of risk attitude, the normative benchmark has to be determined. The HLL consists of nine decision situations and one control situation, thus nine HLL-values are derived. For each HLL-value, a normative benchmark is computed for the NPV and ROA and for both treatments. The relevant normative benchmark for the specific situation (i.e. NPV or ROA and investment or disinvestment treatment) and for the individual risk attitude of the participant is chosen and compared with the actual path of the binomial tree. The relevant normative benchmark indicates the trigger, i.e. from which gross margin it would be optimal to realize the (dis)investment. Appendix 3 formally describes the determination of the risk-adjusted discount rate.

5   Results and discussion

In the following subsections, we present the descriptive statistics and test the validity of our hypotheses derived in section 2. The data analysis is based on the Kaplan-Meier survival estimator (Kaplan and Meier 1958) and a Tobit model (Tobin, 1958). These methods specifically deal with censoring, which is prevalent in the analysis of duration data.

5.1   Descriptive statistics

Table 3 presents some descriptive statistics on the individuals who participated in the experiment as well as an overview of the normatively expected and observed (dis)investment decision behaviour exhibited during the experiment.

As it can be seen from the table, on average, the participants were slightly risk averse (HLL-value = 5.2). Although, 82 out of 135 participants revealed risk aversion, 29 were risk neutral and 24 were risk seeking. Participants' average age was 32.1 years, ranging from 19 to 61 years. The participating farmers were relatively young, possibly expected by their participation in a computer-based experiment. About 22.2 per cent of the participants were female, 51.1 per cent had a university degree and 39.3 per cent had an economic background in education. The average household size was 3.6 persons. The average farm size was 228.9 ha, ranging from 0.13 ha to 3,600 ha. About 65.5 per cent of the participants indicated farming as their main income source and 77.0 per cent of the participants were mainly engaged in crop production. About 17.8 per cent of the participants indicated irrigation use. The majority of the farmers, about 90.3 per cent had a rather positive perception about irrigation based on an evaluation of the statement that

irrigation contributes to stable yields and consistent quality of agricultural and horticultural crops. We also asked farmers to assess the performance of their business using a 100-point scale from 0 to 100 (lower performance to higher performance). On average, they ranked their farm business at 62.5 on the scale. However, we have to consider that it is a subjective indicator for the economic condition of the individual farm.

Table 3 Descriptive statistics

Parameter	Treatment A (investment) with 1350 decisions	Treatment B (disinvestment) with 1350 decisions
Socio-demographic and farm-specific variables		
Average risk attitude of a farmer (HLL-value) [*]	5.2 (2.0)	
Average age of farmers (years)	32.1 (11.9)	
Female farmers (%)	22.2	
Farmers with university degree (%)	51.1	
Farmers with economic background in education (%)	39.3	
Household size	3.6 (1.9)	
Average farm size (ha)	228.9 (452.4)	
Principal-income farmers (%)	65.9	
Crop producers (%)	77.0	
Use of irrigation (%)	17.8	
Farm performance (scale from 0 to 100 points)	62.5 (27.1)	
(Dis)Investment behaviour		
Experimentally observed year of (dis)investment without repetitions of non-(dis)investment	3.0 (2.8)	4.0 (2.9)
Experimentally observed percentage of repetitions with non-(dis)investment (%)	20.2	25.3
Normative (dis)investment year following net present Value (NPV) without repetitions of non-(dis)investment	0.0 (0.0)	0.2 (0.8)
Normative percentage of repetitions with non-(dis)investment following NPV (%)	0.0	0.0
Normative (dis)investment year following real options approach (ROA) without repetitions of non-(dis)investment	4.3 (2.4)	3.2 (2.6)
Normative percentage of repetitions with non-(dis)investment following ROA (%)	37.7	28.2

Notes: Standard deviations are indicated in parentheses. [*]A HLL-value between 0 and 3 expresses risk preference, a HLL-value of 4 implies risk neutrality, and a HLL-value between 5 and 9 expresses risk aversion.

The observed investment and disinvestment time chosen by the participants was on average year 3.0 and year 4.0, respectively. These figures do not take into account repetitions with non-(dis)investment. In 20.2 per cent and 25.3 per cent of the repetitions, participants chose not to invest or to disinvest, respectively. Normative benchmarks derived for the NPV and the ROA were applied to 2,700 random realizations (2 treatments

times 10 repetitions times 135 participants) of an arithmetic Brownian motion generated during the experiment. The average optimal investment and disinvestment time according to the NPV is 0.0 and 0.2, respectively. Following the ROA, the optimal investment and disinvestment time is 4.3 and 3.2, respectively, with non-investment and non-disinvestment in 37.7 per cent and 28.2 per cent of the cases.

## 5.2 Test of H1 'ROA superiority to NPV'

To test *H1*, we compare the observed (dis)investment behaviour with the benchmark prediction according to the NPV and the ROA. Table 4 shows the hit ratio of the observed behaviour and the (dis)investment benchmarks. In treatment A, in 25 per cent of the cases participants invested as predicted by the NPV, while in 16.2 per cent of the cases participants invested optimally according to the ROA. In treatment B, in 12.4 per cent of the cases, participants decided in accordance with the NPV, while in 15.8 per cent of the cases, participants disinvested as predicted by the ROA. In most cases, farmers (dis)invested later than predicted by the NPV. A more balanced ratio between earlier and later (dis)investments is observed by following the ROA rather than following the NPV. This is already an initial indication for the validity of *H1*.

Table 4 Hit ratio of the observed behaviour and (dis)investment benchmarks

Parameter	Treatment A (investment) with 1350 decisions (%)	Treatment B (disinvestment) with 1350 decisions (%)
Earlier (dis)investment than predicted by the net present value (NPV)	0.0	1.5
Optimal (dis)investment as predicted by the NPV	25.0	12.4
Later (dis)investment than predicted by the NPV	75.0	86.1
Earlier (dis)investment than predicted by the real options approach (ROA)	58.6	37.9
Optimal (dis)investment as predicted by the ROA	16.2	15.8
Later (dis)investment than predicted by the ROA	25.2	46.3

For further testing *H1*, we apply the Kaplan-Meier survival estimator, also referred to as the product limit estimator (Kaplan and Meier 1958), as modified by Kiefer (1988) to deal with censored data. Figure 5 shows the survival functions of the Kaplan-Meier estimation of the observed and the optimal (dis)investment decision-making according to the NPV

and the ROA. The staircase-shaped curves illustrate the cumulative option exercise over the years. It indicates the percentage of (dis)investments realized per year. A log-rank test of the equality of the survival functions shows that there is a statistically significant difference between the observed (dis)investment decisions and the normative benchmarks according to the NPV and the ROA (p-value < 0.001). Based on this finding, we conclude that neither the NPV nor the ROA provides an accurate prediction of the experimentally observed (dis)investment behaviour of farmers.
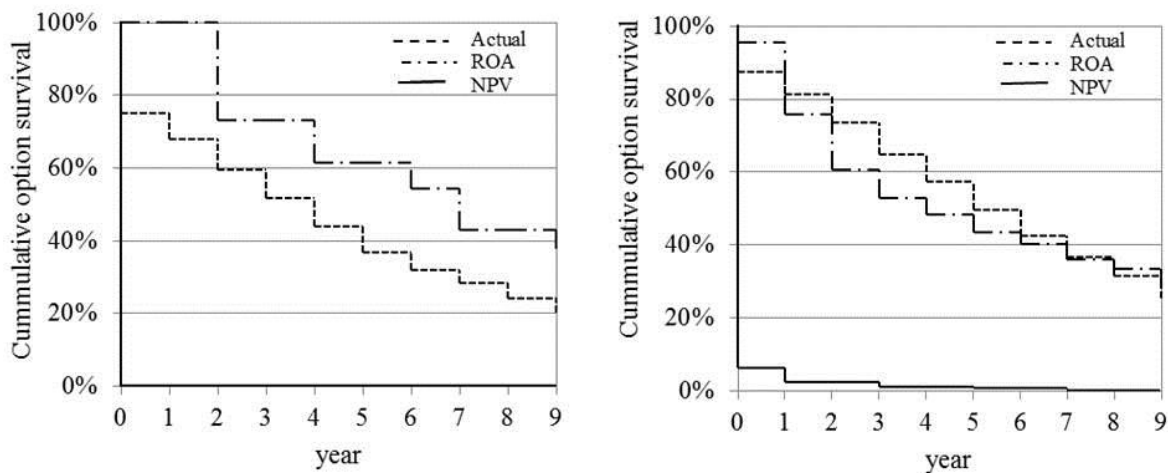
Figure 5 Survival functions of observed and optimal investment (left figure) and disinvestment (right figure) decision-making according to the net present value and the real options approach.

In left graph, the curve of the decision behaviour observed is below that of the optimal decision behaviour according to the ROA and above the curve of the optimal decision behaviour according to the NPV throughout the time. That means that farmers invest later than predicted by the NPV but earlier than suggested by the ROA. In right graph, the curve of the decision behaviour observed is above the curve of the optimal decision behaviour according to the ROA and the NPV during most of the time. It means that farmers disinvest later than predicted by the NPV and the ROA. In both graphs, the curve of the observed decision behaviour is closer to the optimal decision behaviour according to the ROA, meaning that farmers (dis)invest more in accordance with the ROA. With this in mind, we fail to reject *H1*. Our results suggest that the ROA is able to predict actual (dis)investment decisions better than the NPV. Nevertheless, the observed disinvestment reluctance is even more pronounced than predicted by the ROA. These findings are consistent with previous investigations (Oprea et al. 2009; Sandri et al. 2010; Musshoff et al. 2013; Maart-Noelck and Musshoff 2013).

5.3   Test of H2 'learning effect' and H3 'farmer-specific effects'

To test *H2* and *H3*, we run a Tobit regression for each treatment with the individual (dis)investment year of farmers as the dependent variable. A Tobit model (Tobin 1958) is used to estimate linear relationships between variables if the dependent variable is censored as is the case in our study. The time of (dis)investment could only be observed if it falls between zero and nine. The results are presented in Table 5.

In our experiment, each farmer repeated treatment A and treatment B 10 times, so that in each case, farmers had 10 times the option to (dis)invest or not to (dis)invest. Thus, the variable 'repetition' can take a value between 1 and 10. In treatment A, the estimated coefficient of the 'repetition' variable is significant and has a positive sign (p-value < 0.001), meaning that with each repetition of the investment treatment, farmers invest 0.169 years later. This implies that they learn from their experiences of previous investment decisions. Although participants approximate the ROA in later repetitions, their investment behaviour still does not exactly follow an optimal manner. This result confirms previous findings of Oprea et al. (2009). The estimated coefficient of the variable 'repetition' in treatment B is not significant at 5 per cent (p-value = 0.071). Farmers do not approximate the predictions of the ROA over time, but they also do not further deviate from the ROA benchmark. On this basis, we fail to reject *H2* in terms of investment and we reject *H2* in terms of disinvestment.

In the experiment, we examined the presence of an 'order effect'. Farmers were faced with both treatments in a different order, so that some were first faced with the investment treatment and then with the disinvestment treatment or vice versa. According to Scheufele and Bennett (2013), repeated choice tasks may influence outcomes through order effects. The estimated coefficient of the 'order' variable is significant in both treatments, which shows that farmers demonstrate different (dis)investment behaviour dependent on the order in which they are faced with the two treatments. However, it may also indicate a 'learning effect', meaning that farmers acquire routines for repetitive decisions at the beginning of the experiment and apply them to later decisions even if they are related to another treatment.

Table 5 Results of the Tobit regression of the individual (dis)investment year (N = 2700)

Parameter	Treatment A (investment)			Treatment B (disinvestment)		
	Coefficient	p-value		Coefficient	p-value	
Constant	8.324 (0.807)	<0.000	**	7.184 (0.806)	<0.000	**
Repetition (1-10 repetitions)	0.169 (0.043)	0.000	**	0.081 (0.045)	0.071	
Order (1: first A or B, 0: second A or B)	-1.682 (0.256)	<0.000	**	0.713 (0.265)	0.007	**
Risk attitude (HLL-value between 0 and 10)	-0.177 (0.065)	0.006	**	-0.202 (0.068)	0.003	**
Age	-0.051 (0.011)	<0.000	**	-0.036 (0.012)	0.003	**
Gender (1: male, 0: female)	-0.083 (0.323)	0.798		-0.908 (0.331)	0.006	**
University degree (1: yes, 0: no)	0.133 (0.271)	0.623		0.285 (0.280)	0.308	
Economic background in education (1: yes, 0: no)	0.679 (0.271)	0.012	*	0.872 (0.277)	0.002	**
Household size	-0.309 (0.075)	0.000	**	-0.066 (0.074)	0.371	
Farm size (ha)	0.001 (0.000)	0.000	**	0.001 (0.000)	0.006	**
Farm income type (1: principal income, 0: sideline)	-0.059 (0.305)	0.848		0.057 (0.309)	0.854	
Farm type (1: crop production, 0: other)	-0.252 (0.267)	0.344		0.185 (0.275)	0.502	
Irrigation use (1: yes, 0: no)	0.225 (0.357)	0.530		-0.211 (0.368)	0.566	
Farm performance (0-100 scale)	-0.005 (0.005)	0.346		0.009 (0.005)	0.071	
Log Likelihood	-3293			-3165		
Chi^2	145			86		

Notes: Asterisk * and double asterisk ** denote variables significant at 5 and 1 per cent, respectively.
Standard errors are indicated in parentheses.

In treatment A, the estimated coefficients of the variables 'risk attitude', 'age', and 'household size' are significant and have a negative sign, while the variables 'economic background in education' and 'farm size' are significant and have a positive sign. That means that more risk averse farmers, older farmers and farmers with a larger number of family members invest earlier, whereas farmers with an economic background in education and with a larger amount of farmland invest later and therefore more in accordance with the ROA. In treatment B, the estimated coefficients of the variables 'risk attitude', 'age', and 'gender' are significant and have a negative sign, while the variables 'economic background in education' and 'farm size' are significant and have a positive sign. This implies that more risk averse farmers, older farmers, and male participants disinvest earlier

and therefore more in accordance with the ROA, whereas farmers with an economic background in education and who own a larger amount of farmland disinvest later. In contrast to the investigations of Adesina et al. (2000), Carey and Zilberman (2002), O'Brien et al. (2003), Gardebroek and Oude Lansink (2004), Seo et al. (2008), Pushkarskaya and Vedenov (2009), and Willebrands et al. (2012), the variables 'farm income type', 'irrigation use', 'farm type', 'university degree', and 'farm performance' do not appear to affect (dis)investment decisions significantly. The non-significance of the variable 'irrigation use' may indicate that our results are not considerably influenced by the framing of our experiment. The findings of the variables 'risk attitude' and 'age' in respect to disinvestment and the variable 'farm size' regarding to both treatments confirm our expectations (Foltz 2004; Pushkarskaya and Vedenov 2009; Savastano and Scandizzo 2009; Sandri et al. 2010). It is revealed that farmers with an economic background in education result in later (dis)investment timing. It may indicate that farmers who have better information through their economic background in education put a higher value on the option to wait and, for this reason, (dis)invest later than less informed farmers. In both treatments, risk is found to play a role in the decision to (dis)invest in irrigation technology. However, it is surprising that risk averse farmers invest earlier, which is contradictory to our expectation that higher levels of individual risk aversion lead to later investment (Viscusi et al. 2011). A possible explanation for this behaviour may be that more risk averse farmers consider irrigation as a risk management instrument and, therefore, invest earlier than the less risk averse farmers. It is interesting to note that older farmers invest earlier, which might be explained by the fact that the participating farmers were relatively young with an average age of 32.1 years. Based on the literature, older farmers are expected to be less eager to invest in new technology (Gardebroek and Oude Lansink 2004). As many studies find that women invest later than men (Jianakoplos and Bernasek 1998), interestingly, there is no significant effect of the variable 'gender'. Moreover, men were found to disinvest earlier than women, while farmers with a larger household size were found to invest earlier, which does not support the findings of previous studies (Lewellen et al. 1977; Justo and DeTienne 2008). Based on the overall results, we fail to reject *H3*.

6   Conclusions

A better understanding of farmers' decision to (dis)invest in agricultural technology under uncertainty is crucial for gaining insight into the dynamics of adoption and abandonment behaviour, interpreting agricultural outcomes, and designing policies that effectively assist farmers. This study examined the (dis)investment behaviour of farmers under flexibility, uncertainty, and irreversibility, while trying to determine the underlying models of investment consistent with the observed decision behaviour during an experiment. The (dis)investment decisions were modeled as real options, which refer to the rights to acquire and to sell irrigation technology. The observed (dis)investment decisions were contrasted with normative benchmarks, which were derived from the NPV and the ROA.

Our findings were first that neither the NPV nor the ROA provided an exact prediction of farmers' (dis)investment behaviour observed in the experiment. Farmers invested later than predicted by the NPV but earlier than suggested by the ROA. Regarding the disinvestment situation, farmers disinvested later than predicted by the NPV and even later than suggested by the ROA. The results also suggested that the ROA can predict actual (dis)investment decisions better than the NPV. Second, we found that farmers accumulated knowledge through repeated decision-making in investment situations, and hence approximated the predictions of the ROA, but did not further deviate from the ROA benchmark in disinvestment situations. Third, we found that certain socio-demographic and farm-specific variables affected the (dis)investment behaviour of farmers.

When interpreting the results, it is important to take into account that our experimental design is abstracted from reality and is considerably simpler than (dis)investment situations that would occur in an actual business setting. Participants may behave differently in the experimental situation than they do in a similar situation in the real world. Decision makers who are faced with real (dis)investment problems (e.g. technology adoption and abandonment) often have multiple objectives, and they require more time to prepare and to make these far-reaching decisions. An individual's decision behaviour can also be affected by perceptions and beliefs based on available information and can be influenced by attitudes, motives and preferences (McFadden 1999). A common criticism of experiments has to do with whether experimental results are likely to provide reliable inferences outside the laboratory and can be extrapolated to the real world (Levitt and List 2007; Roe and Just 2009). This lack of external validity is considered to be the major weakness of laboratory experiments (Loewenstein 1999). Framing might help render a laboratory experiment more

realistic and, thereby, increase its external validity. Several studies discuss the relevance of framing effects on choices given the fact that decision makers might be more 'attached' to a project that is described in terms that are more familiar to them (Cronk and Wasielewski 2008; Patel and Fiet 2010). Actually, there is an intensive debate on the trade-off between the internal and external validity of economic experiments (Camerer, 2003; Guala, 2005). However, there is a widespread consensus that the benefits of internal validity are more important than the lack of external validity if the experiments aim to test economic theories, as is the case in our study (see Schram 2005).

The general implication from this experimental analysis is that flexibility, uncertainty, and irreversibility play a role in farmers' decision-making process to adopt and abandon irrigation technology. This is extremely relevant from a policy maker's perspective. It highlights the danger of designing policy measures solely based on the NPV given that this approach is not individually sufficient in order to explain (dis)investment decisions. The NPV fails to address the role of sunk costs, temporal flexibility, and uncertainty in the farmer's decision-making process. However, it also is not sufficient to solely focus on the ROA when designing appropriate policy measures, since socio-demographic and socio-economic factors also play a role. Policies that allow farmers to be more certain of future returns or practices that can reduce the uncertainty might encourage a more responsive (dis)investment strategy, regardless of the decision makers' risk attitude. This is particularly relevant if there are public and environmental benefits arising from the adoption of new technologies, such as water-saving technologies and technologies to reduce land salinity. Policy measures, such as subsidies, might improve the adoption of more efficient water-saving practices and technologies. However, this also implies that under uncertainty, the rates of subsidy, which are required to encourage faster uptake of water-saving technologies are likely to be higher than those indicated by the NPV criterion. In addition, it is a challenge for policy makers to consider the effects of certain socio-demographic and farm-specific characteristics on (dis)investment behaviour in the course of the current socio-demographic change in many countries. One example, which might be relevant for (dis)investment decisions, is the ageing of the population. Ageing may change decision makers' (dis)investment behaviour. An understanding of the (dis)investment decisions taken by farmers is therefore important for the formulation of adequate forecasts and policy recommendations in the agricultural sector.

The experimental investigation of real options settings is still in its early stages. In this regard, further research is required for a better understanding of what exactly drives an individual's decision-making in (dis)investment situations and to predict this behaviour in the future. It is possible that potential drivers of psychological inertia also play a role when explaining (dis)investment behaviour. Furthermore, it would be interesting to reveal the heuristics, which participants apply in order to make (dis)investment decisions. Another interesting research avenue would be the testing of whether farmers in developing countries show a similar (dis)investment behaviour as farmers in developed countries.

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Appendix S1: Experimental instructions

Translation from German; Instructions for (dis)investment in irrigation technology

General information

[…] The game consists of four parts and would require approximately 45 minutes of your time. Please read the following instructions carefully as your earnings in the experiment will depend on your decisions. Of course, your data will be treated as confidential and will be analyzed anonymously. […]

In each game, you should try to collect as many Euros (€) as possible because your potential earnings are proportional to the number of Euros (€) you collect during the game. Besides an expense allowance of 10 €, each participant has three times the chance to receive a bonus if he/she completes the entire game. In the first and second parts of the game, one player is randomly selected and is given 100 € cash per 2,500 € achieved in a randomly selected round. The selected players for both parts will, therefore, receive between 270 € and 1,900 € as well as between 0 € and 1,900 €, respectively. In the third part of the game, again one player is randomly selected and is given a cash bonus of between 30 € and 1,155 €. In total, around 125 farmers can participate in the game. They will be informed via e-mail by December 10, 2011 if they receive one of the three cash bonuses in addition to the expense allowance. The earnings can be paid out or transferred to an account specified by the player selected.

Good luck!

Please note that submitted decisions during the game cannot be changed.

First part (instruction: treatment A (investment))

The game consists of various repetitions of one game with an equal basic structure.

Imagine that you as a farmer have liquid assets of 10,000 € at your disposal. Due to the ongoing phenomenon of global warming, the climate changes, which has an increasingly noticeable impact on agricultural production. Therefore, you are considering purchasing an irrigation system. In the time frame between 0 and 9 years, you can invest in an irrigation system only once. You can decide within the next 10 years:

- to immediately invest in an irrigation system
- to wait and see the development of the gross margins that can potentially be achieved (up to 10 years) and to invest in an irrigation system later
- or not to invest in an irrigation system.

The liquid assets you dispose of in your account in a given year will yield an interest rate of 10 per cent meaning that they will increase by a tenth of their value. For example, if you do not decide to invest in an irrigation system within the 10 years (between year 0 and year 9), your chance to invest expires and you will leave the game with your starting credit of 10,000 € that has increased to 25,937 € over the 10 years. In case this game would be randomly selected for the cash premium, you would receive 1,038 € (= 25,937 € : 2,500 € · 100 €).

If you decide to invest in an irrigation system you have to pay 10,000 €. It is assumed that the gross margin observed at the time of investment is guaranteed by an infinite useful lifetime of the investment object.

The gross margin corresponds to the present value of investment returns, which can be achieved at the respective time of investment assuming an infinite useful lifetime of the investment object. A gross margin of 1,200 € and year would then result in a present value of 12,000 € (= 1,200 € · 10), while a gross margin of 1,400 € and year would result in a present value of 14,000 € (= 1,400 € · 10), etc.
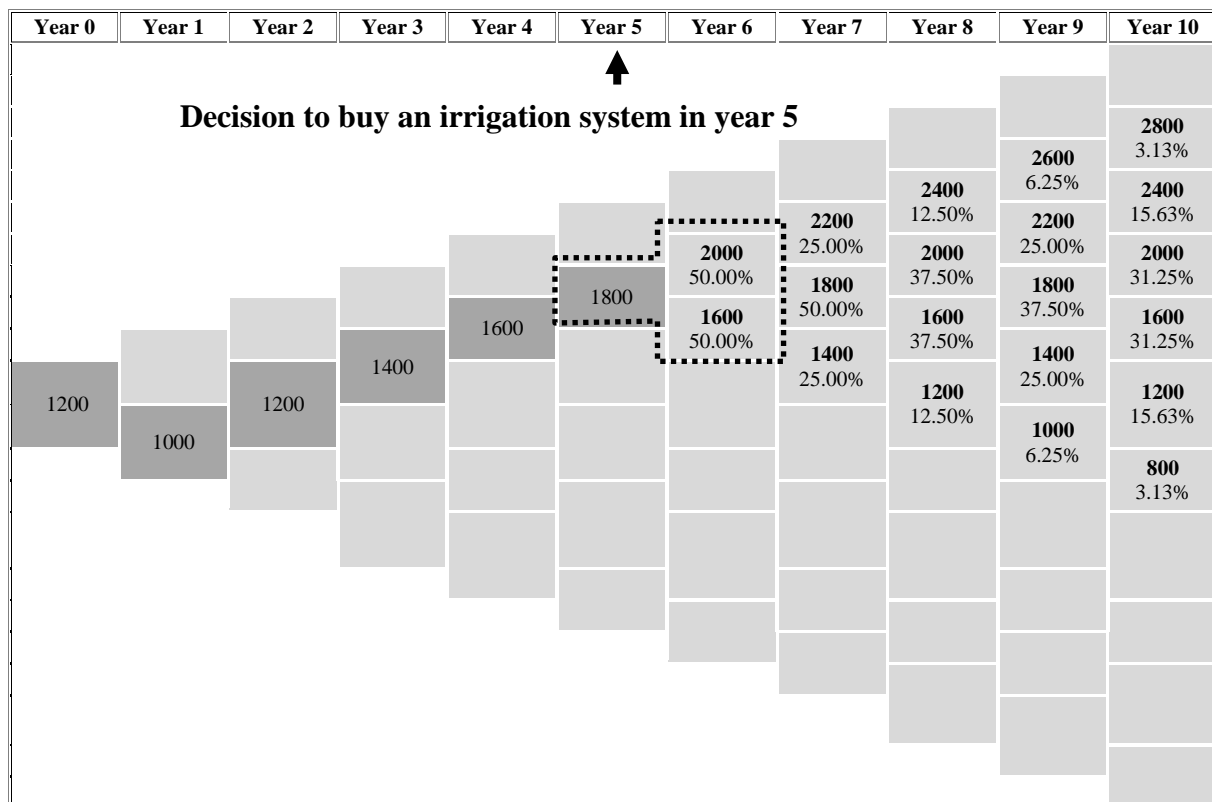
The tree chart below shows the possible gross margins of the investment that you can earn in the respective years when investing in an irrigation system. The tree chart starts with a gross margin of 1,200 € in year 0. Starting from this initial value, the gross margin of the following years increases or decreases by 200 €. The probability of the occurrence of the gross margin in each year is indicated under the gross margin.

Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
										3200 / 0.10%
									3000 / 0.20%	
								2800 / 0.39%		2800 / 0.98%
							2600 / 0.78%		2600 / 1.76%	
						2400 / 1.56%		2400 / 3.12%		2400 / 4.39%
					2200 / 3.12%		2200 / 5.47%		2200 / 7.03%	
				2000 / 6.25%		2000 / 9.38%		2000 / 10.94%		2000 / 11.72%
			1800 / 12.50%		1800 / 15.62%		1800 / 16.41%		1800 / 16.41%	
		1600 / 25.00%		1600 / 25.00%		1600 / 23.44%		1600 / 21.88%		1600 / 20.51%
	1400 / 50.00%		1400 / 37.50%		1400 / 31.25%		1400 / 27.34%		1400 / 24.61%	
1200		1200 / 50.00%		1200 / 37.50%		1200 / 31.25%		1200 / 27.34%		1200 / 24.61%
	1000 / 50.00%		1000 / 37.50%		1000 / 31.25%		1000 / 27.34%		1000 / 24.61%	
		800 / 25.00%		800 / 25.00%		800 / 23.44%		800 / 21.88%		800 / 20.51%
			600 / 12.50%		600 / 15.62%		600 / 16.41%		600 / 16.41%	
				400 / 6.25%		400 / 9.38%		400 / 10.94%		400 / 11.72%
					200 / 3.12%		200 / 5.47%		200 / 7.03%	
						0 / 1.56%		0 / 3.12%		0 / 4.39%
							-200 / 0.78%		-200 / 1.76%	
								-400 / 0.39%		-400 / 0.98%
									-600 / 0.20%	
										-800 / 0.10%

An investment decision example

Imagine you decide to invest in an irrigation system in year 5. The gross margin has developed randomly as shown below and currently amounts to 1,800 €. What exactly you will earn from the investment in an irrigation system depends on the gross margin development in the next year (year 6):

- you will either earn 2,000 € with a probability of 50 per cent
- or you will earn 1,600 € with a probability of again 50 per cent.

Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10

Decision to buy an irrigation system in year 5

									2600 6.25%	**2800** 3.13%
								2400 12.50%	**2200** 25.00%	**2400** 15.63%
						2200 25.00%	**2000** 37.50%	**2000** 31.25%
					2000 50.00%	**1800** 50.00%	**1800** 37.50%	**1600** 31.25%
				1600	1800	**1600** 50.00%	**1600** 37.50%	**1800** 37.50%
			1400			**1400** 25.00%	**1400** 25.00%	**1400** 31.25%
1200		1200				**1200** 12.50%	**1200** 15.63%
	1000					**1000** 6.25%	**800** 3.13%

Example for the calculation of your final account balance in case of an investment in year 10

Imagine the situation of the aforementioned example. In year 5, you decided to invest given a gross margin of 1,800 €. We assume a negative development of the gross margin from year 5 to year 6 resulting in a decrease of 200 €. With this investment, you would, therefore, earn 1,600 €. In this case, your total balance of year 10 would be calculated as follows:

- Your starting credit of 10,000 € increases by 10 per cent up to year 5 to 10,000 € · 1.1^5 = 16,105 €.
- In year 5, your account balance is, therefore, 16,105 €.
- You will invest 10,000 € of these 16,105 € to purchase an irrigation system.
- The residual amount of 6,105 € yields 10 per cent interest by year 10 (another 5 years) meaning that it increases as follows: 6,105 € · 1.1^5 = 9,832 €.
- In year 6, you receive a gross margin from the investment in an irrigation system of 1,600 €. Given that we assume an infinite useful lifetime, the investment will earn 16,000 €, which also will yield 10 per cent interest by year 10 (another 5 years). 16,000 € · 1.1^5 = 25,768 €.

In this example, your total balance in year 10 will correspond to the following: 9,832 € + 25,768 € = 35,600 €.

In this example, your account balance would be 35,600 € in year 10. If this game was randomly selected for determining the cash premium, you would receive 1,424 € (= 35,600 € : 2,500 € · 100 €).

Before the game starts, we would like to ask you to answer some control questions. This is to ensure that you understand all instructions.

If the gross margin of the investment in an irrigation system is 2,200 € in one year, which two gross margins can occur in the next year?

Please indicate the two gross margins here:

_____ €

_____ €

What is the probability (in per cent) that the gross margin in the tree chart increases by 200 € from one year to another?

Please indicate your answer here: _____ per cent

What is the probability (in per cent) that the gross margin in the tree chart decreases by 200 € from one year to another?

Please indicate your answer here: _____ per cent

How much interest (in per cent) do your liquid assets in your account yield per year?

Please indicate your answer here: _____ per cent

What are the costs of the investment in an irrigation system?

_____ €

How much does the investment earn if the gross margin is 1,400 € per year assuming an infinite useful lifetime of the investment object?

_____ €

In the observed year 5, the gross margin in the tree chart is 1,400 €. The possible gross margins which can be realized in the next years are indicated in bold.
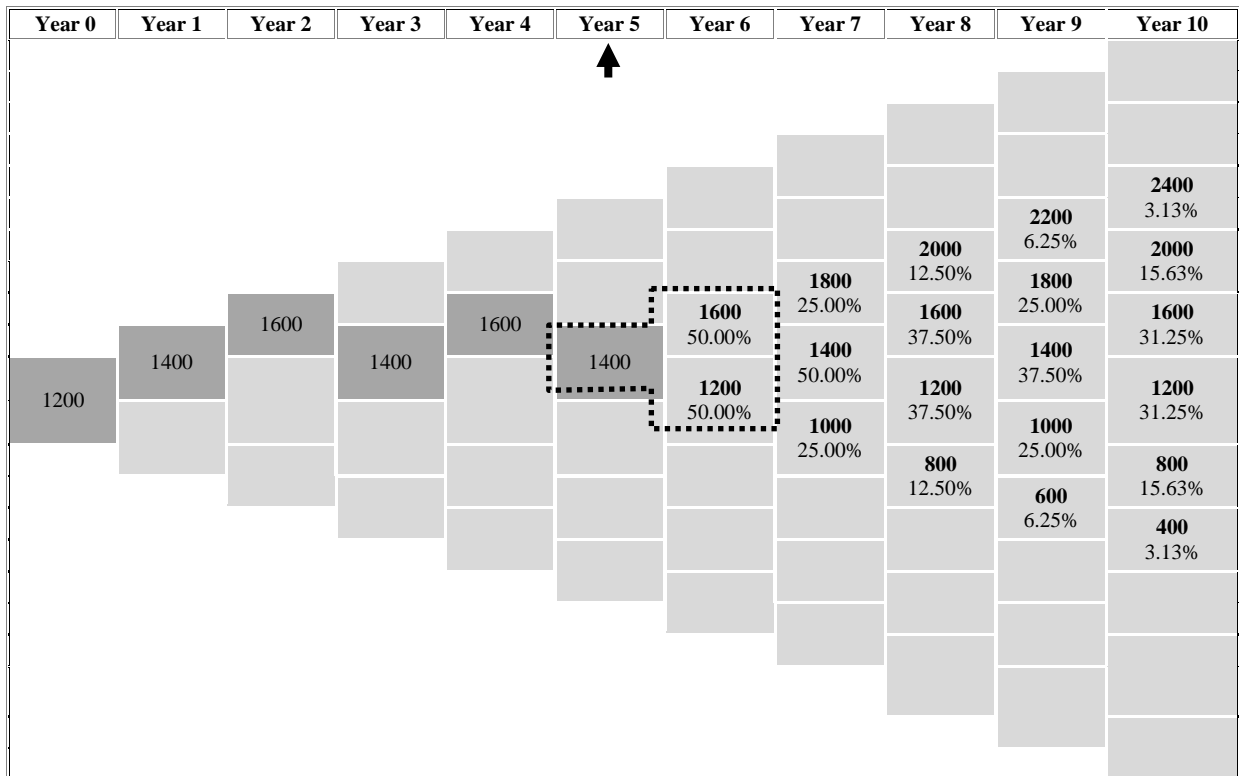
Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
										2400 3.13%
									2200 6.25%	**2000** 15.63%
							2000 12.50%	**1800** 25.00%	
						1800 25.00%		**1600** 37.50%	**1600** 31.25%
		1600		**1600**		**1600** 50.00%	**1600** 37.50%		
	1400		**1400**		**1400**		**1400** 50.00%	**1400** 37.50%	**1400** 31.25%
1200						**1200** 50.00%	**1200** 37.50%		**1200** 31.25%
						1000 25.00%	**1000** 25.00%		
							800 12.50%		**800** 15.63%
								600 6.25%	
									400 3.13%

Which of the two gross margins can potentially be realized in the coming year (year 6)?
Please indicate the two gross margins here:

_____ €
_____ €

You answered all control questions correctly!

Please click 'continue' to start the game.

- Here, the experiment starts –

Second part (instruction: treatment B (disinvestment))

The game consists of various repetitions of one game with an equal basic structure.

Imagine you as a farmer have an irrigation system. Due to changes in the water guidelines you are considering selling your irrigation system. In the time frame between 0 and 9 years, you can sell the irrigation system only once and receive a sales revenue of 5,000 €. You can decide within the next 10 years:

- to immediately sell the irrigation system
- wait and see the development of the gross margins that can potentially be achieved (up to 10 years) when continuing using the irrigation system and to sell the irrigation system later
- or not to sell the irrigation system.

The money you have at your disposal in each year will yield an interest rate of 10 per cent meaning that it increases by a tenth of its value. For example, if you decide to sell the irrigation system immediately you will leave the game with a sales revenue of 5,000 € that has increased to 12,969 € over the 10 years and a gross margin of 400 € in year 0,

Chapter II: Does Timing Matter? A Real Options Experiment to Farmers'
Investment and Disinvestment Behaviours

43

amounting to 13,369 €. In case this game would be randomly selected for the cash premium, you would receive 535 € (= 13,369 € : 2,500 € · 100 €).

The tree chart below shows the possible gross margins, which you can earn in the respective years if you continue to use the irrigation system. The tree chart starts with a gross margin of 400 € in year 0. Starting from this initial value, the gross margin of the following years increases or decreases by 200 €. The probability of the occurrence of the gross margin in each year is indicated under the gross margin.

Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
										2400 / 0.10%
									2200 / 0.20%	
								2000 / 0.39%		2000 / 0.98%
							1800 / 0.78%		1800 / 1.76%	
						1600 / 1.56%		1600 / 3.12%		1600 / 4.39%
					1400 / 3.12%		1400 / 5.47%		1400 / 7.03%	
				1200 / 6.25%		1200 / 9.38%		1200 / 10.94%		1200 / 11.72%
			1000 / 12.50%		1000 / 15.62%		1000 / 16.41%		1000 / 16.41%	
		800 / 25.00%		800 / 25.00%		800 / 23.44%		800 / 21.88%		800 / 20.51%
	600 / 50.00%		600 / 37.50%		600 / 31.25%		600 / 27.34%		600 / 24.61%	
400		400 / 50.00%		400 / 37.50%		400 / 31.25%		400 / 27.34%		400 / 24.61%
	200 / 50.00%		200 / 37.50%		200 / 31.25%		200 / 27.34%		200 / 24.61%	
		0 / 25.00%		0 / 25.00%		0 / 23.44%		0 / 21.88%		0 / 20.51%
			-200 / 12.50%		-200 / 15.62%		-200 / 16.41%		-200 / 16.41%	
				-400 / 6.25%		-400 / 9.38%		-400 / 10.94%		-400 / 11.72%
					-600 / 3.12%		-600 / 5.47%		-600 / 7.03%	
						-800 / 1.56%		-800 / 3.12%		-800 / 4.39%
							-1000 / 0.78%		-1000 / 1.76%	
								-1200 / 0.39%		-1200 / 0.98%
									-1400 / 0.20%	
										-1600 / 0.10%

A selling decision example

Imagine you decide to sell the irrigation system in year 5 and receive the sales revenue of 5,000 €. The gross margin has developed randomly as shown below and currently amounts to 600 €.

Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10

Decision to sell the irrigation system in year 5

								1400 6.25%	1600 3.13%
						1200 12.50%	1200 6.25%		1200 15.63%
					1000 25.00%		1000 25.00%		
				800 50.00%		1000 25.00%		1000 25.00%	800 31.25%
400		400		400	600	800 37.50%		800 31.25%	
	200		200		**400 50.00%**	600 50.00%	600 37.50%		400 31.25%
						400 37.50%			
						200 25.00%	200 25.00%		0 15.63%
						0 12.50%		-200 6.25%	-400 3.13%

In this case, your total balance of year 10 would be calculated as follows:

-   The gross margin of 400 € of year 0 increases by 10 per cent for each of the remaining years up to year 10, i.e. $400 € \cdot 1.1^{10} = 1{,}037 €$
-   The gross margin of 200 € of year 1 increases by 10 per cent for each of the remaining years up to year 10, i.e. $200 € \cdot 1.1^{9} = 472 €$
-   The gross margin of 400 € of year 2 increases by 10 per cent for each of the remaining years up to year 10, i.e. $400 € \cdot 1.1^{8} = 857 €$
-   The gross margin of 200 € of year 3 increases by 10 per cent for each of the remaining years up to year 10, i.e. $200 € \cdot 1.1^{7} = 390 €$
-   The gross margin of 400 € of year 4 increases by 10 per cent for each of the remaining years up to year 10, i.e. $400 € \cdot 1.1^{6} = 709 €$
-   The gross margin of 600 € of year 5 increases by 10 per cent for each of the remaining years up to year 10, i.e. $600 € \cdot 1.1^{5} = 966 €$
-   The sales revenue of 5000 € that you receive in year 5 (because you decided to sell the irrigation system) also increases by 10 per cent for each of the remaining years up to year 10, i.e. $5000 € \cdot 1.1^{5} = 8{,}053 €$.

In this example, your total balance in year 10 will correspond to the following:

1037 € + 472 € + 857 € + 390 € + 709 € + 966 € + 8053 € = 12,484 €.

In this example, your account balance would be 499 €. If this game was randomly selected for the cash premium, you would receive 499 € (= 12,484 € : 2,500 €) · 100 €).

A no-selling decision

Imagine you decide not to sell the irrigation system within the 10 years (between year 0 and year 9), your chance to sell expires and you will leave the game with the gross margin

that has increased by 10 per cent for each of the remaining years up to year 10. The gross margin has developed randomly as shown below:

Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10

Decision not to sell the irrigation system

Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
							1000			
						800		800		800
					600				600	
400		400		400						
	200		200							

In this case, your total balance of year 10 would be calculated as follows:

- The gross margin of 400 € of year 0 increases by 10 per cent for each of the remaining years up to year 10, i.e. $400\,€ \cdot 1.1^{10} = 1{,}037\,€$
- The gross margin of 200 € of year 1 increases by 10 per cent for each of the remaining years up to year 10, i.e. $200\,€ \cdot 1.1^{9} = 472\,€$
- The gross margin of 400 € of year 2 increases by 10 per cent for each of the remaining years up to year 10, i.e. $400\,€ \cdot 1.1^{8} = 857\,€$
- The gross margin of 200 € of year 3 increases by 10 per cent for each of the remaining years up to year 10, i.e. $200\,€ \cdot 1.1^{7} = 390\,€$
- The gross margin of 400 € of year 4 increases by 10 per cent for each of the remaining years up to year 10, i.e. $400\,€ \cdot 1.1^{6} = 709\,€$
- The gross margin of 600 € of year 5 increases by 10 per cent for each of the remaining years up to year 10, i.e. $600\,€ \cdot 1.1^{5} = 966\,€$
- The gross margin of 800 € of year 6 increases by 10 per cent for each of the remaining years up to year 10, i.e. $800\,€ \cdot 1.1^{4} = 1{,}171\,€$
- The gross margin of 1,000 € of year 7 increases by 10 per cent for each of the remaining years up to year 10, i.e. $1{,}000\,€ \cdot 1.1^{3} = 1{,}331\,€$
- The gross margin of 800 € of year 8 increases by 10 per cent for each of the remaining years up to year 10, i.e. $800\,€ \cdot 1.1^{2} = 968\,€$
- The gross margin of 600 € of year 9 increases by 10 per cent for each of the remaining years up to year 10, i.e. $600\,€ \cdot 1.1^{2} = 660\,€$
- In year 10, you receive a gross margin of 800 €. Given that we assume an infinite useful lifetime continuing using the irrigation system will earn 8,000 € (= 800 € · 10).

In this example, your total balance in year 10 will correspond to the following:

1037 € + 472 € + 857 € + 390 € + 709 € + 966 € + 1,171 € + 1,331 € + 968 € + 660 € + 800 € + 8000 € = 17,361 €

In this example, your account balance would be 17,361 €. If this game was randomly selected for the cash premium, you would receive 694 € (= 17,361 € : 2,500 € · 100 €).

Before the game starts, we would like to ask you to answer some control questions. This is to ensure that you understand all instructions.

If the gross margin of the irrigation system is 800 € in one year, which two gross margins can occur in the next year?

Please indicate the two gross margins here:

<div align="center">

____ €

____ €

</div>

What is the probability (in per cent) that the gross margin in the tree chart increases by 200 € from one year to another?

Please indicate your answer here: ____ per cent

What is the probability (in per cent) that the gross margin in the tree chart decreases by 200 € from one year to another?

Please indicate your answer here: ____ per cent

How much interest (in per cent) do your liquid assets in your account yield per year?

Please indicate your answer here: ____ per cent

What is the sales revenue of the irrigation system?

<div align="center">

____ €

</div>

In the observed year 5, the gross margin in the tree chart is 600 €. The possible gross margins that can be realized in the next years are indicated in bold.

Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10

↑

										1600 3.13%
									1400 6.25%	**1200** 15.63%
								1200 12.50%	**1000** 25.00%	**800** 31.25%
		800		**800**		**800** 50.00%	**1000** 25.00%	**800** 37.50%	**600** 37.50%	**400** 31.25%
	600		**600**		**600**	**400** 50.00%	**600** 50.00%	**400** 37.50%	**200** 25.00%	**0** 15.63%
400							**200** 25.00%	**0** 12.50%	**-200** 6.25%	**-400** 3.13%

Which of the two gross margins can potentially be realized in the coming year (year 6)? Please indicate the two gross margins here:

_____ €
_____ €

You answered all control questions correctly!

Please click 'continue' to start the game.

- Here, the experiment starts –

[It is randomly determined in which order the individuals were faced with the investment and disinvestment situations. The farmers repeated both treatments (investment and disinvestment in irrigation technology) 10 times.]

Third part (instruction: Holt and Laury lottery)

Also for the third part of the game one participant who receives a cash premium is selected randomly. The cash premium depends exclusively on your own decisions and on chance. […]

Fourth part (Ex post perception of the experiment and personal information)

Finally, we would like to ask you some questions about personal details. All results of the survey will be presented anonymously, and it will not be possible to draw any inferences of the actual persons or farms providing the information. […]

Appendix S2: Normative benchmarks

Normative benchmarks that represent the NPV and ROA have to be derived. In the following, we analytically and numerically describe the derivation of the normative benchmark for the last two investment periods in figure 4 (section 4). First, we calculate the investment trigger for period 9. According to the experimental design described in section 3, the investment cost I is constant over time (i.e. 10,000). The present value of investment returns V_9 observed in period 9 will either increase by a value h (i.e. 2,000) with probability p (i.e. 0.5) or decrease by h with probability $1 - p$ in period 10. The investment option expires in period 9 and no flexibility exists to postpone the investment decision. Therefore, the values of the investment following the NPV $\left(\hat{F}_9\right)$ and following the ROA $\left(\tilde{F}_9\right)$ are identical and defined as:

$$\hat{F}_9 = \tilde{F}_9 = max(E(NPV_9); 0), \qquad\qquad \text{A2-1}$$

where

$$E(NPV_9) = \left(\left(p \cdot (V_9 + h) + (1 - p) \cdot (V_9 - h)\right) \cdot q^{-1}\right) - I$$

Here $E(\cdot)$ denotes the expectation operator, $q^{-1} = 1/(1 + r)$ is a discount factor and r denotes the risk-free interest rate (i.e. 10% per year). By equating the expected present value defined in equation (A2-1) and the investment cost I, we obtain the investment trigger. Since the investment option expires in period 9, the investment trigger according to the ROA $\left(\tilde{V}_9\right)$ corresponds with the investment trigger following the NPV $\left(\hat{V}_9\right)$:

$$\hat{V}_9 = \tilde{V}_9 = h - 2 \cdot p \cdot h + I \cdot q \qquad\qquad \text{A2-2}$$

That means for our example:

$$\hat{V}_9 = \tilde{V}_9 = 2,000 - 2 \cdot 0.5 \cdot 2,000 + 10,000 \cdot 1.1 = 11,000$$

Second, we calculate the investment trigger for period 8. In this period, the investment can be implemented either immediately in period 8 or it can be postponed for one period. As the NPV ignores the entrepreneurial flexibility, the value of investment as well as the investment trigger in period 8 is equal to the investment trigger in period 9, that is, $\hat{V}_9 = \hat{V}_8 = 11,000$. The ROA takes into account the flexibility of postponing the investment decision. Starting from period 8, the present value V_{10} in period 10 can take the following values: $V_8 + 2 \cdot h$ with probability p^2; $V_8 - 2 \cdot h$ with probability $(1 - p)^2$; and V_8 with probability $2 \cdot p \cdot (1 - p)$. The investment can be deferred which has the potential advantage that it allows the decision maker to take into account new information about the expected present value of the investment returns that arrives in the subsequent period. A rational decision maker would only realize an investment immediately if the actual expected NPV is higher than the discounted expected NPV of investing one period later. According to the ROA, the value of the investment $\tilde{F}_8$ is:

$$\tilde{F}_8 = max(E(NPV_8); E(NPV_9) \cdot q^{-1}), \qquad\qquad \text{A2-3}$$

where

$$E(NPV_8) = \left(\left(p \cdot (V_8 + h) + (1 - p) \cdot (V_8 - h)\right) \cdot q^{-1}\right) - I, \text{ and}$$

$$E(NPV_9) = \left(p \cdot \left((p \cdot (V_8 + 2 \cdot h) + (1 - p) \cdot (V_8 + h - h)\right) \cdot q^{-1} - I\right) + (1 - p) \cdot 0\right) \cdot q^{-1}$$

By equating $E(NPV_8)$ and $E(NPV_9)$, we receive the investment trigger $\tilde{V}_8$:

$$\tilde{V}_8 = \frac{q \cdot h - 2 \cdot p \cdot q \cdot h + I \cdot q^2 + 2 \cdot p^2 \cdot h - p \cdot I \cdot q}{q - p} \qquad\qquad \text{A2-4}$$

That means for our example:

$$\tilde{V}_8 = \frac{1.1 \cdot 2{,}000 - 2 \cdot 0.5 \cdot 1.1 \cdot 2{,}000 + 10{,}000 \cdot 1.1^2 + 2 \cdot 0.5^2 \cdot 2{,}000 - 0.5 \cdot 10{,}000 \cdot 1.1}{1.1 - 0.5}$$

$$= 12{,}667.$$

By repeating the described procedure for period 7 to 0, the normative benchmark of the ROA can be completed.

Appendix S3: Risk-adjusted discount rate

On the basis of the results from the Holt and Laury lottery (HLL), the respective risk-adjusted discount rates are determined. According to Holt and Laury (2002), a power risk utility function is assumed, which implies decreasing absolute risk aversion (DARA) and constant relative risk aversion (CRRA):

$$U(V) = V^{1-\theta}, \tag{A3-1}$$

where U denotes utility, V describes the present value of the investment and disinvestment returns and θ is the constant relative risk-aversion coefficient. Based on equation (A3-1) we can derive θ for each individual from his/her choices in the HLL. Thus, the certainty equivalent CE of a risky prospect can be formulated as:

$$CE = V\left(E\big(U(V)\big)\right) = E\big(U(V)\big)^{\frac{1}{1-\theta}} = E(V) - RP \tag{A3-2}$$

where $E(V)$ is the expected present value of the investment and disinvestment returns and RP is a risk premium. The present value of the certainty equivalent CE_0 of an uncertain payment V_T at time T can be defined as follows:

$$CE_0 = CE_T \cdot (1 + r)^{-T} = (E(V_T) - RP_T) \cdot (1 + r)^{-T} \tag{A3-3}$$

where r is the risk-free interest rate. An equivalent risk-adjusted discount rate $r^* = r + v$ can be derived from equation (A3-3) using the following equation:

$$(E(V_T) - RP_T) \cdot (1 + r)^{-T} = E(V_T) \cdot (1 + r + v)^{-T} \tag{A3-4}$$

$$\rightarrow v = (1 + r) \cdot \left(\left(\frac{E(V_T)}{E(V_T) - RP_T}\right)^{1/T} - 1\right)$$

The risk loading v, and thus the risk-adjusted discount rate $r + v$ depend on the risk premium RP as well as on the length of the discounting period T.

Applying dynamic programming to the binomial tree using the risk-adjusted discount rates from equation (A3-4) is problematic because the certainty equivalent of the up and down movements, and thus the risk-adjusted discount rates, are not constant over time. This leads to a non-recombining binomial tree for the stochastic variable, in which the number of potential states increases exponentially with the number of years (Longstaff and Schwartz 2001). Therefore, we first fix the level of the returns at its initial value when determining the risk-adjusted discount rate by equation (A3-4). Second, we fix T at one period in equation (A3-4). Finally, we derive nine discount rates representing different risk attitudes for each treatment. The risk-adjusted discount rates vary in the range from 7.72 per cent (HLL-value = 0-1) to 13.14 per cent (HLL-value = 9-10) in the investment treatment and between 6.69 per cent and 16.51 per cent in the disinvestment treatment.

III. Investment Behavior of Ugandan Smallholder Farmers: An Experimental Analysis

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Abstract

In this study, we experimentally analyze the investment behavior of smallholder farmers in Uganda. We consider a problem of optimal stopping, stylizing an option to invest in a project. We ascertain whether, and to what extent, the real options approach and the classical investment theory can predict farmers' investment behaviors. We also examine differences in the investment behavior with respect to the presence of a price floor, which is often used to stimulate investments. Furthermore, we look at learning effects. Our results show that both theories do not explain exactly the observed investment behavior. However, our results suggest that real options models better predict the decision behavior of farmers than the classical investment theory. The presence of a price floor and learning from personal experience during the experiment do not significantly affect the investment behavior. However, we find that specific socio-demographic and socio-economic characteristics affect the investment behavior of farmers.

Key words

Experimental economics, investment choices, price floors, real options, Uganda.

JEL classification

C91, D03, D81, D92.

1   Introduction

Investment decisions affect a household's income and consumption patterns in the long term, particularly poor farm households in developing countries (Hill 2010a). Almost every important economic farm decision is constrained by uncertainty over future returns stemming from the risks associated with price fluctuations, crop and livestock diseases, or adverse weather conditions. In this regard, it can be observed that decision makers are often reluctant to invest. Examples of such inertia have been reported in the literature and include the adoption of new technologies (Kabunga et al. 2012), selection of perennial crop varieties (Hill 2010a), investment in conservation intervention (Winter-Nelson and Amegbeto 1998), and crop insurance markets (Hill and Viceisza 2012).

In order to stimulate investments, agricultural policies frequently use price floors, which ensure a price above a certain limit (Kim et al. 1992; Foltz 2004; Sckokai and Moro 2009). Price floors have also been used in the agricultural sector to assure supply security for certain commodities. For example, Shonkwiler and Maddala (1985), Holt and Johnson (1989), and Holt (1994) found that price floors have contributed to stabilizing prices for agricultural commodities and raising farm income. However, there are some studies that doubt the effectiveness of a minimum price (e.g., Dixit and Pindyck 1994). In some cases, it can be observed that price floors do not have a stimulating effect on investment (Patlolla et al. 2012; Maart-Noelck et al. 2013).

In the extant literature, several reasons have been offered to explain farmers' slow response to changed framework conditions, including economic and sociological factors, such as financial constraints (Moser and Barrett 2006), risk aversion (Knight et al. 2003), and non-monetary goals of the decision maker (Musshoff and Hirschauer 2008). The real options approach (ROA) – also referred to as the new investment theory – has been discussed as a possible alternative or an additional explanation for economic inertia (Abel and Eberly 1994; Dixit and Pindyck 1994; Purvis et al. 1995). The ROA evaluates uncertainty, temporal flexibility, and irreversibility in investment decision making and generates results that can be different from the classical investment theory. The ROA states that an investor may increase profits by deferring an irreversible investment decision rather than realizing the investment immediately, even if the expected net present value (NPV) is positive. The main idea is that an investment decision can be treated as the exercising of an option. That means that an investor has the option to invest now or defer the decision to a later date after more information is known about uncertain future prospects. The option to postpone a

decision in order to adapt to changing conditions becomes quite valuable for an investor, especially when future returns of an investment are uncertain.

Specifically, this study focuses on smallholder coffee farmers in rural Uganda, a setting in which the importance of uncertainty in influencing economic behavior of poor households has been documented. For example, Hill (2010a) empirically examined the investment and abandonment behavior of poor rural households using field data. The author considered the decision of Ugandan coffee-farming households to invest in or to abandon coffee trees, a high risk but high return activity due to price volatility and the trees' susceptibility to disease. Hill (2010b) noted the possibility that by affording some minimum price guarantee, price insurance would encourage coffee farmers to invest more household resources in coffee production.

Our study is inspired by previous and current research on normative and econometric analyses of investment problems using the ROA. Normative applications of the real options theory to agricultural investment decisions include among others Khanna et al. (2000) and Luong and Tauer (2006). However, these applications merely indicate the explanatory potential of the ROA for observed economic inertia. Some studies provide empirical evidence for the validity of the ROA using econometric approaches based on field data, such as Richards and Green (2003), Wossink and Gardebroek (2006), and Hill (2010a). However, an econometric validation of theoretical models explaining investment behavior, such as the ROA, is difficult for several reasons. For instance, the results of the ROA usually refer to investment triggers, which are not directly observable (Odening et al. 2005). Furthermore, besides options effects, risk aversion or financial constraints may cause farmers' reluctance to invest and the various effects are difficult to disentangle (Huettel et al. 2010). Experimental methods are a natural way to overcome these difficulties. A fundamental difference of experimental methods to econometrical analyses based on field data is that investigators can observe individuals' actual decision behavior in a controlled environment. Experimental methods allow them to study the question of interest more precisely by controlling extraneous factors which may affect individual behavior, and thus improves internal validity (Harrison and List 2004; Roe and Just 2009).

The use of experimental methods in investigating the ROA is growing. Rauchs and Willinger (1996) were among the first in testing the irreversibility effect of real options in an experimental setting with students. They investigated how increased expected information affected participants' investment choices and showed that decision makers

chose a more flexible current option when anticipating more information. Yavas and Sirmans (2005) carried out a laboratory experiment with students and found that participants invested earlier than predicted by the ROA and thus failed to recognize the benefit of the option to wait. However, their willingness to pay for an investment included an options value when they had to compete with other investors. Another real options investment experiment with students was conducted by Oprea et al. (2009) who focused on learning effects of participants. Their research revealed that participants can learn from personal experience to closely approximate optimal exercise of wait options. The study closest to ours is Maart-Noelck and Musshoff (2013) who experimentally examined the decision behavior of German farmers in an agricultural and non-agricultural investment situation, but the study did not focus on policy impact analysis. They found that the timing of investments was not exactly predictable with the ROA or with the NPV but lied between both benchmarks. All of these studies consider investment decisions of decision makers, including convenience groups (e.g., students) and real decision makers (e.g., farmers) in developed countries but no real decision makers in a developing country. However, this is of particular interest because it is not possible to simply apply the results of experiments investigating the investment behavior of individuals in developed countries to individuals in developing countries, given the complexity of the ROA and the different level of education in developing countries.

The main objective of this paper is to experimentally investigate the investment behavior of smallholder farmers while trying to determine the underlying models of investment consistent with actual decision behavior. First, we ascertain whether, and to what extent, the ROA and the NPV criterion can predict farmers' investment behavior. Second, we investigate whether the presence of a price floor has an effect on farmers' investment behavior. Third, we examine the effect of personal experience during the experiment and specific socio-demographic and socio-economic characteristics on farmers' decision behavior. In addition, we carry out a lottery-choice experiment based on Holt and Laury (2002) to elicit farmers' risk attitudes, as an individuals' risk attitude is of great relevance for decision making under uncertainty (Koundouri et al. 2006). To achieve these objectives we combine data generated from investment and lottery-choice experiments with comprehensive household survey data which were collected in Uganda from July to August 2012. By examining the investment behavior of smallholder farmers in Uganda, we

gain some understanding of the dynamics of how uncertainty affects economic behavior in the context of a developing country.

This paper contributes to the extant literature by addressing the following three aspects: First, to the best of our knowledge, it is the first experimental contribution using models of irreversible investment under uncertainty to analyze the investment behavior of farmers in a developing country. This allows us to observe the effects of uncertainty, irreversibility, and the option to wait on an individual's investment decision under controlled conditions compared to an econometric analysis of field data. Second, the effect of a price floor on investment behavior has not yet been analyzed experimentally in a developing country. This understanding might be valuable to support and tailor agricultural policies aimed at inducing changes in investment conditions as one can observe investment decisions with and without a price floor. Third, individual risk propensity of farmers in a developing country is measured to determine the normative benchmark for the investment decision. Therefore, we adapt the method used in Holt and Laury (2002) to measure risk attitudes of people with a limited level of education. From a policy maker's perspective, it is imperative to understand farmers' investment behavior in order to gain insight into the dynamics of how uncertainty affects decision behavior and to predict this behavior in the future in order to design policies that will enable poor smallholder farmers to improve their incomes and welfare.

The remainder of this paper is structured as follows: Section 2 presents the relevant literature from which the research hypotheses are derived. In section 3, we explain the design of the experiments. The sampling procedure, incentive design, and the experimental implementation are described in detail in section 4. In section 5, we describe the calculation of the normative benchmarks and the approach to data analysis. We present and discuss our results in section 6, and lastly, section 7 concludes this paper.

2   Theory and hypotheses

In accordance with the classical investment theory, a decision maker should realize an investment if the investment costs are covered by the present value of the investment returns, that is, if its NPV is positive (Jorgenson 1963; Tobin 1969). In contrast to the NPV, the ROA does not imply an 'either now-or-never' investment decision and argues that it might not be optimal to invest immediately even if the NPV is positive. In reality, many investment decisions are characterized by uncertainty regarding future returns,

temporal flexibility, and some degree of irreversibility. The ROA addresses these aspects of an investment decision by valuing the option to invest now compared with investing at a later stage. The value of an investment option is called 'options value' and consists of the intrinsic value and the value of waiting (Trigeorgis 1996, p. 124). According to the ROA, the expected investment returns do not only have to cover the investment costs but also the opportunity costs or the profit that could be realized if the investment is postponed; that is, the investment trigger is shifted upwards (Pindyck 1991; Abel and Eberly 1994; Dixit and Pindyck 1994).

In the following, we describe the investment decision as a simple optimal stopping problem and assume a risk neutral decision maker. We choose a discrete time framework. The investment can be implemented once, either immediately or it can be postponed up to one period. The investment cost $I = 10,000$ needs to be paid immediately when one decides to invest. The present value of investment returns in period 0 is $V_0 = 10,000$. The future development of the present values of the investment returns, which is paid out one period after implementation, is uncertain and follows a binomial arithmetic Brownian motion (Dixit and Pindyck 1994, p. 68), i.e. starting from V_0 in period 0, the present value in period 1 will either increase by a value $h = 2,000$ with probability $p = 0.5$ or decrease by h with probability $1 - p$. In period 2 the present value can take the values $V_0 + 2 \cdot h$ with probability p^2; $V_0 - 2 \cdot h$ with probability $(1 - p)^2$; and V_0 with probability $2 \cdot p \cdot (1 - p)$. According to the NPV the value of the investment $\hat{F}$ equals:

$$\hat{F} = max[\hat{E}(NPV_0); 0], \tag{1}$$

where

$$\hat{E}(NPV_0) = \left((p \cdot (V_0 + h) + (1 - p) \cdot (V_0 - h)) \cdot q^{-1} \right) - I$$

Herein, $q^{-1} = 1/1 + r$ is a discount factor, and r denotes the risk-free interest rate (e.g. 10% per period). By equating the expected present value of the investment returns defined in equation (1) and the investment cost I we receive the investment trigger $\hat{V}_0$:

$$\hat{V}_0 = h - 2 \cdot p \cdot h + I \cdot q \tag{2}$$

In our example, the investment trigger $\hat{V}_0$ according to the NPV equals 11,000.

The decision can be deferred which has the potential advantage that it allows the decision maker to take into account new information about the expected present value of the investment returns that arrives in the subsequent period. A rational decision maker would

only realize an investment immediately if the actual expected NPV is higher than the discounted expected NPV of investing one period later. According to the ROA, the value of the investment $\tilde{F}$ is:

$$\tilde{F} = max\big[\hat{E}(NPV_0); \tilde{E}(NPV_1)q^{-1}\big],$$ (3)

where

$$\tilde{E}(NPV_1) = \big[p \cdot \big[(p \cdot (V_0 + 2 \cdot h) + (1 - p) \cdot (V_0 + h - h))q^{-1} - I\big] + (1 - p) \cdot 0\big] \cdot q^{-1}$$

By equating (1) and (3) we receive the investment trigger $\tilde{V}_0$:

$$\tilde{V}_0 = \frac{q \cdot h - 2 \cdot p \cdot q \cdot h + I \cdot q^2 + 2 \cdot p^2 h - p \cdot I \cdot q}{q - p}$$ (4)

In our example, the investment trigger $\tilde{V}_0$ according to the ROA equals 12,667. The investment trigger following the NPV differs from the investment trigger following the ROA. The difference is expressed as follows:

$$\tilde{V}_0 - \hat{V}_0 = \frac{p \cdot h}{q - p}$$ (5)

Apparently, $\hat{V}_0$ is smaller than $\tilde{V}_0$ as long as $p > 0$; that is, the higher investment trigger according to the ROA leads to a later investment in comparison to the predictions of the NPV. Against this background, we formulate the following hypothesis:

H1 'ROA superiority to NPV': The ROA outperforms the NPV in explaining the investment behavior of farmers.

Price floors are a common instrument as market intervention to stimulate investments. Governments often seek to assist farmers by setting price floors in agricultural markets, which ensure a price above a certain limit. There are a number of studies which focus on price floor effects on investment behavior, but these studies offer conflicting results. For example, Sckokai and Moro (2009) used empirical farm data and showed that an increase in the intervention price significantly stimulated farm investment, mainly through reduced price volatility. Chavas and Kim (2004) presented an econometric analysis of the effects of price floors on price dynamics and price volatility in a multimarket framework and provided evidence that the price support program reduced price volatility significantly, although this effect disappeared in the long term. Chavas (1994) developed a theoretical model for price floors and examined how sunk cost and temporal risk affected the rental value of capital as well as investment and entry-exit decisions. The author argued that

because of sunk costs, it may be socially optimal for government-provided price floors to reduce the uncertainty of the investment. However, Dixit and Pindyck (1994) doubted the effectiveness of a minimum price and argued that the long-run effect of the price floor policy may be harmful even to those it is intended to help. They emphasized the importance of the actual level of the price floor. Patlolla et al. (2012) focused on price floors in India's sugar processing industry and investigated the extent to which the government's price floor policy reduced factories' incentives to improve their sugar recovery rates. They argued that the price floor policy created a disincentive for private and public firms to be technically efficient in converting sugar cane to refined sugar and found empirical evidence. Maart-Noelck et al. (2013) used an experimental approach to examine the effect of a price floor on the investment behavior of students. They focused on the behavior of participants in a farmland investment situation and concluded that the price floor did not have a significant impact on the decision behavior.

With respect to the decision problem described in *H1*, we introduce a price floor $V_{min} = 10,000$ equal to the investment cost I. The equations (1) and (3) have to be modified for the price floor case. The value of the investment with price floor according to the NPV $\hat{F}^{WPF}$ can be calculated as follows:

$$\hat{F}^{WPF} = max[\hat{E}(NPV_0)^{WPF}; 0], \tag{6}$$

where

$$\hat{E}(NPV_0)^{WPF} = \left((p\ max(V_{min}; V_0 + h) + (1-p)max(V_{min}; V_0 - h)) \cdot q^{-1}\right) - I$$

The value of the investment with price floor according to the ROA $\tilde{F}^{WPF}$ is:

$$\tilde{F}^{WPF} = max[\hat{E}(NPV_0)^{WPF}; \tilde{E}(NPV_1)^{WPF} q^{-1}], \tag{7}$$

where

$$\tilde{E}(NPV_1)^{WPF} = p\ max\left(0; \left((p\ max(V_{min}; V_0 + 2 \cdot h) \right.\right. \tag{8}$$
$$\left.\left. + (1-p)\ max\ (V_{min}; V_0 + h - h)) \cdot q^{-1} - I\right)\right)$$
$$+ (1-p)\ max\left(0\left((p\ max(V_{min}; V_0 - h + h) \right.\right.$$
$$\left.\left. + (1-p)max(V_{min}; V_0 - 2 \cdot h)) \cdot q^{-1} - I\right)\right)$$

The investment triggers can be derived analogously to the procedures described in *H1*. In our example, the investment trigger $\hat{V}_0^{WPF}$ according to the NPV equals 10,000, while the investment trigger $\tilde{V}_0^{WPF}$ according to the ROA equals 13,143. Due to a higher expected value of the investment returns, the NPV trigger is substantially lower in the WPF treatment compared to the NPF treatment. The ROA trigger in the WPF treatment lies above the trigger in the NPF treatment, which can be explained by the occurrence of an ambiguous effect. Reduced uncertainty due to a guaranteed price and higher opportunity costs caused by higher expected values of future investment returns outweigh each other to a certain extent in the WPF treatment. We derive the following hypothesis:

H2 'Price floor effect': Price floors do not stimulate significantly farmers' willingness to invest.

In reality, decision makers are repeatedly faced with similar decision situations and previous decisions can influence the decision making process and potential future decisions. Essentially, this means that the decision behavior is influenced by previous experiences. Usually, a decision maker tends to avoid repeating past mistakes, and in the case that something positive results from a decision, the individual is more likely to reach their decision in a comparable way, given a similar situation. This phenomenon is referred to as the 'learning effect'. In the existing literature, there are various studies that have shown that learning can affect the behavior of decision-makers in various decision situations. For instance, Cameron (1999) and Baerenklau (2005) found that farmers' technology adoption decisions were substantially influenced by learning over time using econometric approaches based on field data. Brennan (1998) applied a normative approach and focuses on the role of learning in dynamic portfolio decisions. In this study, he analyzed the effect of uncertainty about returns on the risky asset of the portfolio decisions of an investor who has a long investment horizon and observed a learning effect over time with regard to optimal portfolio allocation. Oprea et al. (2009) conducted a laboratory experiment with students who faced multiple investment opportunities. Their results showed that subjects responded to *ex-post* errors. Subjects tended to exercise the wait option prematurely, but over time their average investment behavior converged close to optimum. Loewenstein (1999) showed that 'stationary replication' in an experiment is a useful tool to observe how people learn in repetitive situations at different complexity levels. In reality, people usually have several opportunities for learning. These opportunities are then recreated, to some extent, in laboratories with replications of the

task. With regard to our experiment, participants are faced with repeated choice tasks in which they have to choose when to take an ongoing investment opportunity. We construct the following hypotheses:

H3 'learning effect': Farmers approximate optimal exercise of the ROA if they are given a chance to learn from personal experience in investment decisions.

3   Experiment design

In the following, we describe the experiment's design. Our experiment consists of three parts. In the first part, we use a lottery-choice experiment adapted from Holt and Laury (2002) to elicit the risk attitudes of farmers. The second and third parts of the experiment include two randomized investment treatments. These two treatments stylize a NPF (i.e. no price floor) and a WPF (i.e. with price floor) option to invest in a project. A complete set of instructions for the experiment is included in the Appendix. The experiment was preceded by a household survey that collected information on household demographics and economic characteristics.

3.1   Lottery-choice experiment design

The lottery-choice experiment proposed by Holt and Laury (2002) is a widely used method for the elicitation of subjective risk attitudes. In the Holt and Laury lottery (HL lottery), participants make 10 choices between two systematically varied options, namely option A (the safe option) or option B (the risky option). In our design, option A offered the chance to either win 6,000 UGX or 4,800 UGX with a certain probability, while option B offered the chance to win 11,550 UGX or 300 UGX with the same probability (see Table 1). The payoffs in the safe option have a lower range than those in the risky option. We use the rate of 1:3,000 to get the equivalent payoffs in Ugandan shillings compared to the original task. The earnings are held constant across the choice tasks, whereas the probabilities of the earnings vary in 10% intervals between the choice tasks.

The expected values of the options change as participants move from one to the next choice task. Up to the fourth choice task, the expected value of the safe option A is higher than the expected value of the risky option B. From the fifth task, the expected value of option B exceeded the expected value of option A. Participants were asked to make 10 choices of either option A or option B, one for each choice task. The switching point from the safe to the risky option allows us to determine their individual risk attitude. A risk

seeking participant would switch to option B in the first three decision rows, while a risk averse participant would switch to option B between the decision rows five to nine. In turn, a risk neutral participant would always decide in favor of the option with the higher expected value. Therefore, the person would switch from choosing option A to option B in row five. A HL lottery value (= number of safe choices) between one and three expressed risk preference, a HL lottery value of four implied risk neutrality, and a HL lottery value between five and 10 expressed risk aversion of the participant.

Table 1 Payoff matrix of the Holt and Laury lottery

Task	Option A	Option B	EV^A	EV^B	CRRA ranges[a]	Risk aversion class[b]
1	With 10% prize of 6,000 With 90% prize of 4,800	With 10% prize of 11,550 With 90% prize of 300	4,920	1,425	$r < -1.71$	Extremely RL
2	With 20% prize of 6,000 With 80% prize of 4,800	With 20% prize of 11,550 With 80% prize of 300	5,040	2,550	$-1.71 < r$ < -0.95	Highly RL
3	With 30% prize of 6,000 With 70% prize of 4,800	With 30% prize of 11,550 With 70% prize of 300	5,160	3,675	$-0.95 < r$ < -0.49	Very RL
4	With 40% prize of 6,000 With 60% prize of 4,800	With 40% prize of 11,550 With 60% prize of 300	5,280	4,800	$-0.49 < r$ < -0.14	RL
5	With 50% prize of 6,000 With 50% prize of 4,800	With 50% prize of 11,550 With 50% prize of 300	5,400	5,925	$-0.14 < r$ < 0.15	RN
6	With 60% prize of 6,000 With 40% prize of 4,800	With 60% prize of 11,550 With 40% prize of 300	5,520	7,050	$0.15 < r$ < 0.41	Slightly RA
7	With 70% prize of 6,000 With 30% prize of 4,800	With 70% prize of 11,550 With 30% prize of 300	5,640	8,175	$0.41 < r$ < 0.68	RA
8	With 80% prize of 6,000 With 20% prize of 4,800	With 80% prize of 11,550 With 20% prize of 300	5,760	9,300	$0.68 < r$ < 0.97	Very RA
9	With 90% prize of 6,000 With 10% prize of 4,800	With 90% prize of 11,550 With 10% prize of 300	5,880	10,425	$0.97 < r$ < 1.37	Highly RA
10	With 100% prize of 6,000 With 0% prize of 4,800	With 100% prize of 11,550 With 0% prize of 300	6,000	11,550	$1.37 < r$	Extremely RA

Notes: Prizes are displayed in Ugandan shillings (UGX). At the time of the experiments, the exchange rate was approximately 1 € to 3,000 UGX, so prizes range from approximately 0.1 € to 3.85 €. The fourth and fifth column shows the expected values (EV) of the respective option.
[a] Constant relative risk aversion coefficient assuming a power risk utility function.
[b] RL, RN, and RA respectively for risk lover, neutral, and averse.
Source: Author's own illustration according to Holt and Laury (2002).

Pretests have shown that conducting a standard HL lottery with individuals in a rural developing country setting like Uganda might not be appropriate; thus we incorporated some modifications. The standard HL lottery is modified in this experimental design by replacing monetary values with images of bags of colored balls (green, blue, red, and yellow) representing probabilities of different payoffs (300 UGX, 4,800 UGX, 6,000 UGX, and 11,550 UGX). Each payoff is a ball of a particular color. The choice tasks were presented all at once to the participants. Fig. 1 shows the 10 choice tasks the participants faced in this lottery.
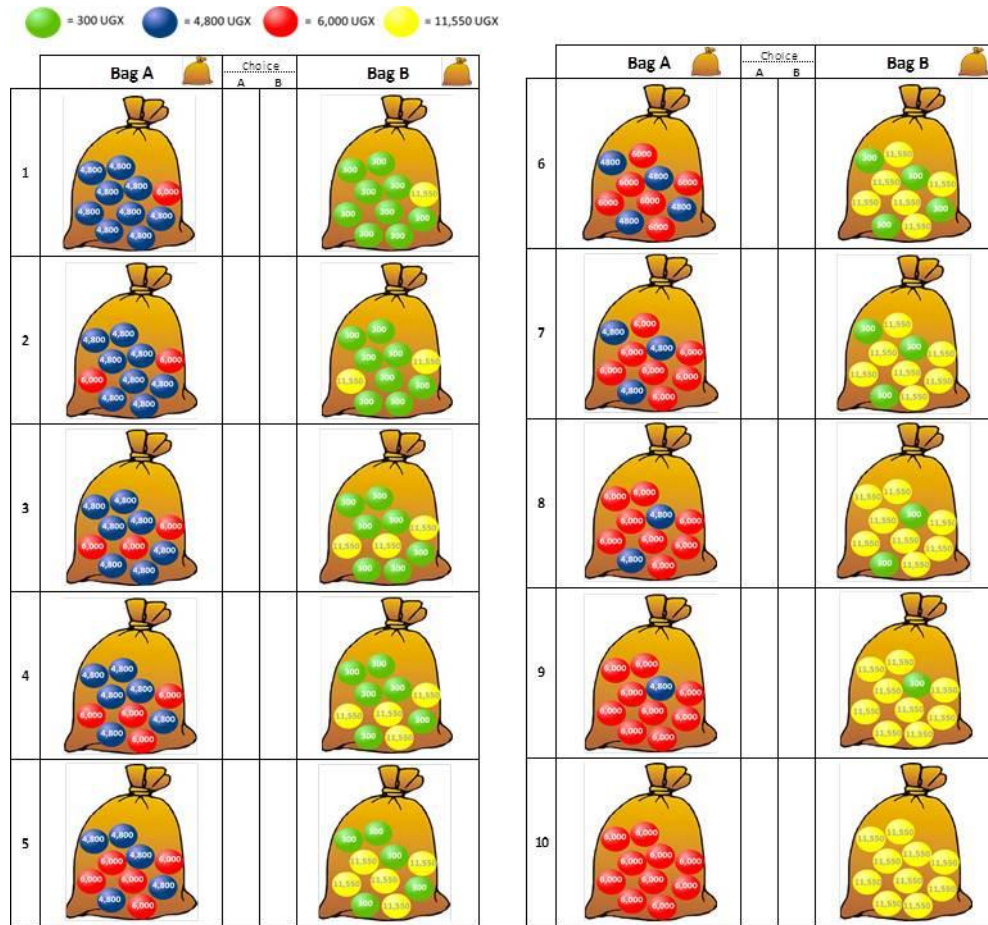
Fig. 1 Graphical display of the modified Holt and Laury lottery (in Ugandan shillings)

3.2 Investment experiment design

The design of the real options experiment was used to develop the model outlined in the previous section. In the NPF and WPF treatment, participants were given the hypothetical possibility to purchase the right to participate in a coin tossing game. Apart from the price floor, both treatments were absolutely identical. The order in which participants were faced with the two treatments was randomly determined. Each participant repeats the NPF and WPF treatment 10 times, having the option to invest 20 times in total. Within each repetition of the respective treatment, participants could decide to take or to postpone an ongoing investment opportunity in one of five possible periods. Every participant started the experiment with a deposit of 10,000 UGX for each repetition. The initial investment outlay was also 10,000 UGX. For simplicity reasons, the risk-free interest rate was fixed at 10% per period. The return in period 0 was always 10,000 UGX. The returns evolved stochastically and followed an arithmetic Brownian motion with no drift and a standard deviation of 2,000 UGX over five periods. According to a state- and time-discrete approximation of an arithmetic Brownian motion (Dixit and Pindyck 1994, p. 68), the

returns in period 1 either increase to 12,000 UGX with a probability of 50% or decrease to 8,000 UGX with a probability of 50% depending on a coin that has been tossed, i.e. upper amount if tail (fish) appears or lower amount if head (emblem) appears. The binomial tree of potential returns which was shown to the participants in the NPF and WPF treatment is illustrated in Fig. 2. The price floor is illustrated in the right part of Fig. 2 by the line which truncates the investment returns below 10,000 UGX.
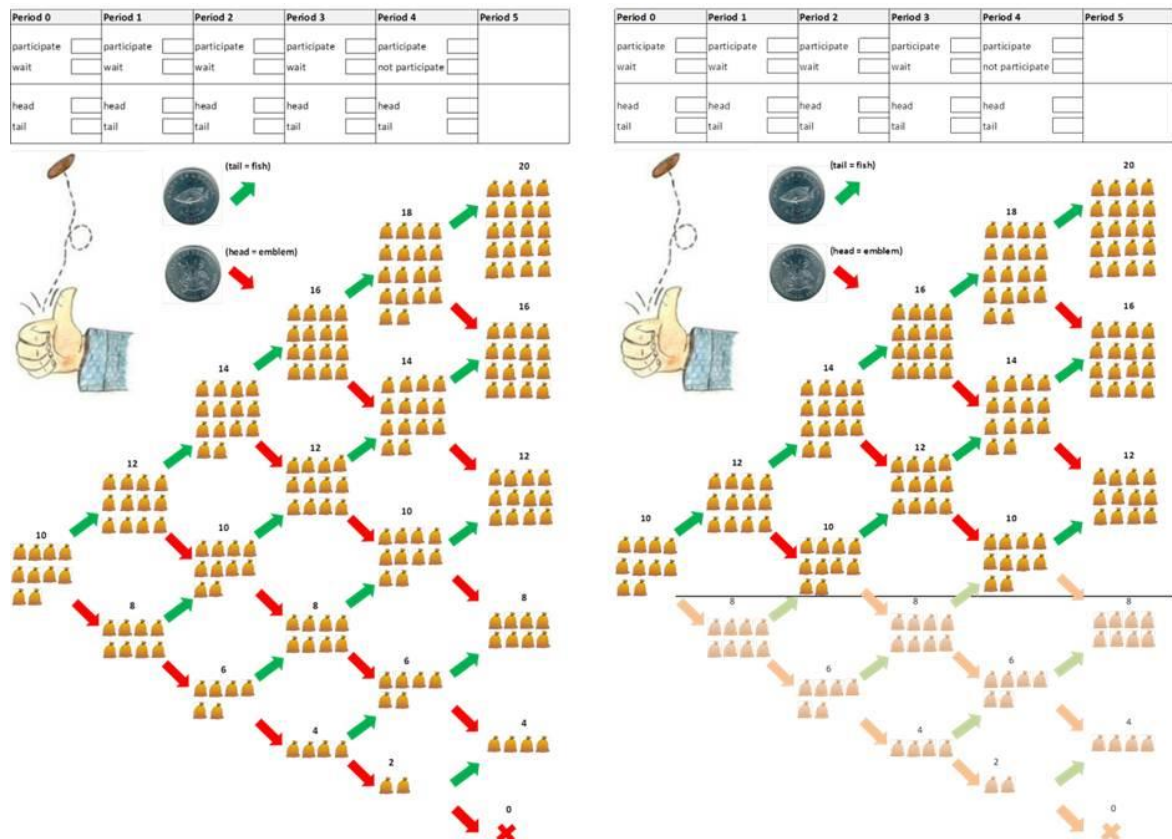
Fig. 2 Graphical display of the binomial tree of potential investment returns (in thousand UGX) in the NPF (left) and WPF treatment (right)

Each participant had three options: First, a participant could invest immediately, i.e. he/she paid the initial outlay of 10,000 UGX in period 0 and received 12,000 UGX or 8,000 UGX with a probability of 50% in period 1. Second, a participant could decide to postpone the investment decision and could invest at any time between periods 1 to 4. In case a participant decided not to invest in period 0, he/she would again be faced with the investment decision in period 1. By tossing a coin, it was randomly determined if the return in period 1 increased or decreased starting from the value of period 0. Third, a participant could choose not to invest at any point throughout the 5 periods, i.e. he/she saved the initial outlay of 10,000 UGX. The deposit and the returns minus the initial outlay

realized before period 5 increased by the risk-free interest rate of 10% for every period left in the decision tree.

In the WPF treatment, a minimum investment return is guaranteed. The minimum return is equal to the initial investment outlay of 10,000 UGX. More precisely, the return develops in accordance with the state- and time-discrete approximation of an arithmetic Brownian motion as described above. Only if a participant decided to exercise the investment option and indeed observed a return less than 10,000 UGX in the following period would a fictional authority compensate for the difference to reach 10,000 UGX. In this case, the participant would only loose the interest payment of one period on the investment cost compared to a situation in which the participant does not implement the investment.

3.3 Variables used in analysis

Individuals' socio-demographic and socio-economic characteristics naturally vary and may also have an impact on the investment time in our experiment. Therefore, in addition to the investment and lottery-choice experiments, participants attended a household survey during which they completed a comprehensive questionnaire capturing information on household demographics and economic characteristics. The main variables collected through the survey were age, gender, education, household size, district, per capita household expenditure as a proxy variable for wealth, total land owned, access to a savings account, access to credit, and membership in a farmer group. The selected variables are known in the extant literature to possibly have an influence on the investment behavior and are, therefore, considered in our analysis: age (e.g., Gardebroek and Oude Lansink 2004), gender (e.g., Jianakoplos and Bernasek 1998), education (e.g., Hill 2010a), household size (e.g., Lewellen et al. 1977), geographic region (e.g., Baerenklau 2005), wealth (e.g., Hill and Viceisza 2012), farm size (e.g., Savastano and Scandizzo 2009), access to a savings account (e.g., Dupas and Robinson 2013), access to credit (e.g., Fafchamps and Pender 1997), and membership in farmers' organizations (e.g., De Souza Filho et al. 1999).

A participant's ability to reason with numbers and probabilities may affect the understanding and decision making in the experiments and hence the opportunity to obtain an accurate measurement of their investment behaviors and risk attitudes (Dave et al. 2010; Cole et al. 2011). Therefore, we included three additional tasks, adapted from Viceisza (2011) and Charness and Viceisza (2011), to assess farmers' ability to process percentage and probabilistic information and to explore the relationship between their decision

behavior and the test score in the quiz: (i) 'Imagine, we toss a coin and 'head' comes up. What comes up if we toss the coin again?' Participants were faced with three possible answers: head, tail, one cannot predict exactly. (ii) 'If the chance of winning a prize is 10%, how many people out of 100 would be expected to get the prize?' (iii) 'When you draw the red ball, you win! Look at the two boxes and mark the correct sentence.' One box contains two red and two blue balls, while the other box contains four red and four blue balls. Participants have to decide whether the chance of winning is higher if they choose the first box, the second box, or the chance of winning is equal regardless of which box they choose.

4 Data collection

In the following subsections, we describe the sampling procedure, the incentive design, and the implementation of the experiment that was conducted.

4.1 Study location and sampling procedure

Data used in this study was obtained from experiments and a household survey of 332 smallholder coffee farmers randomly selected from two districts of Masaka and Luwero in Uganda from July to August 2012. These two districts, located in the Central Region, have been broadly classified as having similar agro-climatic conditions and farming systems. For the selection of smallholder farmers to be interviewed, we used a multi-stage sampling procedure. At first, we randomly selected parishes and villages. Within each selected village, smallholder farmers were then randomly selected using updated, village-level household lists. The farmers were then recruited via the local extension service to participate in a household survey and an experiment. The invitation to attend our experiment was provided orally by the recruiters and contained the date, time, and place of the study, a brief and general purpose of the study, and the type of compensation that could be expected. The household survey took place one day prior to the actual experiments. Our participants were either the household head or the spouse because they are those most likely to be faced with important economic decisions.

4.2 Experiment implementation

The 332 smallholder coffee farmers were allocated randomly to groups for the experimental sessions. In total, we conducted 56 sessions during the course of 30 days. On

one day, two sessions were held. Each session involved a group of six farmers.[1] In the experiment, choices made by participants were not time constrained. On average the complete session lasted approximately three hours. The experimental sessions were held in several villages and conducted in classrooms of local schools or in a meeting room at the main gathering place of a farmer's group or association. All of the sessions were held in locations which were familiar to the farmers and usually within walking distance or accessible by bicycle. The rooms were equipped with tables and chairs and were spaced out to prevent conferring among the participants. A team of seven enumerators conducted all of the experimental sessions. One of the enumerators served as the experimenter, and the author served as the assistant experimenter. The other enumerators were placed next to the participants to record their choices in case participants were illiterate. Each participant had their own enumerator. All sessions were conducted in Luganda, one of the main indigenous Bantu languages in south central Uganda. Prior to the first session, the enumerators were trained on the experiment protocol and to carefully avoid giving specific instructions about how to answer.

Each experiment session consisted of registration, instruction, practice, decision making, and payment. In the beginning of each experiment, the participant received a personal number, which randomly determined his/her seat that remained the individual's location throughout the session. The experiment instructions were read aloud to all participants as a group by the experimenter and supported by posters and graphical examples displayed on a large board at the front of the room to improve the understanding. During the presentation of the instructions, participants were encouraged to ask questions about any unclear issues. With regard to the lottery-choice experiment, we used real bags of colored balls representing probabilities of the different payoffs to further facilitate comprehension. Each choice task in the experiment was conducted in the following way: The assistant experimenter placed the appropriate balls in the bags, while the experimenter explained the values attached to each ball. The participants then considered their decision and made their choice by pointing to the preferred bag on the sheet in front of them, and their enumerator recorded the choice.

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[1] However, four farmers were excluded from the analysis. One farmer left before completing all tasks, and three farmers participated in the household survey but were not able to undertake (or arrived too late to participate) the experiment.

Before the investment experiment started, the participants had to answer some control questions to ensure that they entirely understood the instructions. After completing the control questions, participants also played a trial round to become familiar with the experiment. In the entire experiment, participants were not provided with the optimal investment strategy according to the NPV and ROA; rather, they decided on an intuitive basis. Both investment treatments were chosen in a randomly determined order and applied to the whole group. Each repetition of the respective treatment in the investment experiment was conducted in the following way. Each participant considers their decision, i.e. to either invest immediately and to participate in the coin tossing game or to postpone the decision and first see the development of the decision tree. The enumerator records the decision by marking the appropriate box on the decision sheet in front of them. Once the enumerator has marked the decision for the period, the participant can no longer change the decision. When all six participants have made their decisions, the experimenter tosses a coin. The enumerator records the result of the coin tossing by marking the appropriate box on the decision sheet, i.e. whether head (emblem) or tail (fish) appears. The experiment then continues with the next period. If a participant had chosen to wait in period 0, he/she makes a decision whether to participate or to wait in period 1 after having observed the outcome of the previous period. If a participant had chosen to participate in the coin tossing game in period 0, the game is over for him/her and he/she has to wait for the next repetition of the game. Nevertheless, the experimenter tosses the coin for each period in this repetition. The second repetition of the experiment starts in period 0 with again the opportunity to invest in 1 of 5 time periods. This procedure is repeated 10 times for each treatment.

Overall, our impression was that the formulation of the instructions was well understood by the participants because of the various interview techniques applied such as visual, oral, and written explanations as well as the practical implementation with real bags and colored balls. Further support of respondents' comprehension of the instructions is seen, for example, in the unproblematic answering of the control questions during the experiment.

4.3   Incentive design

The decisions in the experiments were related to real earnings to ensure incentive compatibility and to motivate participants to take the tasks more seriously. Participants were informed at the beginning of the experiment that when they have completed all decision tasks in the experiment, one repetition of the NPF and WPF treatment and one

decision task from the HL lottery would be selected at random and played out for real money. This random lottery incentive system is commonly used in lottery-choice risk experiments (Humphrey and Verschoor 2004). Nevertheless, there is an ongoing controversial debate on the use of monetary incentives as rewards for participants in experiments and the practice of paying only some participants for only some of their decisions. Camerer and Hogarth (1999) found that using high financial incentives for a fraction of participants rather than providing small incentives for each of the participants often improves participants' performance during the experiment because participants often overweigh their chances of being selected. We chose one participant at random for payment for each of the experimental parts of our payment design; hence we had three winners per session. The earnings of two participants for the NPF and WPF treatment in the investment experiment were based on their individual scores attained on one randomly chosen repetition of the respective treatment. Each repetition had exactly the same probability to be drawn. The potential earnings varied between 6,800 UGX and 24,000 UGX for the NPF treatment and between 1,400 UGX and 24,000 UGX for the WPF treatment. The average payoffs in the investment experiment were 15,287 UGX (approximately 5.1 €) in the NPF treatment and 14,956 UGX (approximately 5.0 €) in the WPF treatment. The earning of the participant from the lottery-choice experiment was based on his/her preference expressed between various mutually exclusive alternatives in the lottery. Each decision task had exactly the same probability to be drawn. The potential earning varied between 300 UGX and 11,550 UGX. The average payoff in the lottery-choice experiment was 6,674 UGX (approximately 2.2 €). All participants received a show-up fee of 5,000 UGX as a compensation for their time. This compares to one day of casual farm labor wage in this area. Participants were paid in cash by the assistant experimenter at the end of the experiment.

The payment in the experiment was conducted in the following way: In both treatments of the investment experiment, farmers were informed that one participant of the group and one repetition of the game would be randomly selected for payment. The winner was then determined by drawing a number between one and six out of a bag. The holder of the number that was picked from the bag was the winner and received the payment. The repetition relevant for payment was determined by drawing a number between one and 10 out of a bag. The number that was picked from the bag was the choice that counts for payment. In the lottery-choice experiment, farmers were informed that one participant of

the group would be randomly selected and would receive a prize between 300 UGX and 11,550 UGX depending on his/her decision. Choosing the winner and the decision task relevant for payment was conducted in the same way as in the investment experiment by drawing a number out of a bag. A third draw decided whether the low or high prize of 'Bag A' or 'Bag B' would be realized. In case the participant chose 'Bag A', he/she had to draw a ball out of this bag and would have the chance to win 4,800 UGX or 6,000 UGX with the respective probability. If the participant chose 'Bag B', he/she had to draw a ball out of this bag and would have the chance to win either 300 UGX or 11,550 UGX with the respective probability.

5   Normative benchmarks

To evaluate the actual investment behavior that farmers show in the experiment, we derive normative benchmarks which reflect the NPV and the ROA, respectively. The determined normative benchmarks mark the threshold levels on which it becomes optimal to invest according to the NPV and ROA, the so-called investment triggers. The investment triggers following the NPV can be directly determined via annualizing the investment costs. In contrast, the investment triggers of the ROA have to be calculated by dynamic stochastic programming (Trigeorgis 1996, p. 312). Fig. 3 illustrates the normative benchmarks of the investment according to the NPV and the ROA for a risk neutral decision maker for both the NPF and WPF investment treatment. The investment triggers of the ROA decrease exponentially reflecting the diminishing time value of the investment option. The trigger value of the ROA starts in period 0 at 14,070 points in the NPF treatment and at 14,436 points in the WPF treatment. The triggers of the ROA of both treatments equal the triggers of the NPV in period 4, when the option to invest expires and it is not possible to postpone the decision.
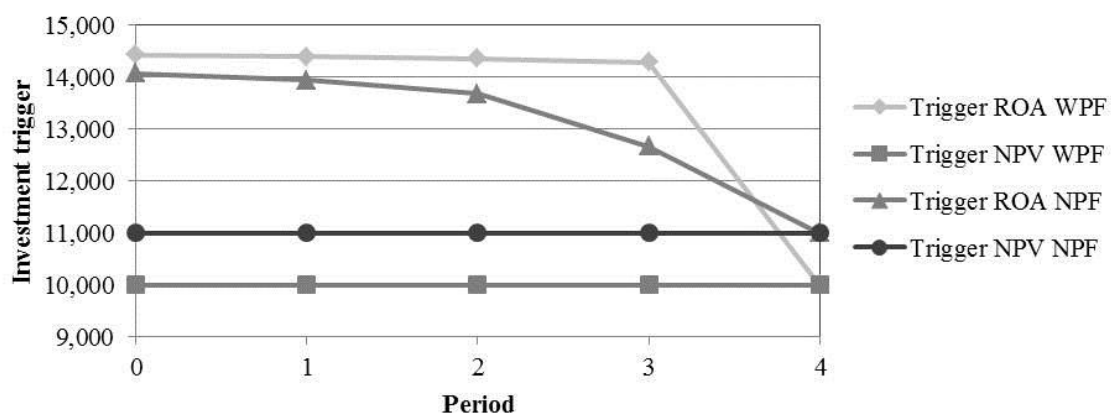
Fig. 3 Investment triggers for a risk neutral decision maker

For the determination of the normative benchmarks we do not assume that the decision makers are risk neutral, rather we take into account the individual risk attitude participants show in the HL lottery. On the basis of these results, we determine the respective risk-adjusted discount rates. Following Holt and Laury (2002), we assume a power risk utility function, which implies decreasing absolute risk aversion (DARA) and constant relative risk aversion (CRRA):

$$U(V) = V^{1-\theta} \tag{9}$$

Here U denotes utility, V describes the present value of the investment returns, and θ is the risk aversion coefficient. Based on equation (9) we can derive θ for each individual from his/her choices in the HL lottery. Thus, the certainty equivalent (CE) of a risky prospect can be calculated as follows:

$$CE = V\left(E\big(U(V)\big)\right) = E\big(U(V)\big)^{\frac{1}{1-\theta}} = E(V) - RP \tag{10}$$

where $E(V)$ is the expected present value of the investment returns and RP is a risk premium. The present value of the certainty equivalent CE_0 of an uncertain payment V_T at time T can be defined as follows:

$$CE_0 = CE_T \cdot (1+r)^{-T} = (E(V_T) - RP_T) \cdot (1+r)^{-T} \tag{11}$$

where r is the risk-free interest rate. An equivalent risk-adjusted discount rate $r^* = r + v$ can be derived from equation (11) using the following equation:

$$(E(V_T) - RP_T) \cdot (1+r)^{-T} = E(V_T) \cdot (1+r+v)^{-T} \tag{12}$$

$$\rightarrow v = (1+r)\left(\left(\frac{E(V_T)}{E(V_T) - RP_T}\right)^{1/T} 1\right)$$

The risk loading v, and thus the risk-adjusted discount rate $r + v$ depend on the risk premium RP as well as on the length of the discounting period T.

Applying dynamic programming to the binominal tree displayed in figure 1 using risk-adjusted discount rates from equation (12) is problematic because the certainty equivalent of the up and down movements, and thus the risk-adjusted discount rates are not constant over time. This leads to a non-recombining binomial tree for the stochastic variable, in which the number of potential states increases exponentially with the number of periods (Longstaff and Schwartz 2001). Therefore, we first fix the level of the returns at its initial

value. Second, we fix T at one period in equation (12). We derive 9 discount rates per treatment representing different risk attitudes for each treatment. In the NPF treatment, the risk-adjusted discount rates vary between 9.28% (HL lottery value = 0) and 10.62% (HL lottery value = 9) and in the WPF treatment between 7.77% (HL lottery value = 0) and 8.05% (HL lottery value = 9).

6   Experimental results

In the following subsections, we present the descriptive statistics and test the validity of our hypotheses derived in Section 2.

6.1   Descriptive statistics

Table 2 presents some descriptive statistics on the individuals who participated in the experiment as well as an overview of the normatively expected and actual investment decision behavior.

As can be seen from the table, on average, the participants were slightly risk averse (HL lottery value = 5.20). Although 77.11% of the participants revealed risk aversion, 9.34% of them were risk neutral, and 13.55% of them were risk seeking. The average age of participants is 50.21 years and ranges from 18 to 90 years. About 39% of the participants are female. The education of the household head is on average 6.67 years of schooling. The average household size is 6.56. About 43% of the participants live in the Luwero district, while 57% of them live in the Masaka district. In order to assess whether farmers have a basic comprehension of probabilities, we conducted a short quiz composed of three simple questions before the experimental sessions started. On average, each farmer answered two out of the three questions correctly. The average annual per capita household expenditure on non-food items is approximately 516,855 UGX. The mean farm size for each farmer is about 5.73 acres, ranging between 1 acre and 42 acres. About 28% of the farmers indicated that they have access to a savings account, while 43% claimed that they are able to access financial credit for agricultural activities whenever they need it. The majority of farmers, about 80%, are members of a farmer group organization.

Table 2 Descriptive statistics of respondents' characteristics (N = 332)

Parameter	NPF treatment with 3,320 decisions	WPF treatment with 3,320 decisions
Socio-demographic characteristics		
Risk attitude (HL lottery value)[a]	5.20 (1.96)	
Age (years)	50.21 (14.28)	
Gender (dummy = 1 if female, 0 otherwise)	0.39 (0.49)	
Education (years)	6.67 (3.60)	
Household size (number)	6.56 (3.10)	
District (dummy = 1 if from Masaka, 0 = if from Luwero)	0.57 (0.50)	
Quiz test score (number of questions correctly answered) [b]	2.05 (0.78)	
Socio-economic characteristics		
Annual per capita household expenditure (UGX)[c]	516,855 (392,949)	
Total land owned (acres)[d]	5.73 (4.53)	
Access to a savings account (dummy = 1 if yes, 0 otherwise)	0.28 (0.45)	
Access to credit (dummy = 1 if yes, 0 otherwise)	0.43 (0.50)	
Member of farmer group (dummy = 1 if yes, 0 otherwise)	0.80 (0.40)	
Investment behavior		
Actual investment period without repetitions of non-investment	2.49 (1.45)	2.45(1.46)
Actual share of repetitions with non-investment (%)	40.27	38.49
Normative investment period following NPV without repetitions of non-investment	1.39 (0.79)	0.00 (0.00)
Normative share of repetitions with non-investment following NPV (%)	36.81	0.00
Normative investment period following ROA without repetitions of non-investment	2.66 (0.94)	2.99 (0.10)
Normative share of repetitions with non-investment following ROA (%)	59.04	0.00

Notes: Standard deviations are indicated in parentheses in column two and three.
[a] A HL lottery-value between 0 and 3 expresses risk preference, a HL lottery value of 4 implies risk neutrality, and a HL lottery value between 5 and 9 expresses risk aversion.
[b] The quiz contains three questions, in total. About 76%, 92% and 37% of the participants correctly answered question one, two and three, respectively.
[c] At the time of the experiments, the exchange rate was approximately 3,000 UGX per €.
[d] 1 acre = 0.40 hectare.
Source: Survey data.

The actual investment period chosen by participants in the experiment is on average period 2.49 in the NPF treatment and period 2.45 in the WPF treatment. These figures do not take into account repetitions with non-investment. In 40.27% and 38.49% of the repetitions, participants chose not to invest, respectively. The optimal investment period predicted by the NPV is 1.39 in the NPF treatment and 0.00 in the WPF treatment. The share of repetitions of non-investments is 36.81% and 0.00%, respectively. The optimal investment period predicted by the ROA is 2.66 in the NPF treatment and 2.99 in the WPF treatment. The share of repetitions of non-investments is 59.04% and 0.00%, respectively. This is already an initial indication for the validity of *H1*. Participants invested on average

much earlier than predicted by the NPV and closer to the predictions of the ROA in both treatments.

6.2   Validity test of hypotheses

To verify *H1 'ROA superiority to NPV'* and *H3 'Learning effect'*, the data set of the NPF and WPF treatment is pooled, whereas we analyze the data set separately to test *H2 'Price floor effect'*.

Test of H1 'ROA superiority to NPV'

To test *H1*, we compare the actual investment behavior with the benchmark prediction according to the NPV and the ROA. We apply the Kaplan-Meier survival estimator, also referred to as the product limit estimator (Kaplan and Meier 1958), as modified by Kiefer (1988) to deal with censored data. In our experiment, in 40.27% in the NPF treatment and in 38.49% in the WPF treatment of the total 6,640 cases, participants decided not to invest, which means that a defined investment period was not observed. In this case, data is right-censored as durations end after the time frame of observation.

Fig. 4 shows the survival functions of the Kaplan-Meier estimation of the actual and the optimal investment behavior according to the NPV and ROA. The staircase-shaped curves illustrate the cumulative option exercise over the periods. It indicates the percentage of investments realized per period. Declines in the survival curve occur whenever participants decide to invest. A log-rank test of the equality of the survival functions shows that there is a statistically significant difference between the actual investment behavior and the normative benchmarks according to the NPV and the ROA (p-value < 0.001). An additional analysis that examined both treatments separately generates similar results. Based on this finding, we conclude that neither the NPV nor the ROA provides an accurate prediction of the experimentally observed investment behavior of farmers.
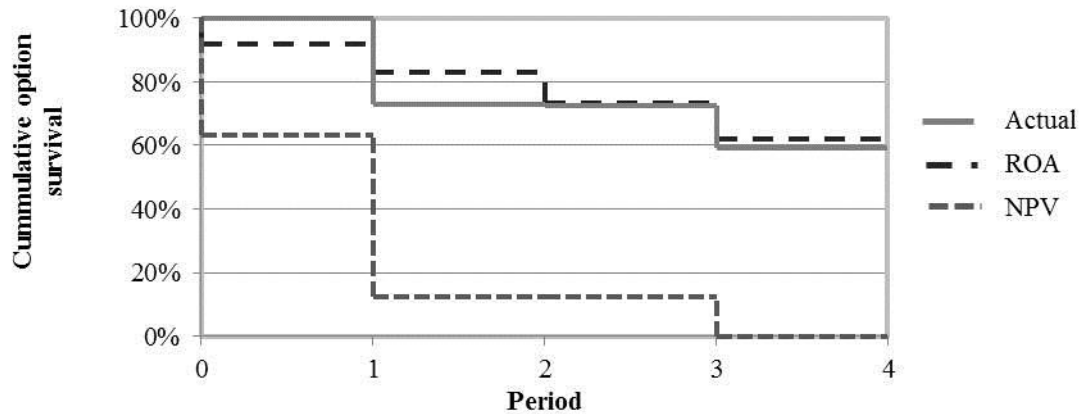
Fig. 4 Survival functions of actual and optimal investment behavior according to NPV and ROA

In Fig. 4, the curve of the actual investment behavior is below that of the optimal decision behavior according to the ROA and above the curve of the optimal decision behavior according to the NPV. That means that farmers invest later than predicted by the NPV but earlier than suggested by the ROA. However, the curve of the observed decision behavior seems to be closer to the optimal decision behavior according to the ROA, meaning that farmers invest more in accordance with the ROA. Against this background, we fail to reject *H1 'ROA superiority to NPV'*. Our results show that the ROA is able to predict actual investment decisions better than the NPV. These findings are consistent with previous investigations (Oprea et al. 2009; Maart-Noelck and Musshoff 2013).

Test of H2 'Price floor effect'

To test *H2*, we compare the participants' actual investment behavior in the NPF and WPF treatment and find that it does not differ significantly. Fig. 5 illustrates the survival functions for both treatments. The log-rank test shows a p-value of 0.094 and thus gives statistical evidence for the equality of the survival functions. This result shows that the price floor does not have a statistically significant effect on Ugandan smallholder farmers' investment behavior. Thus, we fail to reject *H2 'Price floor effect'*. In accordance to the theoretical predictions of the ROA, price floors do not stimulate investments in our experiment.
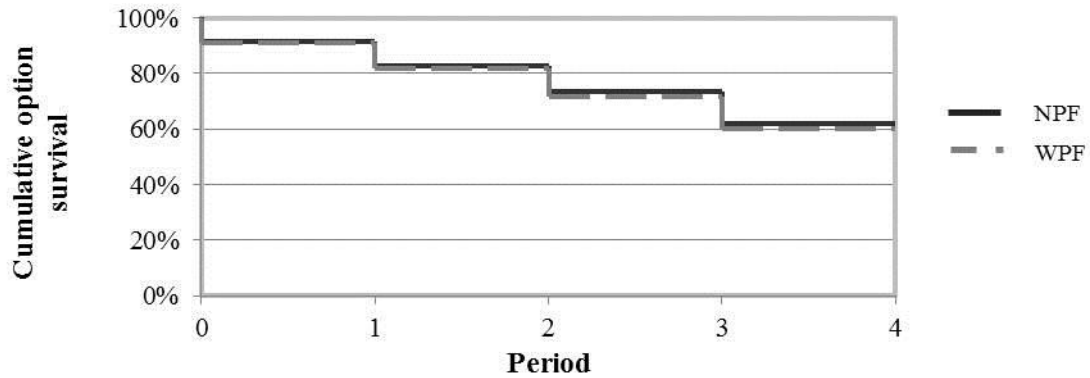
Fig. 5 Comparison of the survival functions for the NPF and WPF treatment

Test of H3 'Learning effect'

To test *H3* and to analyze the impact of further variables on the investment time, we run a Tobit regression. The dependent variable in the regression model is the individual investment period of farmers. Table 3 presents the results of the Tobit regression model. In our experiment, farmers were faced with repeated investment opportunities. Each farmer repeated the NPF and WPF treatment 10 times so that in each case they had 10 times the option to invest. The estimated coefficient of repetition is not statistically significant, which is surprising because previous findings of Oprea et al. (2009) reveal that participants consider the value of waiting in investment decisions over time if they are given a chance to learn from personal experience. On this basis, we reject *H3 'Learning effect'*.

In the experiment, farmers were faced with both treatments in a different order so that some were at first faced with the NPF treatment and then with the WPF treatment or with both treatments in a reverse order. According to Day et al. (2012) and Scheufele and Bennett (2013), repeated choice tasks may influence outcomes through order effects. We examined the presence of an 'order effect', meaning that we tested whether farmers show different investment behaviors when faced with the treatments in a different order. The coefficient order is positive and statistically significant. This result shows that farmers demonstrate significantly different investment behaviors dependent on the order in which they are faced with the two treatments. Participants who are first faced with the WPF treatment and second with the NPF treatment invest later or more inert than participants who are faced with the treatments in reverse order. This result shows that the abolishment of price floors causes pronounced increases in inertia. However, it may also indicate a 'learning effect', meaning that farmers acquire routines for repetitive decisions at the beginning of the experiment and apply them to later decisions even if they are related to

another treatment. The non-significant coefficient of the variable treatment reinforces the results of the *H2 'Price floor effect'* analysis. It indicates that participants do not invest significantly different in the WPF treatment compared to the NPF treatment, i.e. price floors do not stimulate investments in our experiment.

Table 3 Results of the Tobit regression of the individual investment period (N = 6,640)

Variable	Coefficient	Standard error	*p*-value	
Repetition	0.009	0.011	0.398	
Order of experiment *(0 = NPF-WPF, 1 = WPF-NPF)*	0.330	0.065	<0.000	**
Treatment *(0 = NPF, 1 = WPF)*	-0.115	0.063	0.069	
Risk attitude	0.173	0.017	<0.000	**
Age *(years)*	-0.000	0.002	0.863	
Gender *(1= female)*	0.116	0.069	0.091	
Education *(years)*	0.022	0.011	0.035	*
Household size *(number)*	0.043	0.012	0.000	**
District *(0 = Luwero, 1 = Masaka)*	-0.820	0.070	<0.000	**
Quiz test score *(number)*	0.024	0.044	0.576	
Per capita household expenditure *(UGX)*	8.196	0.000	0.485	
Total land owned *(acres)*	0.024	0.008	0.002	**
Access to a savings account *(dummy)*	0.237	0.079	0.003	**
Access to credit *(dummy)*	0.099	0.068	0.145	
Member of a farmer group *(dummy)*	-0.448	0.088	<0.000	**
Constant	2.798	0.234	<0.000	**
Log-likelihood		-11376,50		
Chi^2		440.012		

Notes: *p < 0.05, **p < 0.01.
Source: Survey data.

The coefficients of the variables risk attitude, education, household size, total land owned, and access to a savings account are positive and statistically significant. Our findings that participants who are more risk averse, have a higher education level and a larger household size, and own more land invest later confirm results in other studies (Viscusi et al. (2011) for risk; Hill (2010a) for education; Lewellen et al. (1977) for household size; Savastano and Scandizzo (2009) for farm size). Also, participants who have access to a savings account invest later, which does not support the results of Dupas and Robinson (2013). They found that savings accounts improve investment levels of individuals; thus we expect that participants who have access to a savings account invest earlier. The coefficient of the variable district is negative and significant and indicates that participants from the Masaka district invest earlier than participants from the Luwero district. This result is surprising due to the fact that farmers in Masaka are more enterprising compared to those in Luwero. Baerenklau (2005) supports the result by implying that investment behaviors of individuals

may differ across regions. The coefficient of the variable member of a farmers group is also negative and significant and implies that participants who are members of a farmer group invest earlier, confirming results in other studies (e.g., De Souza Filho et al. 1999). There is no significant effect of age, gender, per capita household expenditure, access to credit, and quiz test score, although some other studies find an effect (Jianakoplos and Bernasek (1998) for age; Gardebroek and Oude Lansink (2004) for gender; Hill and Viceisza (2012) for wealth; Fafchamps and Pender (1997) for credit; Cole et al. (2011) for math literacy).

7   Conclusions

A better understanding of farmers' decision to invest in a project under uncertainty is crucial for gaining insights into the dynamics of how uncertainty affects their investment behavior, interpreting agricultural outcomes, and designing policies that effectively assist farmers. Many investment options faced by smallholder farmers in developing countries are characterized by uncertain returns and especially poorer farmers may be impacted by such uncertainty. Therefore, this study examined the investment behavior of Ugandan smallholder farmers under flexibility, uncertainty, and irreversibility, while trying to determine the underlying models of investment consistent with actual decision behavior during an experiment and to analyze the effect of a price floor. The investment decisions were modeled as real options, which refer to the rights to invest in a project. The observed investment decisions were contrasted with normative benchmarks, which were derived from the NPV and the ROA.

Our findings are first that neither the NPV nor the ROA provides an exact prediction of farmers' investment behavior observed in the experiment. Ugandan farmers invest later than predicted by the NPV but earlier than suggested by the ROA. However, the results suggest that the ROA can predict actual investment decisions better than the NPV. Second, the actual investment behavior does not differ significantly with respect to the presence of a price floor, which coincides with the theoretical predictions of the ROA. Third, we do not find evidence for a learning effect, meaning that Ugandan farmers do not learn from personal experience during the experiment and approximate the predictions of the ROA over time. However, we find that specific socio-demographic and socio-economic variables such as risk attitude, education, household size, total land owned, access to a

savings account, and membership of a farmer group affect the investment behavior of farmers.

When interpreting the results, it is important to consider that our experimental design is abstracted from reality and is considerably simpler than investment situations that would occur in an actual business setting. Participants may act differently in the experimental situation than they do in a similar situation in the real world. A common criticism of experiments has to do with whether experimental results are likely to provide reliable inferences outside the laboratory and can be extrapolated to the real world (Levitt and List 2009; Roe and Just 2009). This lack of external validity is considered to be the major of laboratory experiments (Loewenstein 1999). Actually, there is an intensive debate on the trade-off between the internal and external validity of economic experiments (Camerer, 2003; Guala, 2005). However, there is a widespread consensus that the benefits of internal validity are more important than the lack of external validity if the experiments aim to test economic theories, as is the case in our study (see Schram 2005).

Our study shows that flexibility, uncertainty, and irreversibility play a role in farmers' decision making process to invest in a project. This finding is extremely relevant from a policy maker's perspective. It highlights the danger of designing policy measures solely based on the NPV given that this approach is not individually sufficient in order to explain investment decisions. The NPV fails to address the role of sunk costs, temporal flexibility, and uncertainty in the farmer's decision making process. However, it also is not sufficient to solely focus on the ROA when designing appropriate policy measures, since socio-demographic and socio-economic factors also play a role. Policies that allow farmers to be more certain of future returns or practices that can reduce the uncertainty might encourage a more responsive investment strategy, regardless of the decision makers' risk attitude. An understanding of the investment decisions taken by farmers is therefore important for the formulation of adequate forecasts and policy recommendations in the agricultural sector.

Several opportunities present themselves for future research. First, it is possible that potential drivers of psychological inertia also play a role when explaining investment behavior. A behavioral phenomenon that might influence the intuitive choice of investment triggers towards postponement of this decision is the escalation of commitment effect (Staw 1981; Denison 2009). This effect describes the phenomenon that it is difficult to dissuade someone from a course that the person had previously adopted. That would mean that decision makers have the tendency to persist on a failing course of action. With regard

to our investment experiment, participants are faced with repeated decision situations in which object returns may fall x-times in a row. Then, participants have the choice either to invest or to continue waiting in the hopes that returns increase. Here, the question arises, whether or not participants follow specific rules of thumb in their decision-making process. It would be interesting to reveal the heuristics, which participants apply to make investment decisions. Second, more research is needed to examine whether the actual price floor level has an effect on the investment behavior. Here, it would be interesting to test different price floor levels. Third, to increase the validity of our results it would be useful to investigate whether farmers in developing countries show a similar investment behavior in different framing situations, e.g., investment in agricultural technology. Fourth, the finding that farmers' investment behaviors differ across regions shows that it is not possible to infer from our results to other developing countries; instead it highlights the importance to conduct further investment experiments in other developing countries. Another interesting path to be taken would be to examine the disinvestment behavior of farmers. To the best of our knowledge, there are no experimental studies that consider farmers' behavior under uncertainty with regard to long-term disinvestment decisions in developing countries. The experimental investigation of real options settings in developing countries is still in its early stages. Therefore, in this regard further research is required to better understand what exactly drives individuals' decision making in investment situations and to predict this behavior in the future.

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Appendix: Experimental instructions

Outline

The experiment session comprises:

1. Sign-in (location and arrival)
2. Introduction and agenda (an introduction of the experimenter, enumerators, assistant experimenter, and the project)
3. Quiz
4. Instructions, practice, and decision making (coin tossing games are randomized)
    - 4.1 Lottery game
    - 4.2 Coin tossing game (no price floor)
    - 4.3 Coin tossing game (with price floor)
5. Payment

1 Sign-in (location and arrival)

- Each participant will present his/her photo ID before he/she will be signed in. The participant will then draw a number out of a bag. This number (personal number of the respondent) randomly determines his/her seat, which is the individual's location throughout the experiment session.
- The experiment will be conducted in sessions of six participants in classrooms in local schools or in a meeting room at the main gathering place of a farmer's group or association.
- Each participant will have his/her own enumerator.
- The typical layout of the room will be as follows:

Front of room (experimenter, and white board)	
Seat 1	Seat 2
Seat 3	Seat 4
Seat 5	Seat 6
Back of room (assistant experimenter/cashier)	

Notes:
- *Text in italics is not part of the participant instructions.*
- *The instructions are explained orally by the experimenter in the local language.*
- *Once all the participants are seated, the explanation will start.*

2 Introduction and agenda

- Hello and welcome. Thank you for coming to our workshop today.
- *The experimenter introduces himself, the enumerators, and the assistant experimenter. The experimenter introduces the institution and the project, typically as follows:*
    - In Uganda, we are conducting a research project on farmers' decision behavior in investment situations.
    - We have been holding discussions with farmers across many parts of Uganda. In particular, we have talked to farmers in …, but we have not been here before.

- We are very grateful that we can do the workshop in this area today and that you find some time to participate. Thank you very much for that.
- For the upcoming tasks, you will receive cash payments for the decisions you make. We provide these payments for two purposes:
  i. Because you came here today and you are spending your time with us. This is time in which you could be doing something else, so we would like to remunerate this.
  ii. Also, we would like you to take this decision seriously, so that it represents your decision making behavior of normal real life decisions.
- Today's workshop will include the following steps:
  - First, we explain the instructions of the different tasks on decision making.
  - Then, we will do a practice run together to show how it works. Then, you will make your decisions. Today, we will do several types of decisions. In a moment, I will explain all the different tasks on decision making in more detail, one after another.
  - Then, you will receive your payment. Payment will be effected in private and in cash at the end of today's workshop.
- I have some additional general comments:
  - Please turn off your mobile phones, etc.
  - All decisions you make or answers you give during the workshop are private, confidential, and anonymous.
  - Since all decisions and answers are private, please do not talk to each other anymore. If you have questions, please ask us by raising your hand.
  - Please do not discuss with your neighbor except for the enumerator next to you. The enumerator next to you will record your answers.
  - When making decisions, you should make the decision that you prefer the most as you will receive the cash payment on the basis of that decision, given that you have been selected as a winner. Please make your decisions as if they are real life decisions.
  - If there are any questions at any point, please raise your hand and ask.
  - Any questions before we start?

3 Quiz

- *The experimenter hands out the questionnaire to the enumerator. Then, explanation and decision making would start.*
- We will start today's workshop with a short quiz.
- The quiz contains several tasks. It is not a test; you do not need to worry if the questions seem difficult.
- *Questions are asked with regard to probabilities and percentage calculation. This basically enables the participants to start thinking about the material and the decisions they will be presented with during the workshop. The participants make their choice, and their enumerators record the answers and tick the relevant box.*
- Now, we are coming to the first task.
- 1. Imagine, we toss a coin and the 'head' (emblem) comes up. What comes up if we toss the coin again? (possible answers: a = head, b = tail, c = one cannot predict exactly)
- Now, we are coming to the second task.
- 2. If the chance of winning a prize is 10%, how many people out of 100 would be expected to get the prize? If you don't know, put an X.

- Now, we are coming to the last task of this quiz.
- 3. When you draw the red ball, you win! Look at the two boxes and mark the correct sentence. (Possible answers: a = my chance to win is higher if I choose Box A. b = my chance to win is equal, it does not matter which box I choose. c = my chance to win is higher if I choose Box B.)
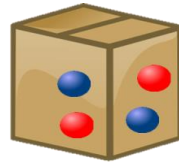
Box A   Box B
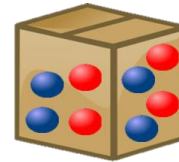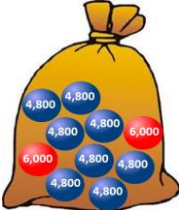
4 Instructions and decision making

4.1 Lottery game

- In the first session, you are asked to choose between two bags. You will be asked to make a number of repeated choices.
- I will now explain the first session. Then, you will make your decisions in this session.
- *Posters are displayed on a large white board at the front of the room. This is used to illustrate the basics of the game as explained below.*
- The objective of this task is to win money. There are four possible prizes: 300 UGX, 4,800 UGX, 6,000 UGX, and 11,550 UGX. The four different colored balls represent the four possible prizes. The green ball is worth 300 UGX, the blue ball is worth 4,800 UGX, the red ball is worth 6,000 UGX, and the yellow ball is worth 11,550 UGX.
- Note that we will randomly select one winner out of you for this task.
- *Show poster 2: The picture of the sheet with the lottery game*
- *Real balls will also be shown.*

Choose your preferred bag by marking either **Bag A** or **B** in each row.

[…]   […]

- How are you going to win these prizes?
- To win these prizes, you will first have to choose between two bags, Bag A and Bag B for each of the 10 rows. How do these two bags differ? Each bag contains 10 balls. The two bags contain differently colored balls (green, blue, red, and yellow) with a different value. We draw only one ball of the selected bag, which will be the prize. If you choose Bag A, you can win a prize of 6,000 UGX (red ball) or a prize of 4,800 UGX (blue ball). And if you choose Bag B, you can win a prize of 11,550 UGX (yellow ball) or a prize of 300 UGX (green ball). We are going to ask you which of these two bags you prefer.
- Note that with Bag A the difference between the prizes is small, while it is large in the case of Bag B.
- In addition, in Bag A the prize of 6,000 UGX is smaller than the prize of 11,550 UGX in Bag B, and the prize of 4,800 UGX in Bag A is greater than the prize of 300 UGX in Bag B.
- Thus, you will choose between Bag A and Bag B in 10 rows, one after another.
- Let's focus on the first row.
- *Show poster 2: example for Bag A or Bag B in row one*

- Bag A:
  - Bag A contains nine blue balls and one red ball. Each blue ball is worth 4,800 UGX, and the red ball is worth 6,000 UGX.
  - If this bag is selected and the red ball is subsequently drawn, you will win 6,000 UGX. In the case that one of the blue balls is drawn, you will win 4,800 UGX.
  - So, if we pick a ball from the bag, it may be blue or red. But, it is more likely that we pick one of the blue balls because there are more blue balls (than red balls) in the bag.
- Bag B:
  - Now, let's look at Bag B. What is different about it? Well, this bag contains nine green balls and one yellow ball. Each green ball is worth 300 UGX, and the yellow ball is worth 11,550 UGX.
  - If this bag is selected and the yellow ball is subsequently drawn, you will win 11,550 UGX. In the case that one of the green balls is drawn, you will win 300 UGX.
  - So, if we pick a ball from the bag, it may be a green or a yellow one. But, it is more likely that we pick one of the green balls because there are more green balls (than yellow balls) in the bag.

- This explains row one. How do the other rows differ from row one?
- *Show poster 3: example for Bag A or Bag B in row two*

- Note that when we go from row one to row two, the only aspect that changes is the number of red balls in the bags. That is, the value of the balls does NOT change.
- Bag A:
    - Bag A contains eight blue balls and two red balls. Each blue ball is worth 4,800 UGX and each red ball is worth 6,000 UGX.
    - If this bag is selected and the red ball is subsequently drawn, you will win 6,000 UGX. In the case that one of the blue balls is drawn, you will win 4,800 UGX.
    - So, if we pick a ball from the bag, it may be blue or red. But, it is more likely that one of the blue balls is drawn because there are more blue balls (than red balls) in the bag.
- Bag B:
    - Bag B contains eight green balls (each worth 300 UGX) and two yellow balls (each worth 11,550 UGX). Each green ball is worth 300 UGX, and each yellow ball is worth 11,550 UGX.
    - If this bag is selected and the yellow ball is subsequently drawn, you will win 11,550 UGX. In the case that one of the green balls is drawn, you will win 300 UGX.
    - So, if we pick a ball from the bag, it may be green or yellow. But, it is more likely that one of the green balls is drawn because there are more green balls (than yellow balls) in the bag.
- *Quiz participants for understanding (control questions):*
- Now, what happens if we go from row two to row three?
- *Show poster 4: example for Bag A or Bag B in row three*

- How many blue and red balls does Bag A contain?
- How many green and yellow balls does Bag B contain?
- Suppose you choose Bag A and the red ball is drawn, how much do you win?
- Suppose you choose Bag B and the yellow ball is drawn, how much is it worth?
- *etc.*
- So, we are going to ask you to decide for bag A or B in each of the 10 rows.
- Note that your choice should really be guided by your preferences. There are no wrong or right decisions.
- *Then, participants are informed that only one row will be selected for payment and that only one person wins the prize.*
- How will we determine the amount of money you will win for participating in this task? Now, we will explain the payment for this game.
- Only one person will receive a payment for one of the choices he/she made in this task. However, you do not know yet for which of the choices the selected person will receive the payment, so that you better think about each choice very carefully. You will only find out at the end of this task for which of these choices the selected person is going to receive a payment.
- The payment in this game comprises three draws:
  - The first draw is to determine the person who wins a prize. Remember, in the beginning of today's workshop, you got a personal number. We will ask one of you to draw a number between 1 and 6 out of a bag. The holder of the number that is picked from the bag will be the winner of one of the prizes.
  - The second draw is to determine the row for which you will get paid. We will ask the selected person to draw a number between one and 10 out of a bag. The number that is picked from the bag will be the choice that counts for the selected person.
  - The third draw is to determine whether the person receives the low or high prize. We will ask the selected person to draw a ball out of Bag A in case he/she chose Bag A or one out of Bag B in case he/she chose Bag B. The ball that is picked from the respective bag will be the choice that counts for him/her.

- Are there any questions before we start?
- *Then, decisions will be made.*
- Which bag do you choose? Choose your preferred bag by marking either Bag A or B in each row.
- *The enumerators ask their farmers for each of the 10 rows which bag they prefer. The participants make their choice by pointing at the bag they prefer, and their enumerators record the answers and tick the relevant box.*

4.2 Coin tossing game (no price floor treatment)

- The second/third session is a coin tossing game. It is possible to buy the right to participate in a coin tossing game and to earn money during the game.
- I will now explain the session. Then, you will make your decisions in this session.
- *Posters are displayed on a large white board at the front of the room. This is used to illustrate the basics of the game as explained below. Calculators are provided in case participants want to use them.*
- The objective of this task is to collect as many bags as possible. The more bags you earn, the greater your earnings. One bag is worth 1,000 UGX.
- The game consists of 10 repetitions of the same game. In each game, you will have the chance to earn some bags. How many bags you earn will depend on your decisions during the game.
- In the beginning of each game, you will have a starting balance of 10 bags.
- Imagine a friend offers you to participate in a coin tossing game. You can decide within 5 periods:
- to either immediately participate in the game and pay 10 bags and get a payoff in the following period,
- to wait and see the development of the bags that can potentially be achieved (up to 4 periods) and to participate in the coin tossing game later
- or not to participate in the coin tossing game and save the 10 bags.
- *Show poster 1: decision tree*
- In the period between 0 and 4, you can decide to participate in the game only once. If you decide to participate in the game, regardless in which period you participate, you have to pay 10 bags.
- Is this clear?
- Any questions at this point?
- The tree chart below shows the possible bags which you can earn in the respective periods when participating in the coin tossing game.
- In each game, you will start with a score of 10 bags in period 0. In the next period (period 1) and in any subsequent period: your bags can either increase by 2 bags or they can decrease by 2 bags depending on a coin that will be tossed, i.e. upper amount if tail (fish) appears or the lower amount if head (emblem) appears.
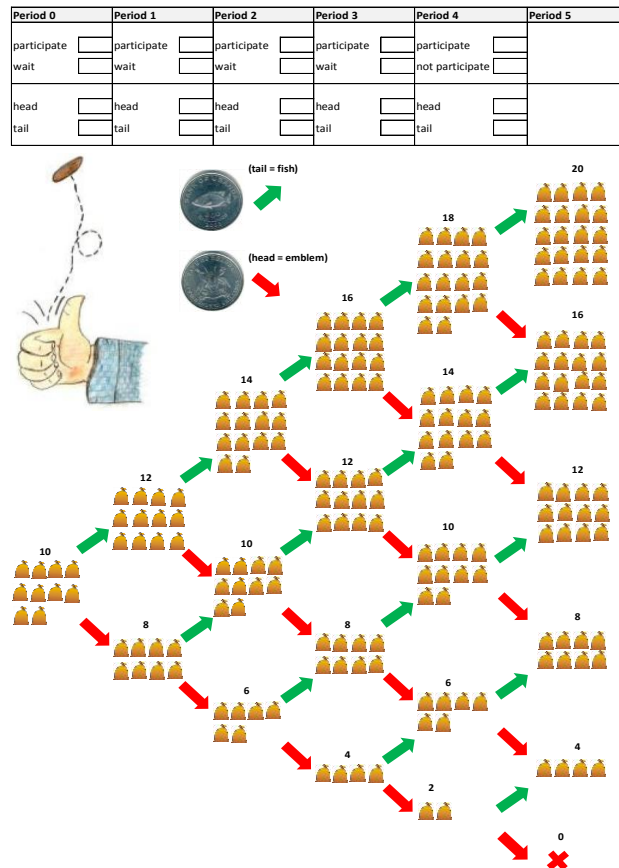
Period 0		Period 1		Period 2		Period 3		Period 4		Period 5
participate		participate		participate		participate		participate		
wait		wait		wait		wait		not participate		
head		head		head		head		head		
tail		tail		tail		tail		tail		

- Each period involves the following steps: You decide whether or not to participate in the coin tossing game. The enumerator will record your decision by marking the appropriate box on the decision form in front of you. Once the enumerator has marked your decision for the period, you can no longer change it. When all of you have made the decisions, the experimenter will toss a coin. The enumerator will mark the appropriate box on the decision form for the coin tossing, i.e. if head or tail appears. We then go to the next period. If you had chosen not to participate in the earlier period, you will make a decision whether or not to participate in this period after having observed the outcome of the previous period. If you had chosen to participate in the coin tossing game, the game is over for you and you have to wait for the next repetition of the game. Nevertheless, we toss the coin for each period in this game.
- We will now see a participation decision example.
- *Show poster 2: participation decision example*
- Imagine, you decide to participate in the coin tossing game in period 3. Tossing the coin will decide how the score will develop (it is a fair coin, i.e. head or tail appear with the same probability).
- In period 0, you do not participate in the game. Nevertheless, the coin will be tossed and head comes up. The bags decrease by 2 bags, from 10 bags to 8 bags.
- In period 1, you still decide not to participate. The coin will be tossed and tail comes up. The bags increase by 2 bags, from 8 bags to 10 bags.
- In period 2, you still decide not to participate. Nevertheless, the coin will be tossed and tail comes up. The bags increase by 2 bags, from 10 bags to 12 bags.
- In period 3, you decide to participate in the game and to pay 10 bags.
- If heads comes up, you will get 10 bags in period 4.
- If tails comes up, you will get 14 bags in period 4.

- We assume that the coin is tossed and head comes up, thus, resulting in a score of 10 bags in period 4.
- The development could be the following:

- *Show poster 3: participation decision example (decision tree)*

Period 0		Period 1		Period 2		Period 3		Period 4		Period 5	
participate		participate		participate		participate	✖	participate			
wait	✖	wait	✖	wait	✖	wait		not participate			
head	✖	head		head		head		head	✖		
tail		tail	✖	tail		tail	✖	tail			

- We will now see an example for the calculation of your final account balance.
- *Show poster 4: example calculation final account balance*
- Imagine the situation of the aforementioned example. In period 3 at a score of 12 bags, you decided to participate in the coin tossing game.
- We assume that a coin is tossed and head comes up, thus, resulting in a score of 10 bags in period 4.
- In this case, your total balance of period 5 would be calculated as follows:
- Your starting balance of 10 bags will yield 10% interest by period 3 (10 bags $(0.1 \cdot 3 + 1 = 13$ bags)). This means that for each period you decided not to participate in the game you receive 1 bag.
- In Period 3 you decided to participate in the coin tossing game and to pay 10 bags (13 bags - 10 bags = 3 bags).
- In Period 4, you receive 10 bags from the participation in the coin tossing game.
- These 10 bags will yield 10% interest by Period 5 (another 1 period). (10 bags $(0.1 \cdot 1 + 1)) = 11$ bags.
- In this example, your total balance in Period 5 will correspond to the following: 3 bags + 11 bags = 14 bags.
- In this game, your account balance would be 14 bags in Period 5.
- If this game was randomly selected for the cash premium, you would receive 14,000 UGX.
- Now, we will see an example if you decide not to participate in the coin tossing game.
- For example, if you decide not to participate in the coin tossing game within the 5 periods (between period 0 and period 4), your chance to participate expires, and you will leave the game with your starting balance of 10 bags that has increased to 15 bags over the 5 periods (10 bags $(0.1 \cdot 5 + 1 = 15$ bags)). This means that for

- each period in that you decided not to participate in the game, you receive 1 bag, which is 10% of your starting balance. You can think of this increase as an interest payment.
- In case this game is randomly selected for the cash premium, you will receive 15,000 UGX.
- Now, we will explain the payment in this game.
- One participant will be randomly selected for payment.
- And only one repetition of the game will be randomly selected for payment. However, you do not know yet for which of the decisions we will pay the chosen participant, so that you better think about each decision very carefully.
- The payment in this game comprises two draws:
    - The first draw is to determine the participant who receives the payment. We will ask one of you to draw a number between 1 and 6 out of a bag. The holder of the number that is picked from the bag will receive the payment.
    - The second draw is to determine the repetition for which the chosen participant will get paid. We will ask the selected person to draw a number between 1 and 10 out of a bag. The number that is picked from the bag will be the choice that counts for payment.
- Before we start the game, we would like to ask you to answer some questions. This is to ensure that you understood the instructions.
- *Participants who did not answer the control questions correctly are informed that they have incorrect answers and are asked to re-think their answers and try again. If they make mistakes again, the enumerator goes over the instructions and quiz them for a third time, and then asks them to proceed regardless of their answers. Importantly, we record the number of attempts each participant needed to answer the control questions correctly.The participants make their choice and their enumerators record the choice.*
- *Quiz participants for understanding (questions):*
    - What is the value of 1 bag?
    - If the score of the coin tossing game is 12 bags in one period, which two values can occur in the next period?
    - If you flip a coin, what is the chance that it lands 'head' (emblem) or 'tail' (fish)?
    - How much is the interest rate?
    - How much do you have to pay if you choose to participate in the coin tossing game?
- We are now going to do a practice period. The purpose of the practice period is to familiarize you with the procedure. Nothing that you do in the practice period will affect your earnings.
- *Practice period*
- This was a practice period. Now, we are going to start the real experiment where you can win real money.
- We are going to ask you to make a decision for each game. Remember that we will repeat this game 10 times.
- Is this clear?
- *Then, decisions will be made.*

4.3   Coin tossing game (with price floor treatment)

- The second/third session is a coin tossing game. It is possible to buy the right to participate in a coin tossing game and to earn money during the game.
- I will now explain the session. Then, you will make your decisions in this session.
- *Posters are displayed on a large white board at the front of the room. This is used to illustrate the basics of the game as explained below. Calculators are provided in case participants want to use them.*
- The objective of this task is to collect as many bags as possible. The more bags you earn, the greater your earnings. One bag is worth 1,000 UGX.
- The game consists of 10 repetitions of the same game. In each game, you will have the chance to earn some bags. How many bags you earn will depend on your decisions during the game.
- In the beginning of each game, you will have a starting balance of 10 bags.
- Imagine a friend offers you to participate in a coin tossing game. You can decide within 5 periods:
- to either immediately participate in the game and pay 10 bags and get a payoff in the following period,
- to wait and see the development of the bags that can potentially be achieved (up to 4 periods) and to participate in the coin tossing game later,
- or not to participate in the coin tossing game and save the 10 bags.
- In the period between 0 and 4, you can decide to participate in the game only once. If you decide to participate in the game, regardless in which period you participate, you have to pay 10 bags.
- Is this clear?
- Any questions at this point?
- The tree chart below shows the possible bags which you can earn in the respective periods when participating in the coin tossing game.
- In each game, we always guarantee you a payoff of 10 bags from participating in the coin tossing game. You will start with a score of 10 bags in period 0. In the next period (period 1) and in any subsequent period: your bags can either increase by 2 bags or they can decrease by 2 bags depending on a coin that will be tossed, i.e. upper amount if tail (fish) comes up or the lower amount if head (emblem) comes up. If the bags decrease under the score of 10 bags (light bags below the black line), you will get the missing bags from us, so that you always have a minimum of 10 bags.
- *Show poster 1: decision tree*
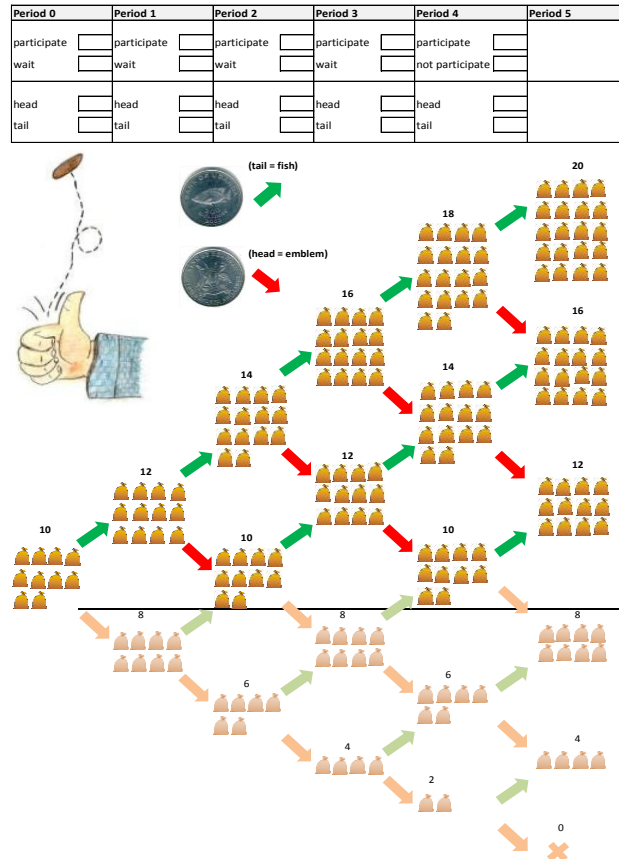
Period 0		Period 1		Period 2		Period 3		Period 4		Period 5
participate		participate		participate		participate		participate		
wait		wait		wait		wait		not participate		
head		head		head		head		head		
tail		tail		tail		tail		tail		

- Each period involves the following steps: You decide whether or not to participate in the coin tossing game. The enumerator will record your decision by marking the appropriate box on the decision form in front of you. Once the enumerator has marked your decision for the period, you cannot change it anymore. When all of you have made the decisions, the experimenter will toss a coin. The enumerator will mark the appropriate box on the decision form for the coin tossing i.e. if head or tail comes up. We then go to the next period. If you had chosen not to participate in the earlier period, you will make a decision whether or not to participate in this period after having observed the outcome of the previous period. If you had chosen to participate in the coin tossing game, the game is over for you and you have to wait for the next repetition of the game. Nevertheless, we toss the coin for each period in this game.
- We will now see a participation decision example.
- *Show poster 2: participation decision example*
- Imagine, you decide to participate in the coin tossing game in period 2. Tossing the coin will decide how the score will develop (it is a fair coin, i.e. head or tail appear with the probability).
- In period 0, you do not participate in the game. Nevertheless, the coin will be tossed and tail comes up. The bags increase by 2 bags, from 10 bags to 12 bags.
- In period 1, you still decide not to participate. The coin will be tossed and head comes up. The bags decrease by 2 bags, from 12 bags to 10 bags.
- In period 2, you decide to participate in the game and to pay 10 bags.
- If heads comes up, you will get 8 bags in period 3.
- If tails comes up, you will get 12 bags in period 3.
- We assume that the coin is tossed and head comes up, thus, resulting in a score of 8 bags in period 3.

- The development could be the following:

- *Show poster 3: participation decision example (decision tree)*

Period 0	Period 1	Period 2	Period 3	Period 4	Period 5
participate ☐	participate ☐	participate ✖	participate ☐	participate ☐	
wait ✖	wait ✖	wait ☐	wait ☐	not participate ☐	
head ☐	head ✖	head ✖	head ☐	head ☐	
tail ✖	tail ☐	tail ☐	tail ☐	tail ☐	

- We will now see an example for the calculation of your final account balance.
- *Show poster 4: example calculation final account balance*
- Imagine the situation of the aforementioned example. In Period 2 at a score of 10 bags, you decided to participate in the coin tossing game.
- We assume that in period 3 a coin is tossed and head comes up, thus, resulting in a score of 8 bags.
- In this case, your total balance of period 5 would be calculated as follows:
- Your starting balance of 10 bags will yield 10% interest by period 2 (10 bags $(0.1 \cdot 2 + 1 = 12$ bags$))$. This means that for each period you decided not to participate in the game you receive 1 bag.
- In Period 2 you decided to participate in the coin tossing game and to pay 10 bags (12 bags - 10 bags = 2 bags).
- In Period 3, you receive 8 bags from the participation in the coin tossing game. In this case the bags decrease under the score of 10 bags (light bags below the black line). As we guarantee you a payoff of 10 bags, you will get the 2 missing bags from us.
- These 10 bags will yield 10% interest by Period 5 (another 2 periods). (10 bags $(0.1 \cdot 2 + 1)) = 12$ bags.
- In this example, your total balance in Period 5 will correspond to the following: 2 bags + 12 bags = 14 bags.
- In this game, your account balance would be 14 bags in Period 5.
- If this game was randomly selected for the cash premium, you would receive 14,000 UGX.
- Now, we will see an example if you decide not to participate in the coin tossing game.

- For example, if you decide not to participate in the coin tossing game within the 5 periods (between period 0 and period 4), your chance to participate expires and you will leave the game with your starting balance of 10 bags that has increased to 15 bags over the 5 periods (10 bags (0.1 · 5 + 1= 15 bags)). This means that for each period in that you decided not to participate in the game, you receive 1 bag, which is 10% of your starting balance. You can think of this increase as an interest payment.
- In case this game is randomly selected for the cash premium, you will receive 15,000 UGX.
- Now, we will explain the payment in this game.
- One participant will be randomly selected for payment.
- Only one repetition of the game will be randomly selected for payment. However, you do not know yet for which of the decisions we will pay the chosen participant, so that you better think about each decision very carefully.
- The payment in this game comprises two draws:
  - The first draw is to determine the participant who receives the payment. We will ask one of you to draw a number between 1 and 6 out of a bag. The holder of the number that is picked from the bag will receive the payment.
  - The second draw is to determine the repetition for which the chosen participant will get paid. We will ask the selected person to draw a number between 1 and 10 out of a bag. The number that is picked from the bag will be the choice that counts for payment.
- Before we start the game, we would like to ask you to answer some questions. This is to ensure that you understood the instructions.
- *Participants who did not answer the control questions correctly are informed that they have incorrect answers and are asked to re-think their answers and try again. If they make mistakes again, the enumerator goes over the instructions and quiz them for a third time, and then asks them to proceed regardless of their answers. Importantly, we record the number of attempts each participant needed to answer the control questions correctly. The participants make their choice and their enumerators record the choice.*
- *Quiz participants for understanding (questions):*
  - What is the value of 1 bag?
  - If the score of the coin tossing game is 12 bags in one period, which two values can occur in the next period?
  - If you flip a coin, what is the chance that it lands 'head' (emblem) or 'tail' (fish)?
  - How much is the interest rate?
  - How much do you have to pay if you choose to participate in the coin tossing game?
  - How many bags do we always guarantee you in case the bags decrease under the score of 10 bags?
- We are now going to do a practice period. The purpose of the practice period is to familiarize you with the procedure. Nothing that you do in the practice period will affect your earnings.
- *Practice period*
- This was a practice period. Now, we are going to start the real experiment where you can win real money.
- We are going to ask you to make a decision for each game. Remember that we will repeat this game 10 times.

- Is this clear?
- *Then, decisions will be made.*

IV. Do Changing Probabilities or Payoffs in Lottery-Choice Experiments Affect the Results? Evidence from Rural Uganda

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Abstract

This study compares risk attitudes of smallholder farmers elicited from two different lottery designs (i) with fixed payoffs and changing probabilities and (ii) with fixed probabilities and changing payoffs. We utilize experimental data collected from 332 randomly selected smallholder farmers in Uganda. Both methods reveal high proportions of farmers who are classified as risk averse. However, comparing the different risk attitude categories shows that the two elicitation methods yield significantly different results. Furthermore, we find relatively low inconsistency rates in the response behavior for the two methods compared to other studies in the past. Specific socio-demographic and socio-economic characteristics also affect farmers' risk attitudes.

Key words

Elicitation of risk attitude, inconsistency rates, laboratory experiment in the field, Uganda.

JEL classification

C91, C93, D81, O13.

1   Introduction

The majority of people in developing countries rely on agriculture as their main source of livelihood and often perform in precarious and risky conditions. In agricultural production, where farmers' crop yields and incomes are dependent on various exogenous factors such as weather conditions and price fluctuations respectively, risk is ubiquitous in farming decisions (Menapace et al. 2012). Ultimately, risk plays a significant role in almost every important economic farm decision such as crop selection (Price and Wetzstein 1999), technology adoption (Purvis et al. 1995), conservation intervention (Winter-Nelson and Amegbeto 1998), and crop insurance markets (Hill and Viceisza 2012). However, people naturally differ in the way they make risky decisions, and these differences are often described as differences in risk attitude. Therefore, understanding the risk attitude of economic agents provides useful insights in understanding their economic behavior (Reynaud and Couture 2012). From a policy-maker's perspective, it is imperative to understand farmers' risk attitudes in order to gain insight of how risk affects the decision behavior and to predict this behavior under different policy conditions (Bhattamishra and Barrett 2010). Harrison (2011) notes that welfare evaluation of any proposed policy with risky outcomes should consider people's risk attitudes. As a result, many researchers have studied individual risk attitudes, and a variety of methods have been used for testing risk attitudes in laboratory and field settings.

There is extensive literature regarding the elicitation of individuals' risk attitudes in both developed and developing countries. A variety of methods has evolved for testing these attitudes, including lottery choice task decisions (eg., Holt and Laury 2002), self-assessment questions (e.g., Dohmen et al. 2011), hypothetical gambles (e.g., Anderson and Mellor 2009), and willingness to pay analyses (e.g., Kahneman et al. 1990). Studies that explored risk attitudes of individuals in a developed country setting include among others Holt and Laury (2002), Eckel and Grossman (2002, 2008), Dave et al. (2010), and Reynaud and Couture (2012). The studies conducted by Binswanger (1980), Humphrey and Verschoor (2004), Jacobson and Petrie (2009), Yesuf and Bluffstone (2009), and Harrison et al. (2010) examined risk attitudes of individuals in a developing country context. A troubling result of previous investigations is that often risk attitudes of an individual vary significantly across different elicitation methods (Isaac and James 2000; Andersen et al. 2006; Dave et al. 2010; Reynaud and Couture 2012). Several reasons have been offered to explain this behavior, including context dependency (Reynaud and Couture

2012), differences in cognitive abilities of subjects and task complexity (Anderson and Mellor 2009), and non-expected utility preferences (Starmer 2000). Furthermore, several developing country field studies utilizing complex risk attitude elicitation methods, including lottery choice task decisions, reported relatively high inconsistency rates in individuals' response behavior, which may indicate a low level of comprehension (e.g., Galarza 2009; Jacobson and Petrie 2009; Doerr et al. 2011; Engle-Warnick et al. 2011). As a result, inconsistent subjects are usually excluded from the analysis, which often means excluding a large portion of the data. These problems show that there is a danger that risk attitudes are not estimated correctly and consequently might result in different policy recommendations. Therefore, a valid measure of risk attitudes is a critical input for properly designing effective policy instruments in the agricultural sector as well as for an adequate single-farm decision support. It can support quantifying optimal portfolios, introducing efficient risk prevention policies and designing optimal insurance instruments (Gollier 2001; Harrison et al. 2005a).

In the last decade, the Holt and Laury lottery (HLL hereafter) has virtually become the standard method for the elicitation of subjective risk attitudes. It has been used in a great variety of contexts and with different subject groups, including convenience groups such as students (e.g., Andersen et al. 2006; Deck et al. 2008; Abdellaoui et al. 2011) and real decision-makers such as managers (e.g., Masclet et al. 2009; Holm et al. 2012). Brick et al. (2012) applied a similar design to that of Holt and Laury (2002) but differs in that, instead of changing probabilities and fixing payoffs, probabilities are fixed and payoffs change (BL hereafter). Brick et al. (2012) assumed that people have more difficulties with varying probabilities than with varying amounts of payoffs and thus modified the HLL accordingly.

The objectives of this study are twofold: First, we compare two different risk attitude elicitation methods to answer the questions of how the choice of method affects the results and how well these methods are understood by individuals in a rural, developing country setting. Specifically, we evaluate the consistency of risk measures in the two elicitation methods as well as the inconsistency rates in the response behavior. Our risk attitude elicitation methods are based on the well-known incentive-compatible lotteries used in Holt and Laury (2002) and Brick et al. (2012), in which subjects were given a series of choices between two systematically varied options. The two methods differ in the variation of probabilities and the fixing of payoffs or vice versa. In our experiment, both risk attitude

elicitation methods are modified from the original lottery-choice experiments by replacing probabilities expressed in percent with images of bags of colored balls to represent probabilities of different payoffs and henceforth are described as modified HLL and modified BL. Conducting a standard HLL and BL with individuals in a rural developing country setting might not be appropriate; thus, we incorporated a modification aiming to reduce inconsistency rates and to provide more reliable measures of risk attitudes. Second, we identify and compare influencing socio-demographic and socio-economic factors of risk attitudes across the two elicitation methods. This allows us to check the robustness of explanatory factors of risk attitudes and examine whether these factors vary depending on the elicitation method. Specifically, this study focuses on a sample of smallholder farmers in Uganda, a setting in which the importance of risk in influencing economic behavior of poor households has been documented (Hill 2009, 2010). To achieve these objectives, we combine data generated from lottery-choice experiments with comprehensive household survey data which were collected in Uganda from July to August 2012.

Our study contributes to the extant literature by addressing the following two aspects: First, to the best of our knowledge, this study is the first to compare the effects of changing probabilities while keeping payoffs constant or vice versa on risk attitudes based on the Holt and Laury (2002) and Brick et al. (2012) experimental designs, using the same sample of subjects. This comparison may add to the knowledge on which method may work better in a developing country context. Second, our work extends the previous research by proposing an adequately experimental design to measure risk attitudes of people with a limited level of education, which may be used as an appropriate elicitation tool within a developing country context.

The remainder of this paper is structured as follows: Section 2 presents the relevant literature from which the research hypotheses are derived. In Section 3, we explain the two risk attitude elicitation methods used to measure the risk attitudes. The sampling procedure, incentive design, and the experimental implementation are described in detail in Section 4. We present and discuss our findings in Section 5, and lastly, Section 6 concludes this paper.

2   Literature review and hypotheses

The existing literature on risk behavior suggests various methods to measure risk attitude, but only few studies compare different elicitation methods, in particular, for data collected in developing countries among resource-poor farmers. Binswanger (1980) measured the risk attitudes of Indian farmers by using two different methods, a hypothetical questionnaire and an experimental gambling method with real payoffs, and discovered inconsistencies in the measures of risk aversion in the two methods. Reynaud and Couture (2012) compared two different risk elicitation methods, namely the Holt and Laury (2002) and the Eckel and Grossman (2008) lottery tasks, on a sample of French farmers. They found that the risk preference measures were affected by the type of method used and demonstrated that risk attitudes were context-dependent. However, both lotteries applied were not incentive-compatible. Charness and Viceisza (2011) compared three distinct non-incentivized elicitation methods, the Holt and Laury (2002) lottery tasks, an adaptation of a simple binary method initially proposed by Gneezy and Potters (1997), and a willingness-to-risk scale pioneered by Dohmen et al. (2011) using a sample drawn from the rural population in Senegal. The results indicated that the simple binary method had substantially more predictive power compared to the HLL, which revealed a relatively low level of understanding. The willingness-to-risk question generated results that were unlikely to be accurate according to patterns in other risk attitude elicitation studies. Dave et al. (2010) used two different elicitation methods with different degrees of difficulty and also came to a similar conclusion. They analyzed how and when a simpler but coarser risk attitude elicitation method may be preferred to a more complex but finer one. They found that the more complex method had superior predictive accuracy, but had the disadvantage that participants made inconsistent choices. Andersen et al. (2006) examined the properties of the multiple price list method as well as some variants on the basic design and found that the elicitation of risk attitudes was sensitive to procedures, subject pools, and the format of the multiple price list tables. They recruited a sample from Denmark. Maart-Noelck and Musshoff (2013) applied the incentive-compatible HLL and two psychometric methods on a sample of German students and German and Kazakhstani farmers and found that students responded consistently across all three elicitation methods, whereas German farmers, and especially Kazakhstani farmers, were more inconsistent. Thus far, it has not been investigated how risk attitudes assessed by two different risk attitude elicitation methods differing in the variation of probabilities or payoffs based on Holt and Laury

(2002) and Brick et al. (2012) compare to each other in a within-sample experiment. Therefore, we analyze the consistency of risk measures across the two different elicitation methods which we have used and adapted to individuals in a rural developing setting. We formulate the following hypothesis:

H1 'Modified HLL vs. modified BL': There is a consistency between the risk attitude determined in the modified HLL and the response behavior in the modified BL.

Risk attitudes measured in lottery choice task decisions are usually based on the point at which participants switch from the safe option to the risky one. A common problem with such designs is that when participants fail to understand a task, they tend to switch back and forth between the lottery options as they move down the decision rows. This makes a risk measure based on a switching point from risky to safe lottery option problematic. Multiple switching behaviors have been observed in numerous studies using the HLL, but were especially prevalent in a developing country context. Galarza (2009) observed an inconsistency rate of 52% in a study conducted with Peruvian cotton farmers. Jacobson and Petrie (2009) found that approximately 55% of Rwandan participants made at least one inconsistent switch. The experiment was conducted with a random sample of the adult population in Rwanda. Brick et al. (2012) found that about 41% of the sample of South African fishers showed multiple switching behaviors, and Charness and Viceisza (2011) found that 51% of the participating farmers in Senegal switched lotteries at least twice. De Brauw and Eozenou (2011) found an inconsistency rate of 14% among Mozambican farmers, which matched with most case studies of developed countries which had lower inconsistency rates. Holt and Laury (2002) found an inconsistency rate of 13% for students in the United States, and Dave et al. (2010) found an inconsistency rate of 8.5% for an adult population in Canada. The relatively large proportion of participants in developing countries that made inconsistent choices in lottery choice task decisions could indicate that the HLL might not be the most appropriate within this setting. Therefore, we analyze the inconsistency rates of the two elicitation methods and evaluate whether the modified BL is better able to reduce inconsistencies in the response behavior compared to the modified HLL following the argumentation of Brick et al. (2012). Our hypothesis is:

H2 'Inconsistency rates of modified BL vs. modified HLL': The modified BL outperforms the modified HLL in reducing the inconsistency rates in the response behavior.

Individuals' characteristics naturally vary and may also have an impact on the risk attitudes (Doss et al. 2008). In our study, we focus on specific socio-demographic (age, gender,

education, household size and number of dependents, and district) and socio-economic characteristics (wealth, farm size, access to a savings account, and access to credit) of respondents to examine whether these factors influence their risk attitudes and whether these factors are consistent across the two elicitation methods. In the extant literature, there is no consensus, which socio-demographic and socio-economic characteristics have an influence on risk attitudes. Although some studies find that risk attitudes differ significantly based on specific characteristics, other studies find no significant relationship. Table 1 provides a summary of the variables and their impact on the risk attitude from other studies. Our last hypothesis is as follows:

H3 'Farmer-specific effects for risk attitude': Socio-demographic and socio-economic variables have a significant effect on the risk attitude of farmers.

Table 1 Overview of socio-demographic and socio-economic variables and their impact on risk attitude

Variable	Study		Impact
Socio-demographic variables			
Age	e.g., Nielsen et al. (2013)	+	Older individuals are more risk averse than younger ones
	e.g., Maart-Noelck and Musshoff (2013)	-	No significant effect
Gender	e.g., Croson and Gneezy (2009)	+	Women are more risk averse than men
	e.g., Mosley and Verschoor (2005)	-	No significant effect
Education	e.g., Harrison et al. (2007)	+	Individuals with higher education are more risk averse than those with less education
	e.g., Reynaud and Couture (2012)	-	No significant effect
Household size	e.g., Miyata (2003)	+	Individuals with larger households are more risk averse
	e.g., Maart-Noelck and Musshoff (2013)	-	No significant effect
Number of dependents	e.g., Hallahan et al. (2004)	+	Individuals with a larger number of dependents are more risk averse
	e.g., Picazo-Tadeo and Wall (2011)	-	No significant effect
Socio-economic variables			
Wealth	e.g., Cohen and Einav (2007)	+	Wealthier individuals are more risk averse
	e.g., Tanaka et al. (2010)	-	No significant effect
Farm size	e.g., Wik et al. (2004)	+	Individuals with more land are more risk averse
	e.g., Reynaud and Couture (2012)	-	No significant effect
Access to a savings account	e.g., Jacobson and Petrie (2009)	+	Individuals with access to a savings account are less risk averse
Access to credit	e.g., Eswaran and Kotwal (1990)	+	Individuals with access to credit are less risk averse

Source: Author's own illustration.

3   Experiment design

This section provides an overview of how the experiment was designed. Both risk attitude elicitation methods were chosen in a randomly determined order. A complete set of instructions for the experiment is included in Appendix 1. The experiment was preceded by a household survey that collected information on household demographics and economic characteristics.

3.1   The Holt and Laury lottery and its modification

In the Holt and Laury (2002) experiment, participants had to make 10 choices between two systematically varied options, namely option A (the relatively safer option) or option B (the relatively riskier option). In our design, option A offered the chance to either win UGX 6,000 or UGX 4,800 with a certain probability, while option B offered the chance to win UGX 11,550 or UGX 300 with the same probability (see Table 2). The payoffs in the safer option have a lower range than those in the riskier option. We use the rate of 1:3,000 (which corresponds to the exchange rate) to get the equivalent payoffs in Ugandan shillings compared to the original task. The earnings are held constant across the choice tasks, whereas the probabilities of the earnings vary in intervals of 10% between the choice tasks. The expected values of the options change as participants move from one to the next choice task. Up to the fourth choice task, the expected value of the safer option A is higher than the expected value of the riskier option B. From the fifth task, the expected value of option B exceeded the expected value of option A.

Participants were asked to make 10 choices of either option A or option B, one for each choice task. The switching point from the safer to the riskier option allowed us to determine their individual risk attitude. A risk seeking participant would switch to option B in the first three decision rows, while a risk averse participant would switch to option B between the decision rows five to nine. In turn, a risk neutral participant would always decide in favor of the option with the higher expected value. Therefore, the person would switch from choosing option A to option B in row five. A HLL-value (= number of safe choices) between one and three expresses risk preference, a HLL-value of four implies risk neutrality, and a HLL-value between five and 10 expresses risk aversion of the participant. Following Holt and Laury (2002), a power risk utility function with a constant relative risk aversion (CRRA) defined over the lottery prize was used to calculate a range of relative risk aversion compatible with each choice. The risk utility function is of the form $U(x) =$

$(x^{1-r})/(1-r)$ where x is the lottery prize and r is the latent risk coefficient. Using this utility function, we can calculate the implied bounds of an individual's CRRA coefficient. For instance, a participant who chose option A six times before switching to option B reveals a CRRA coefficient interval between 0.15 and 0.41. Positive values of the CRRA coefficient denote risk aversion ($r > 0$), a value of zero indicates risk neutralitiy ($r = 0$), and negative values denote risk seeking ($r < 0$).

Table 2 Payoff matrix of the Holt and Laury lottery

| Task	Option A	Option B	EV^A	EV^B	CRRA ranges[a]	Risk aversion class[b]
1	With 10% prize of 6,000 With 90% prize of 4,800	With 10% prize of 11,550 With 90% prize of 300	4,920	1,425	r < -1.71	Extremely RL
2	With 20% prize of 6,000 With 80% prize of 4,800	With 20% prize of 11,550 With 80% prize of 300	5,040	2,550	-1.71 < r < -0.95	Highly RL
3	With 30% prize of 6,000 With 70% prize of 4,800	With 30% prize of 11,550 With 70% prize of 300	5,160	3,675	-0.95 < r < -0.49	Very RL
4	With 40% prize of 6,000 With 60% prize of 4,800	With 40% prize of 11,550 With 60% prize of 300	5,280	4,800	-0.49 < r < -0.14	RL
5	With 50% prize of 6,000 With 50% prize of 4,800	With 50% prize of 11,550 With 50% prize of 300	5,400	5,925	-0.14 < r < 0.15	RN
6	With 60% prize of 6,000 With 40% prize of 4,800	With 60% prize of 11,550 With 40% prize of 300	5,520	7,050	0.15 < r < 0.41	Slightly RA
7	With 70% prize of 6,000 With 30% prize of 4,800	With 70% prize of 11,550 With 30% prize of 300	5,640	8,175	0.41 < r < 0.68	RA
8	With 80% prize of 6,000 With 20% prize of 4,800	With 80% prize of 11,550 With 20% prize of 300	5,760	9,300	0.68 < r < 0.97	Very RA
9	With 90% prize of 6,000 With 10% prize of 4,800	With 90% prize of 11,550 With 10% prize of 300	5,880	10,425	0.97 < r < 1.37	Highly RA
10	With 100% prize of 6,000 With 0% prize of 4,800	With 100% prize of 11,550 With 0% prize of 300	6,000	11,550	1.37 < r	Extremely RA

Source: Author's own illustration according to Holt and Laury (2002).
Notes: Prizes are displayed in Ugandan shillings (UGX). At the time of the experiments, the exchange rate was approximately € 1 to UGX 3,000, so prizes range from approximately € 0.1 to € 3.85. The fourth and fifth columns show the expected values (EV) of the respective option.
[a] Constant relative risk aversion coefficient assuming a power risk utility function.
[b] RL, RN, and RA respectively for risk lover, neutral, and averse.

Pretests have shown that to conduct a standard HLL with individuals in a rural developing setting like Uganda would not have been feasible. Therefore, we incorporated a modification in order to develop an easy to apply and effective method to elicit the risk attitude. The standard HLL is modified in this experimental design by replacing probabilities expressed in percent with images of bags of colored balls (green, blue, red, and yellow) representing probabilities of different payoffs (UGX 300, UGX 4,800, UGX 6,000, and UGX 11,550). Each ball measures a 10% probability and each bag includes 10 balls. The different payoffs are represented in a different color. Apart from using images of bags and balls, the lottery-choice experiment was absolutely identical to

Chapter IV: Do Changing Probabilities or Payoffs in Lottery-Choice
Experiments Affect the Results? Evidence from Rural Uganda

110

the standard HLL, i.e. the same number of tasks and the implied CRRA ranges. The choice tasks were presented all at once to the participants. Figure 1 shows the 10 choice tasks the participants faced in this lottery.
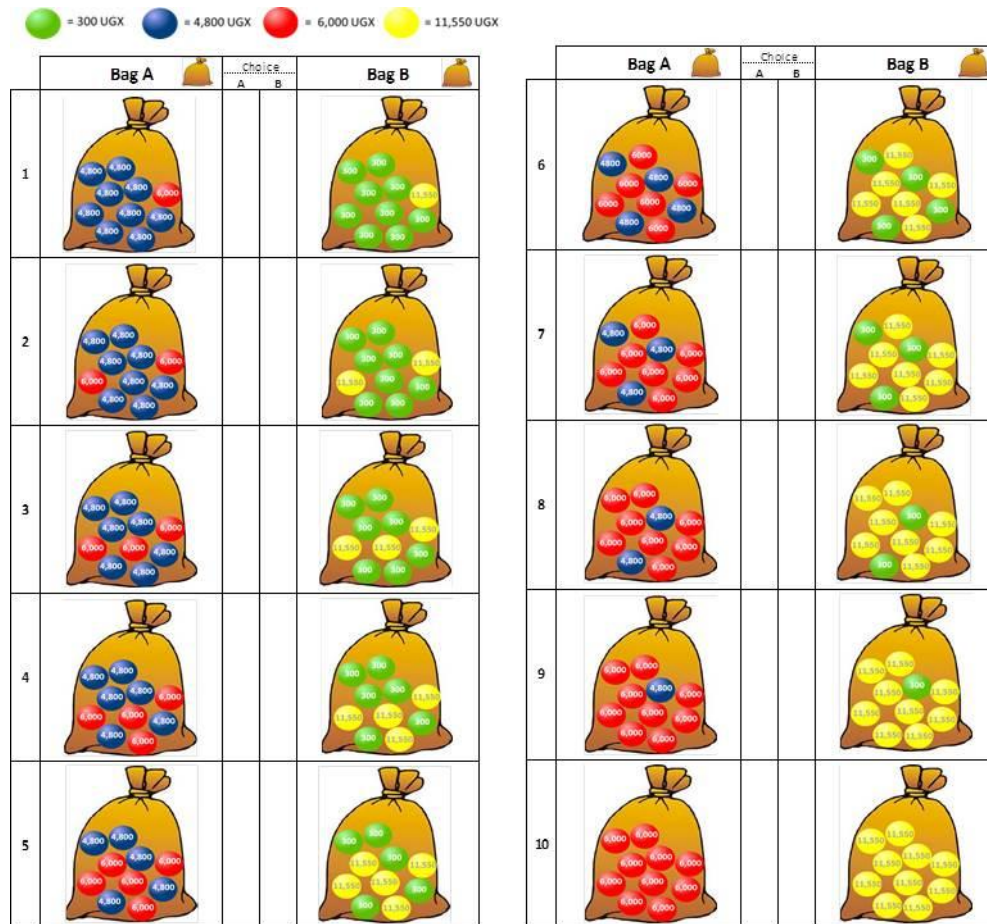
Source: Author's own illustration.

Fig. 6 Graphical display of the modified Holt and Laury lottery (in Ugandan shillings)

3.2 The Brick lottery and its modification

The experimental design used in Brick et al. (2012) is similar to that of Holt and Laury (2002), but with one main difference. Instead of keeping payoffs constant and varying the probabilities of receiving the high and low outcomes, the probabilities are constant and the payoffs are varied. We use the rate of 1:500 to get the equivalent payoffs in Ugandan shillings compared to the original task and to adjust to the payoffs of the HLL. For each choice task, participants were asked to choose between option A and option B. Fixed probabilities of 100% and 50% were used in the experiment. In the first task, for example, option A offered a 100% chance to win UGX 10,000, while option B offered a 50% chance to either win UGX 10,000 or UGX 0 (see Table 3). The payoff associated with option A declines systematically throughout the eight tasks from UGX 10,000 to UGX 1,000, while

the payoff for option B remains unchanged and is fixed at UGX 10,000 and UGX 0. A highly risk seeking participant would choose option B in the first choice task, while a highly risk averse participant would choose option A in the eighth choice task. A risk neutral participant would switch from choosing option A to option B after row three.

Table 3 Payoff matrix of the Brick lottery

Task	Option A	Option B	EV^A	EV^B	CRRA ranges[a]	Risk aversion class[b]
1	With 100% prize of 10,000	With 50% prize of 10,000 With 50% prize of 0	10,000	5,000	$r < -1.41$	Highly RL
2	With 100% prize of 7,500	With 50% prize of 10,000 With 50% prize of 0	7,500	5,000	$-1.41 < r < -0.36$	Very RL
3	With 100% prize of 6,000	With 50% prize of 10,000 With 50% prize of 0	6,000	5,000	$-0.36 < r < 0$	RL
4	With 100% prize of 5,000	With 50% prize of 10,000 With 50% prize of 0	5,000	5,000	$0 < r < 0.24$	RN
5	With 100% prize of 4,000	With 50% prize of 10,000 With 50% prize of 0	4,000	5,000	$0.24 < r < 0.42$	Slightly RA
6	With 100% prize of 3,000	With 50% prize of 10,000 With 50% prize of 0	3,000	5,000	$0.42 < r < 0.57$	RA
7	With 100% prize of 2,000	With 50% prize of 10,000 With 50% prize of 0	2,000	5,000	$0.57 < r < 0.70$	Very RA
8	With 100% prize of 1,000	With 50% prize of 10,000 With 50% prize of 0	1,000	5,000	$r < 0.70$	Highly RA

Source: Author's own illustration according to Brick et al. (2012).
Notes: Prizes are displayed in Ugandan shillings (UGX). At the time of the experiments, the exchange rate was approximately € 1 to UGX 3,000, so prizes range from approximately € 0.33 to € 3.33. The fourth and fifth columns show the expected vales (EV) of the respective option.
[a] Constant relative risk aversion coefficient assuming a power risk utility function.
[b] RL, RN, and RA respectively for risk lover, neutral, and averse.

In our version of the lottery, we use images of bags of colored balls (red, blue, and green) representing probabilities of different payoffs (UGX 0, UGX 10,000, and between UGX 10,000 and UGX 1,000). Each ball measures a 100% or a 50% probability and each bag includes one or two balls. The different payoffs are represented in a different color, except for the varying value of the green ball. Apart from using images of bags and balls, the lottery-choice experiment was absolutely identical to the standard BL, i.e. the same number of tasks and the implied CRRA ranges. The choice tasks were presented all at once to the participants. Figure 2 shows the eight choice tasks presented to participants.
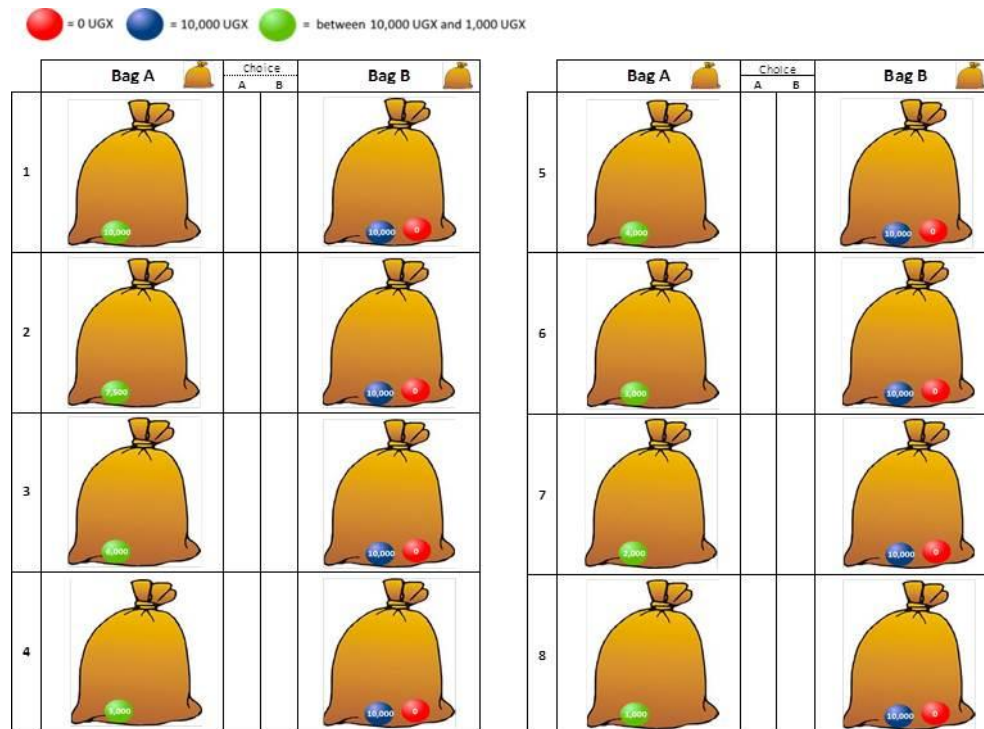
Source: Author's own illustration.

Fig. 2 Graphical display of the modified Brick lottery (in Ugandan shillings)

3.3   Household survey

In addition to the lottery-choice experiments, participants attended a household survey during which they completed a comprehensive questionnaire capturing information on the household demographic composition and economic activities. The main variables collected through the survey were age, gender, education, household size, number of dependents, district, per capita household expenditure as a proxy variable for wealth, total land owned, access to savings account, and access to credit.

A participant's ability to reason with numbers and probabilities may affect the understanding and choice among risky lotteries, and hence, the opportunity to obtain an accurate measurement of risk attitudes (Dave et al. 2010). Therefore, we included three additional tasks, adapted from Viceisza (2011) and Charness and Viceisza (2011), to assess farmers' ability to process percentage and probabilistic information and to explore the relationship between their decision behavior and the test score in the quiz: (i) 'Imagine, we toss a coin and 'heads' comes up. What comes up if we toss the coin again?' Participants were faced with three possible answers: heads, tails, one cannot predict exactly. (ii) 'If the chance of winning a prize is 10%, how many people out of 100 would be expected to get the prize?' Participants had to name the appropriate value. (iii) 'When you draw the red

ball, you win! Look at the two boxes and mark the correct sentence.' One box contains two red and two blue balls, while the other box contains four red and four blue balls. Participants have to decide whether the chance of winning is higher if they choose the first box, the second box, or the chance of winning is equal regardless of which box they choose.

4   Data collection

4.1   Sampling procedure

Data used in this study was obtained from experiments and a household survey of 332 smallholder farmers randomly selected from two districts of Masaka and Luwero in Uganda from July to August 2012. These two districts, located in the Central Region, have been broadly classified as having similar agro-climatic conditions and farming systems. For the selection of smallholder farmers to be interviewed, we used a multi-stage sampling procedure. At first, we randomly selected parishes and villages. Within each selected village, smallholder farmers were then randomly selected using updated, village-level household lists. The farmers were then recruited via the local extension service to participate in a household survey and an experiment. The invitation to attend our experiment was provided orally by the recruiters and contained the date, time, and place of the study, a brief and general purpose of the study, and the type of compensation that could be expected. None of the farmers refused to participate in the household survey and the experiment, which means that our sample does not have a selection bias. The household survey took place one day prior to the actual experiments. Our participants were either the household head or the spouse because they are those most likely to be faced with risky choices and important economic decisions.

4.2   Experiment implementation

The 332 smallholder farmers were allocated randomly to groups for the experimental sessions. In total, we conducted 56 sessions during the course of 30 days. Two sessions were held each day and each session involved a group of six farmers.[1] All participants played both lottery-choice experiments and the order in which they were faced with the two experiments was randomly determined. In the experiment, choices made by

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[1] However, four farmers were excluded from the analysis. One farmer left before completing all tasks, and three farmers participated in the household survey but were not able to undertake (or arrived too late to participate) the experiment.

participants were not time constrained. On average, the complete session lasted between 60 and 90 minutes. The experimental sessions were held in several villages and conducted in classrooms of local schools or in a meeting room at the main gathering place of a farmers' group or association. All of the sessions were held in locations which were familiar to the farmers and usually within walking distance or accessible by bicycle. The rooms were equipped with tables and chairs and were spaced out to prevent conferring among the participants. A team of seven local enumerators that were carefully selected conducted all of the experimental sessions. One of the enumerators served as the experimenter, and the author served as the assistant experimenter. The other enumerators were placed next to the participants to record their choices in case participants were illiterate. Each participant had their own enumerator. All sessions were conducted in Luganda, one of the main indigenous Bantu languages in south central Uganda. Prior to the first session, the enumerators were trained on the experiment protocol and how to carefully avoid giving specific instructions about how to answer.

Each experiment session consisted of registration, instruction, practice, decision making, and payment. In the beginning of the experiment, each participant received a personal number, which randomly determined his/her seat that remained to be the individual's location throughout the session. The experiment instructions were read aloud to all participants as a group by the experimenter and supported by posters of graphical examples displayed on a large board at the front of the room to improve the understanding. During the presentation of the instructions, participants were encouraged to ask questions about any unclear issues. To further facilitate comprehension, we used real bags of colored balls representing probabilities of the different payoffs. Each choice task in the experiment was conducted in the following way: The assistant experimenter placed the appropriate balls in the bags, while the experimenter explained the values attached to each ball. The participants then considered their decision and made their choice by pointing to the preferred bag on the sheet in front of them, and their enumerator recorded the choice. Participants were informed about all parameters and assumptions underlying the experiment, and they had to answer some control questions to ensure that they entirely understood the instructions. Our overall impression was that our version of the instructions was well understood by the participants because of the various interview techniques applied, such as visual, oral, and written explanations, as well as the practical implementation with real bags and colored balls. Further support of respondents'

comprehension of the instructions is seen, for example, in the unproblematic answering of the control questions during the experiment.

4.3   Incentive design

The decisions in the lottery-choice experiments were related to real earnings to ensure incentive compatibility of the experiment and to motivate participants to take the tasks more seriously. Participants were informed at the beginning of the experiment that when they have completed all decision tasks in the respective lottery, one task would be selected at random and played out for real money. This random lottery incentive system is commonly used in lottery-choice risk experiments (Humphrey and Verschoor 2004). Nevertheless, there is an ongoing controversial debate on the use of monetary incentives as rewards for participants in experiments and the practice of paying only some participants for only some of their decisions. Camerer and Hogarth (1999) found that using high financial incentives for a fraction of participants rather than providing small incentives for each of the participants often improves participants' performance during the experiment. We chose one participant at random for payment for each lottery-choice experiment of our payment design; hence we had two winners per session. The earning of the participant was based on his/her preference expressed between various mutually exclusive options in the two lotteries. Each decision task had exactly the same probability to be drawn. The potential earning varied between UGX 300 and UGX 11,550 for the modified HLL and between UGX 0 and UGX 10,000 for the modified BL. The average payoffs of the two lotteries were UGX 6,674 (approximately € 2.2) and UGX 5,687 (approximately € 1.9). Furthermore, all participants received a show-up fee of UGX 5,000 as a compensation for their time. This compares to one day of casual farm labor wage in this area. Participants were paid in cash by the assistant experimenter at the end of the experiment.

5   Experimental results

5.1   Descriptive statistics

Table 4 below presents descriptive statistics on socio-demographic and socio-economic characteristics of participants in the experiment. On average, participants were aged 50.21 years. Of all participants, 39% were female. The education level of the household head was on average 6.67 years of schooling. The average household size and dependency ratio were 6.56 and 1.51, respectively. Of all participants, 57% were from Masaka district, while 43% of them were from Luwero district. In order to assess whether farmers have a basic

comprehension of probabilities, we conducted a short quiz composed of three simple questions before the experimental session started. On average, each farmer answered two out of the three questions correctly. The average annual per capita household expenditure was approximately UGX 516,855. The mean farm size for each farmer was about 5.73 acres. Of all participants, 28% indicated to have access to a savings account, while 43% claimed to be able to access financial credit for agricultural activities whenever they need it.

Table 4 Descriptive statistics of respondent characteristics (N = 332)

Variable name	Variable definition	Mean	Std. dev.
Socio-demographic characteristics			
Age	Age in years	50.21	14.28
Gender	Dummy = 1 if female, 0 otherwise	0.39	-
Education	Years of formal schooling	6.67	3.60
Household size	Number of household members	6.56	3.10
Dependency ratio	Ratio of dependent (less than 15 years of age or greater than 64) to nondependent household members	1.51	1.18
District	Dummy =1 if from Masaka, 0 = Luwero	0.57	-
Probability test score	number of probability questions correctly answered	2.05	0.78
Socio-economic characteristics			
Household expenditure	Annual per capita household expenditure in UGX[a]	516.855	392.949
Total land owned	Total land owned in acres[b]	5.73	4.53
Access to a savings account	Dummy = 1 if access to a savings account, 0 otherwise	0.28	-
Access to credit	Dummy = 1 if access to credit, 0 otherwise	0.43	-

Source: Survey data.
[a] At the time of the experiments, the exchange rate was approximately € 1 to UGX 3,000.
[b] 1 acre = 0.40 hectare.

Figure 3 presents the distribution of safe choices before switching to the risky lottery option by elicitation method.[2] The individual risk attitudes vary between risk seeking and strong risk aversion. The histogram of the modified HLL shows a high peak at 5 (the average value in the range), while there is a high peak at 4 (the average value in the range) and a very high peak at 8 in the histogram of the modified BL. The latter one may be explained by the fact that in lottery option B participants had a 50% chance of receiving nothing, and thus rather chose the safer option A eight times.

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[2] For the participants who showed an inconsistent behavior (i.e. participants who switched at least twice), we assumed the HLL-value at which the participant switched for the first time.
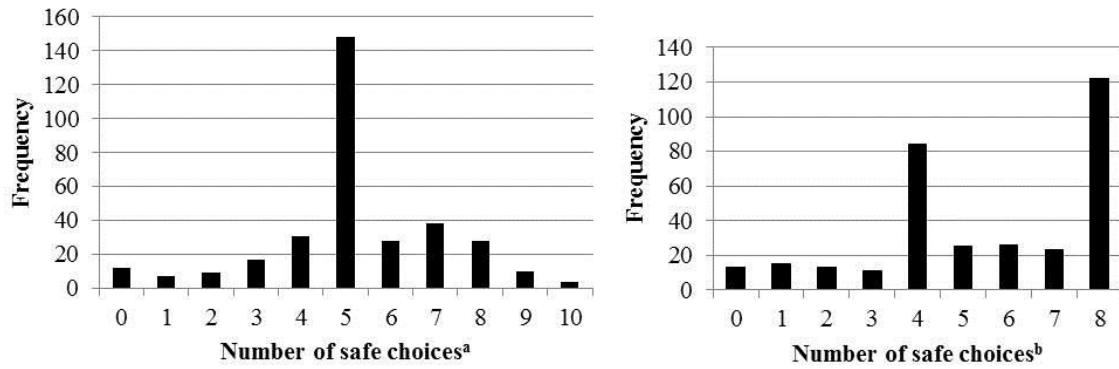
Source: Survey data.
[a] Number of safe choices in the HLL: range of 0-3 = risk seeking (CRRA range: -1.71 to -0.14), 4 = risk neutral (CRRA range: -0.14 to 0.15), range of 5-10 = risk averse (CRRA range: 0.15 to 1.37).
[b] Number of safe choices in the BL: range of 0-3 = risk seeking (CRRA range: -1.41 to 0), 4 = risk neutral (CRRA range: 0 to 0.24), range of 5-8 = risk averse (CRRA range: 0.24 to 0.70).

Fig. 3 Distribution of safe choices in the modified HLL (left figure: N= 332) and modified BL (right figure: N = 332)

5.2 Validity test of hypotheses

Test of H1 'Modified HLL vs. modified BL'

Table 5 presents the summary statistics of the two risk attitude elicitation methods. The two lotteries reveal that there are slightly more risk-seeking (15.66%) (52), more risk neutral (25.30%) (84), and less risk averse (59.04%) (196) participants in the modified BL than compared to the modified HLL with 13.55% (45) risk seeking, 9.34% (31) risk neutral, and 77.11% (256) risk averse participants. The results of the chi-square tests show that there is a significant difference in the proportions of the categories of risk neutral ($p < 0.01$) and risk averse participants ($p < 0.01$) in the two elicitation methods, while there is no significant difference in the category of risk seeking participants. Due to the non-normal distribution of the number of safe choices, it is more appropriate to use the Wilcoxon rank-sum test to examine whether there is a statistically difference between the two elicitation methods.[3] The results reveal that there is a statistically significant difference ($p < 0.10$).[4] An additional analysis, which excludes participants who showed an inconsistent response

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[3] In order to test whether the distribution of the safe choices are normally distributed and to check robustness, we conduct three different tests, namely the Shapiro Francia, the Shapiro Wilk, and the Skewness Kurtosis. All three tests show that the distribution of safe choices in the modified HLL and the modified BL are non-normally distributed ($p < 0.05$). This finding compels us to use non-parametric test statistics to compare whether the two distributions are significantly different from each other (Gardner 1975).

[4] For making possible the comparison between the two risk attitude elicitation methods, given the differences in the number of tasks in each method and the implied CRRA ranges, the number of safe choices are converted into percentages of safe choices.

behavior (e.g., a multiple switching behavior), generates similar results. Here, we excluded 19 participants of the modified HLL and 25 participants of the modified BL. Thus, we reject *H1 'Modified HLL vs. modified BL'*. Essentially, this means that risk attitude measures are affected by the type of method used. Although we found inconsistencies in the individual risk attitude across the two elicitation methods, the tendency of participants being risk averse is the same, which corroborates empirical findings of other studies conducted in developing countries (e.g., Jacobson and Petrie 2009; Yesuf and Bluffstone 2009; Harrison et al. 2010).

Table 5 Summary statistics of the two risk attitude elicitation methods

	Risk category	Modified HLL	Modified BL	Test of significance
Risk category (%)	Risk seeking	13.55 (0.02)	15.66 (0.02)	$\chi^2 = 0.59$
	Risk neutral	9.34 (0.02)	25.30 (0.02)	$\chi^2 = 29.9^{***}$
	Risk averse	77.11 (0.02)	59.04 (0.03)	$\chi^2 = 24.9^{***}$
Distribution of safe choices[a] (%)	Mean	52.04	68.83	$z^b = -1.75^*$
	Std. dev.	19.58	30.27	
	Median	50	75	
	Skewness	-0.37	-0.55	
	Kurtosis	3.85	2.27	

Source: Survey data.
Notes: N = 332. Standard errors are indicated in parentheses. $^*p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.
[a] Due to the difference in scale value, the number of safe choices in the modified HLL (range of 0-10) and the modified BL (range of 0-8) are converted into percentages of safe choices for comparison.
[b] Based on the Wilcoxon rank-sum (Mann-Whitney) test.

Test of H2 'Inconsistency rates of modified BL vs. modified HLL'

To analyze whether the modified BL is better able to reduce inconsistency rates in the response behavior compared to the modified HLL, individuals are classified into four groups as shown in Table 6. With respect to the modified HLL, the first group encompasses participants who first choose option A and at some point switch to option B. The second group comprises participants who always choose option B. We assume that participants in these two groups understood the lottery and therefore consider them as to be consistent. The third group comprises participants who always choose option A. This group is considered as to be inconsistent as we think that participants did not completely understand the lottery, since they should have switched to option B at the latest in decision task 10. In the fourth group there are participants who switch at least twice. With respect to the modified BL, the first group also encompasses participants who first choose option A and at some point switch to option B. The second group comprises participants who always choose option A and the third group comprises participants who always choose option B.

Although the third group is consistent in their response behavior, we think that participants did not completely understand the lottery, since they should have chosen option A at least in the first decision task, which offered a 100% chance to win UGX 10,000. Hence, this group is considered as being inconsistent. The last group comprises participants who switch at least twice. Also in the modified BL, the first two groups are classified as to be consistent, while the last two groups are classified as to be inconsistent in our analysis.

Table 6 Classification of groups by consistency and inconsistency rate (N = 332)

	Group	Description	Modified HLL
Consistent	1	Switch once	303
	2	Always choose option B	10
Inconsistent	3	Always choose option A	4
	4	Switch at least twice	15
	Group	Description	Modified BL
Consistent	1	Switch once	185
	2	Always choose option A	122
Inconsistent	3	Always choose option B	10
	4	Switch at least twice	15

Source: Survey data.

According to this classification scheme, 313 of 332 participants (94.3%) appear to have understood the modified HLL. Another 4 participants (1.2%) always chose option A, and 15 participants (4.5%) switched at least twice. In the modified BL, 307 of 332 participants (92.5%) appear to have understood the lottery. Another 10 participants (3.0%) always chose option B, and 15 participants (4.5%) switched at least twice. In both risk attitude elicitation methods, the inconsistency rates of 5.7% in the modified HLL and 7.5% in the modified BL are relatively low compared to other studies in this field (Galarza 2009; Jacobson and Petrie 2009; Brick et al. 2012; Charness and Viceisza 2011). The relatively low rates of inconsistency may be an indication that our design of the modified HLL and the modified BL was well understood by the participants in Uganda. The inconsistency rates are even slightly lower in the modified HLL compared to the modified BL. Against the assumption of Brick et al. (2012) that people have more difficulties with varying probabilities than with varying amounts of payoffs, we do not find any evidence in our results given the relatively low rates of inconsistency in both methods. On this basis, we reject *H2 'Inconsistency rates of modified BL vs. modified HLL'*.

Test of H3 'Farmer-specific effects for risk attitude'

The interval and ordered probit regression models are used to analyze how socio-demographic and socio-economic factors affect risk attitudes. The interval regression model uses the midpoint CRRA coefficients of the modified HLL and the modified BL as the dependent variable, while the ordered probit regression model uses the number of times a participant chose the safe option in the respective lottery as the dependent variable. We use two regression models as a robustness check of the regression results of each of the two models. Table 7 presents the results of two interval and two ordered probit regression models.

First, the results show that the effects of socio-demographic and socio-economic factors on risk attitudes are the same across the two regression models, confirming robustness of our results. For example, education, district, quiz test score, and winner modified BL all significantly have an effect on risk attitudes in the interval and ordered probit models. Second, all statistically significant explanatory variables (except for quiz test scores in the interval regression) of risk attitude vary across the two elicitation methods. For example, education has a statistically significant negative effect on risk aversion in the modified BL but shows no significant effect in the modified HLL. Third, the results offer insights into characteristics significant in increasing or decreasing risk aversion as well as their relative impact. The coefficients of district indicate that participants from the Masaka district are substantially less risk averse in the modified HLL than compared to participants from the Luwero district. Participants who correctly answered more questions in the quiz are significantly more risk averse in both elicitation methods in the interval regression. Annual per capita household expenditure has a positive impact on risk aversion for both elicitation methods. Age, gender, household size, dependency ratio, total land owned, access to a savings account, and access to credit show no significant effects.

The extant literature offers conflicting evidence on how individual characteristics influence risk attitude. For example, we found that risk aversion decreases with education, which is contradictory to other studies (e.g., Harrison et al. 2007), although deviating from other studies, which did not find a significant impact (e.g., Reynaud and Couture 2012). Previous studies found a positive relationship between risk aversion and wealth (e.g., Cohen and Einav 2007), whereas others do not find a relationship (e.g., Tanaka et al. 2010). We found that a proxy for wealth such as the annual per capita household expenditure is positively associated with risk aversion. Moreover, some of the socio-demographic (age, gender,

household size, and dependency ratio) and socio-economic characteristics (total land owned, access to a savings account, and access to credit) are not significant, which is interesting because many studies found an effect (Eswaran and Kotwal 1990; Miyata 2003; Hallahan et al. 2004; Wik et al. 2004; Croson and Gneezy 2009; Jacobson and Petrie 2009; Nielsen et al. 2013). Although we found a significant effect of several socio-demographic and socio-economic factors on risk attitude, these factors are not consistent across the two elicitation methods. On this basis, we fail to reject *H3 'Farmer-specific effects for risk attitude'*.

Besides testing the effects of socio-demographic and socio-economic characteristics on individuals' risk attitudes, we test for a potential 'order effect' in the experiment to check whether farmers show different decision behavior when they are faced with the two lottery-choice experiments in a different order. Some participants were at first faced with the modified HLL and then with the modified BL or vice versa. According to Harrison et al. (2005b) prior experience with one task may influence participants' behavior in a subsequent task. However, it may also indicate a 'learning effect', meaning that participants acquire routines in one task and apply them to later decisions even if they are related to another task (Scheufele and Bennett 2013). We also included a binary indicator for winning in the first lottery-choice experiment in order to test whether there is an impact on the second lottery-choice experiment. Order in the experiment is not statistically significant in the regression models. However, a participant who first played the modified BL and won is more risk averse in the subsequent modified HLL. This indicates that conducting various successive experiments should be done with caution as prior experience with one task affects behavior in a subsequent task, which was also found by Harrison et al. (2005b).

Table 7 Results of the interval and ordered probit regression with the individual risk attitude as the dependent variable (N = 332)

Variable	Interval regression		Ordered probit regression	
	Modified HLL	Modified BL	Modified HLL	Modified BL
Age *(years)*	0.003	0.001	0.004	-0.001
	(0.003)	(0.005)	(0.004)	(0.004)
Gender *(1= female)*	0.009	0.014	-0.008	0.030
	(0.078)	(0.143)	(0.124)	(0.128)
Education *(years)*	0.008	-0.045**	0.002	-0.042**
	(0.012)	(0.023)	(0.020)	(0.020)
Household size *(number)*	-0.001	-0.021	-0.005	-0.011
	(0.013)	(0.024)	(0.020)	(0.021)
Dependency ratio[a]	-0.008	-0.069	0.019	-0.065
	(0.034)	(0.062)	(0.054)	(0.056)
District *(1 = Masaka)*	-0.220***	0.027	-0.388***	0.056
	(0.078)	(0.144)	(0.126)	(0.128)
Quiz test score *(number)*	0.111**	0.200**	0.159**	0.130
	(0.049)	(0.092)	(0.078)	(0.081)
Annual per capita household expenditure *(UGX)*[b]	7.64e-08	4.35e-07**	1.54e-07	3.98 e-07**
	(1.02e-07)	(1.94e-07)	(1.62e-07)	(1.73e-07)
Total land owned *(acres)*[c]	0.008	-0.005	0.010	-0.003
	(0.008)	(0.016)	(0.013)	(0.014)
Access to a savings account *(dummy)*	0.012	0.179	0.063	0.159
	(0.088)	(0.164)	(0.141)	(0.147)
Access to credit *(dummy)*	-0.016	0.019	-0.081	0.015
	(0.076)	(0.140)	(0.122)	(0.125)
Order of experiment *(1 = first modified BL)*	0.054	-0.151	0.087	-0.135
	(0.076)	(0.142)	(0.121)	(0.127)
Winner modified BL *(dummy)*	0.255*		0.425*	
	(0.153)		(0.244)	
Winner modified HLL *(dummy)*		0.249		0.183
		(0.255)		(0.228)
Constant	-0.422*	0.124	-0.443***	0.107*
	(0.223)	(0.413)	(0.043)	(0.063)
Observations	332	332	332	332
Chi^2	23.43	19.18	24.04	16.12
Log likelihood	-698.0	-621.7	-616.5	-598.0
Interval observations	290	169		
Right censored observations	14	122		
Left censored observations	19	41		
Uncensored observations	9	0		

Source: Survey data

Notes: Standard errors in parentheses. *p < 0.10, **p < 0.05, ***p < 0.01.
Dependent variables: Interval regression: midpoint CRRA coefficients of the modified HL and BL; Ordered probit regression: number of safe choices in the modified HL and BL.
[a] A measure showing the number of dependents (aged 0-14 and over the age of 65) to the number of people (aged 15-64).
[b] At the time of the experiments, the exchange rate was approximately € 1 to UGX 3,000.
[c] 1 acre = 0.40 hectare.

6   Conclusions

Smallholder farmers in a rural developing country setting face risky decisions regularly in their daily lives. Thus, a better understanding of farmers' risk attitudes is crucial in order to gain insight of how risk affects their decision behavior, interpreting agricultural outcomes, and designing policies and programs such as insurance instruments and other safety nets that effectively assist farmers. However, several studies quantifying individual risk attitudes showed that results of different elicitation methods may vary and reported relatively high inconsistency rates in individuals' response behavior, which may indicate a low level of comprehension. The comparison of different risk attitude elicitation methods allows insights into which method may be better adapted to assess risk attitudes of farmers in a developing country. In this study, we elicit the risk attitude of Ugandan smallholder farmers using two different methods based on the Holt and Laury (2002) and Brick et al. (2012) lottery tasks, which differ in the variation of probabilities and the fixing of payoffs or vice versa. Brick et al. (2012) assumed that people have more difficulties with varying probabilities than with varying amounts of payoffs. Furthermore, we evaluate the inconsistency rates in the response behavior and investigate whether risk attitudes are influenced by farmers' socio-demographic and socio-economic factors and whether these factors are consistent across the elicitation methods.

Our results show first that farmers, on average, are risk averse. Second, the different categories of risk attitude indicate a statistically significant difference across the two elicitation methods. That means that risk attitude measures are affected by the type of method used, even though the tendency of participants being risk averse is the same. Third, we found a relatively low rate of inconsistent decisions in both lottery-choice experiments. This finding may be an indication that our version and implementation of the modified HLL and the modified BL was well understood by the participants and thus, an appropriate elicitation method within a developing country context. It also shows that in our case people do not have more difficulties with varying probabilities than with varying amounts of payoffs given the low inconsistency rates in both lottery-choice experiments. Fourth, specific socio-demographic and socio-economic factors are significant determinants of risk attitudes: education, district, and annual per capita household expenditure. The factor quiz test score, which we used assess whether farmers have a basic comprehension of probabilities, and the factor winner modified BL, which we used to assess whether winning in the first lottery-choice experiment influences the behavior in the second lottery-choice

experiment, also have an impact on individuals' risk attitudes. Although these factors are consistent across the two applied regression models, they are not consistent across the two different elicitation methods. This shows that one has to be cautious in making meaningful conclusions about the impact of these factors on risk attitude and therefore policy recommendations.

When interpreting the results, it is important to take into account that our experimental design is abstracted from reality and is considerably simpler than risky situations that would occur in an actual setting. Participants may act differently in the experimental situation than they do in a similar situation in the real world. A common criticism of experiments has to do with whether experimental results are likely to provide reliable inferences outside the experimental setting and can be extrapolated to the real world (Levitt and List 2007; Roe and Just 2009). This lack of external validity is considered to be the major weakness of laboratory experiments (Loewenstein 1999). Nevertheless, we believe that a careful experimental design and implementation, which is adapted to a rural, developing country setting, is essential for a valid measure of individuals' risk attitudes.

Some extensions of the present study might further verify the validity of our results. First, it would be interesting to analyze how the original lottery-choice experiment design with probabilities expressed in percent and the modified lottery-choice experiment design with probabilities expressed in bags of colored balls compares to each other in regard to inconsistency rates in the response behavior. Second, more research is needed in identifying more explanatory factors of risk attitudes and in examining the explanatory power of risk attitude measures in observed actual economic behavior. Third, different risk tasks involving different degrees of difficulty could be considered in order to more carefully address the question of how a participant's ability to reason with numbers and probabilities affects the results of different risk measures. Fourth, another interesting path to be taken would be to test whether farmers in developed countries show similar risk attitudes and inconsistency rates in the two lottery-choice experiments as farmers in developing countries. It would be also worth examining the robustness of our results by conducting the lottery-choice experiments with farmers in another developing country.

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Appendix: Experimental instructions

Outline

The experiment session comprises:

1. Sign-in (location and arrival)
2. Introduction and agenda (an introduction of the experimenter, enumerators, assistant experimenter, and the project)
3. Quiz
4. Instructions, practice, and decision making (coin tossing games are randomized)
   - 4.1 Lottery game (1)
   - 4.2 Lottery game (2)
5. Payment

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1   Sign-in (location and arrival)

- Each participant will present his/her photo ID before he/she will be signed in. The participant will then draw a number out of a bag. This number (personal number of the respondent) randomly determines his/her seat, which is the individual's location throughout the experiment session.
- The experiment will be conducted in sessions of six participants in classrooms in local schools or in a meeting room at the main gathering place of a farmer's group or association.
- Each participant will have his/her own enumerator.
- The typical layout of the room will be as follows:

Front of room (experimenter, and white board)	
Seat 1	Seat 2
Seat 3	Seat 4
Seat 5	Seat 6
Back of room (assistant experimenter/cashier)	

Notes:
- *Text in italics is not part of the participant instructions.*
- *The instructions are explained orally by the experimenter in the local language.*
- *Once all the participants are seated, the explanation will start.*

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2   Introduction and agenda

- Hello and welcome. Thank you for coming to our workshop today.
- *The experimenter introduces himself, the enumerators, and the assistant experimenter. The experimenter introduces the institution and the project, typically as follows:*
  - In Uganda, we are conducting a research project on farmers' decision behavior in risky situations.
  - We have been holding discussions with farmers across many parts of Uganda. In particular, we have talked to farmers in …, but we have not been here before.
  - We are very grateful that we can do the workshop in this area today and that you have found some time to participate. Thank you very much for that.

- For the upcoming tasks, you will receive cash payments for the decisions you make. We provide these payments for two purposes:
    - i. Because you came here today and you are spending your time with us. This is time in which you could be doing something else, so we would like to remunerate this.
    - ii. Also, we would like you to take this decision seriously, so that it represents your decision making behavior of normal real life decisions.
- Today's workshop will include the following steps:
    - First, we explain the instructions of the different tasks on decision making.
    - Then, we will do a practice run together to show how it works. Then, you will make your decisions. Today, we will do several types of decisions. In a moment, I will explain all the different tasks on decision making in more detail, one after another.
    - Then, you will receive your payment. Payment will be effected in private and in cash at the end of today's workshop.
- I have some additional general comments:
    - Please turn off your mobile phones, etc.
    - All decisions you make or answers you give during the workshop are private, confidential, and anonymous.
    - Since all decisions and answers are private, please do not talk to each other anymore. If you have questions, please ask us by raising your hand.
    - Please do not discuss with your neighbor except for the enumerator next to you. The enumerator next to you will record your answers.
    - When making decisions, you should make the decision that you prefer the most as you will receive the cash payment on the basis of that decision, given that you have been selected as a winner. Please make your decisions as if they are real life decisions.
    - If there are any questions at any point, please raise your hand and ask.
    - Any questions before we start?

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3   Quiz

- *The experimenter hands out the questionnaire to the enumerator. Then, explanation and decision making would start.*
- We will start today's workshop with a short quiz.
- The quiz contains several tasks. It is not a test; you do not need to worry if the questions seem difficult.
- *Questions are asked with regard to probabilities and percentage calculation. This basically enables the participants to start thinking about the material and the decisions they will be presented with during the workshop. The participants make their choice, and their enumerators record the answers and tick the relevant box.*
- Now, we are coming to the first task.
- 1. Imagine, we toss a coin and the 'heads' (emblem) comes up. What comes up if we toss the coin again? (possible answers: a = heads, b = tails, c = one cannot predict exactly)
- Now, we are coming to the second task.
- 2. If the chance of winning a prize is 10%, how many people out of 100 would be expected to get the prize? If you don't know, put an X.
- Now, we are coming to the last task of this quiz.

- 3. When you draw the red ball, you win! Look at the two boxes and mark the correct sentence. (Possible answers: a = my chance to win is higher if I choose Box A. b = my chance to win is equal, it does not matter which box I choose. c = my chance to win is higher if I choose Box B.)
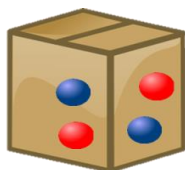
Box A   Box B
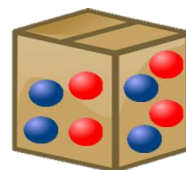
4 Instructions and decision making

4.1 Lottery game (1)

- In the first/second session, you are asked to choose between two bags. You will be asked to make a number of repeated choices.
- I will now explain the first session. Then, you will make your decisions in this session.
- *Posters are displayed on a large white board at the front of the room. This is used to illustrate the basics of the game as explained below.*
- The objective of this task is to win money. There are four possible prizes: 300 UGX, 4,800 UGX, 6,000 UGX, and 11,550 UGX. The four different colored balls represent the four possible prizes. The green ball is worth 300 UGX, the blue ball is worth 4,800 UGX, the red ball is worth 6,000 UGX, and the yellow ball is worth 11,550 UGX.
- Note that we will randomly select one winner out of you for this task.
- *Show poster 1: The picture of the sheet with the lottery game*
- *Real balls will also be shown.*

Choose your preferred bag by marking either **Bag A** or **B** in each row.

[…]   […]

- How are you going to win these prizes?
- To win these prizes, you will first have to choose between two bags, Bag A and Bag B, for each of the 10 rows. How do these two bags differ? Each bag contains 10 balls. The two bags contain differently colored balls (green, blue, red, and yellow) with a different value. We draw only one ball from the selected bag, which will be the prize. If you choose Bag A, you can win a prize of 6,000 UGX (red ball) or a prize of 4,800 UGX (blue ball). And if you choose Bag B, you can win a prize of 11,550 UGX (yellow ball) or a prize of 300 UGX (green ball). We are going to ask you which of these two bags you prefer.
- Note that with Bag A the difference between the prizes is small, while it is large in the case of Bag B.
- In addition, in Bag A the prize of 6,000 UGX is smaller than the prize of 11,550 UGX in Bag B, and the prize of 4,800 UGX in Bag A is greater than the prize of 300 UGX in Bag B.
- Thus, you will choose between Bag A and Bag B in 10 rows, one after another.
- Let's focus on the first row.
- *Show poster 2: example for Bag A or Bag B in row one*

- Bag A:
  - Bag A contains nine blue balls and one red ball. Each blue ball is worth 4,800 UGX, and the red ball is worth 6,000 UGX.
  - If this bag is selected and the red ball is subsequently drawn, you will win 6,000 UGX. In the case that one of the blue balls is drawn, you will win 4,800 UGX.
  - So, if we pick a ball from the bag, it may be blue or red. But, it is more likely that we pick one of the blue balls because there are more blue balls (than red balls) in the bag.
- Bag B:
  - Now, let's look at Bag B. What is different about it? Well, this bag contains nine green balls and one yellow ball. Each green ball is worth 300 UGX, and the yellow ball is worth 11,550 UGX.
  - If this bag is selected and the yellow ball is subsequently drawn, you will win 11,550 UGX. In the case that one of the green balls is drawn, you will win 300 UGX.
  - So, if we pick a ball from the bag, it may be a green or a yellow one. But, it is more likely that we pick one of the green balls because there are more green balls (than yellow balls) in the bag.

- This explains row one. How do the other rows differ from row one?
- *Show poster 3: example for Bag A or Bag B in row two*

- Note that when we go from row one to row two, the only aspect that changes is the number of red balls in the bags. That is, the value of the balls does NOT change.
- Bag A:
    - Bag A contains eight blue balls and two red balls. Each blue ball is worth 4,800 UGX and each red ball is worth 6,000 UGX.
    - If this bag is selected and the red ball is subsequently drawn, you will win 6,000 UGX. In the case that one of the blue balls is drawn, you will win 4,800 UGX.
    - So, if we pick a ball from the bag, it may be blue or red. But it is more likely that one of the blue balls is drawn because there are more blue balls (than red balls) in the bag.
- Bag B:
    - Bag B contains eight green balls (each worth 300 UGX) and two yellow balls (each worth 11,550 UGX). Each green ball is worth 300 UGX, and each yellow ball is worth 11,550 UGX.
    - If this bag is selected and the yellow ball is subsequently drawn, you will win 11,550 UGX. In the case that one of the green balls is drawn, you will win 300 UGX.
    - So, if we pick a ball from the bag, it may be green or yellow. But, it is more likely that one of the green balls is drawn because there are more green balls (than yellow balls) in the bag.
- *Quiz participants for understanding (control questions):*
- Now, what happens if we go from row two to row three?
- *Show poster 4: example for Bag A or Bag B in row three*

- How many blue and red balls does Bag A contain?
- How many green and yellow balls does Bag B contain?
- Suppose you choose Bag A and the red ball is drawn, how much do you win?
- Suppose you choose Bag B and the yellow ball is drawn, how much is it worth?
- *etc.*
- So, we are going to ask you to decide for bag A or B in each of the 10 rows.
- Note that your choice should really be guided by your attitudes. There are no wrong or right decisions.
- *Then, participants are informed that only one row will be selected for payment and that only one person wins the prize.*
- How will we determine the amount of money you will win for participating in this task? Now, we will explain the payment for this game.
- Only one person will receive a payment for one of the choices he/she made in this task. However, you do not know yet for which of the choices the selected person will receive the payment, so you will want to think about each choice very carefully. You will only find out at the end of this task for which of these choices the selected person is going to receive a payment.
- The payment in this game comprises three draws:
    - The first draw is to determine the person who wins a prize. Remember, in the beginning of today's workshop, you got a personal number. We will ask one of you to draw a number between 1 and 6 out of a bag. The holder of the number that is picked from the bag will be the winner of one of the prizes.
    - The second draw is to determine the row for which you will get paid. We will ask the selected person to draw a number between one and 10 out of a bag. The number that is picked from the bag will be the choice that counts for the selected person.
    - The third draw is to determine whether the person receives the low or high prize. We will ask the selected person to draw a ball out of Bag A in case he/she chose Bag A or one out of Bag B in case he/she chose Bag B. The ball that is picked from the respective bag will be the choice that counts for him/her.

- Are there any questions before we start?
- *Then, decisions will be made.*
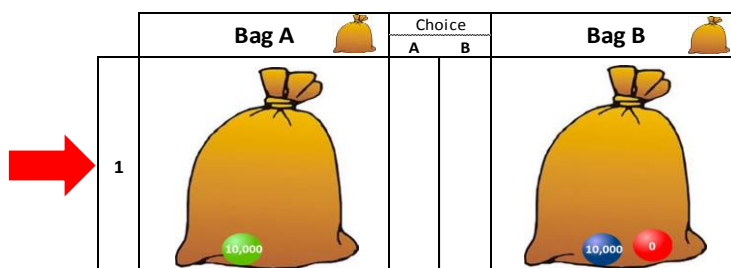- Which bag do you choose? Choose your preferred bag by marking either Bag A or B in each row.
- *The enumerators ask their farmers for each of the 10 rows which bag they prefer. The participants make their choice by pointing at the bag they prefer, and their enumerators record the answers and tick the relevant box.*

4.2 Lottery game (2)

- In the first/second session, you are asked to choose between two bags. You will be asked to make a number of repeated choices.
- I will now explain the second/third session. Then, you will make your decisions in this session.
- *Posters are displayed on a large white board at the front of the room. This is used to illustrate the basics of the game as explained below.*
- The objective of this task is to win money. The differently coloured balls represent the possible prizes. The red ball is worth 0 UGX, the blue ball is worth 10,000 UGX, and the value of the green ball ranges from 10,000 UGX to 1,000 UGX.
- Note that we will randomly select one winner for this task.
- *Show poster 1: The picture of the sheet with the lottery game*
- *Real balls will also be shown.*

Choose your preferred bag by marking either **Bag A** or **B** in each row.
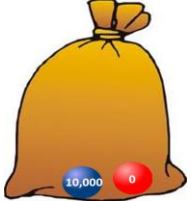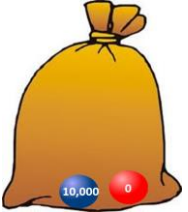

- How are you going to win these prizes?

- To win these prizes, you will first have to choose between two bags, Bag A and Bag B, for each of the 10 rows. How do these two bags differ? The two bags contain differently coloured balls (green, blue, and red). The value of the green ball changes in each decision row, while the values of the blue and the red ball remain the same across the decision rows. We draw only one ball of the selected bag, which will be the prize.
- If you choose Bag A, you can win for sure a certain amount of money (green ball). If you choose Bag B, you can win a prize of 10,000 UGX (blue ball) or nothing (red ball). We are going to ask you which of these two bags you prefer.
- The questions deal with the question of whether you prefer to have a guaranteed smaller amount of money, OR a larger amount of money that involves some risk and you might end up getting nothing. You can never lose any money irrespective of what you choose.
- We will ask you to choose between Bag A and Bag B in eight rows, one after another.
- Let's focus on the first row.
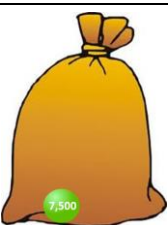- *Show poster 2: example for Bag A or Bag B in row one*

- Bag A:
  - Bag A contains one green ball. This ball is worth 10,000 UGX.
  - If this bag is selected and the green ball is subsequently drawn, you will win 10,000 UGX.
  - So, if you choose bag A, you know what you get for sure.
- Bag B:
  - Now, let's look at Bag B. What is different about it? Well, this bag contains one blue ball and one red ball. The blue ball is worth 10,000 UGX and the red is worth nothing.
  - If this bag is selected and the blue ball is subsequently drawn, you will win 10,000 UGX. There is also the chance that the red ball is drawn. In this case, you will get nothing.
- This explains row one. How do the other rows differ from row one?
- *Show poster 3: example for Bag A or Bag B in row two*

- Note that when we go from row one to row two, the only aspect that changes is the value of the green ball.
- Bag A:
  - Bag A contains one green ball. Now, this ball is worth 7,500 UGX.
  - If this bag is selected and the green ball is subsequently drawn, you will win 7,500 UGX.
  - So, if you choose bag A, you know what you get for sure.
- Bag B:
  - Now, let's look at Bag B. This bag contains one blue ball and one red ball like in the first example. The blue ball is worth 10,000 UGX and the red is worth nothing.
  - If this bag is selected and the blue ball is subsequently drawn, you will win 10,000 UGX. There is also the chance that the red ball is drawn. In this case, you will get nothing.
- *Quiz participants for understanding. Control questions are asked with regard to the probabilities and earnings.*
- Now, what happens if we go from row two to row three?
- *Show poster 4: example for Bag A or Bag B in row three*

- How many balls does bag A contain?
- What is the value of the green ball?
- How many blue and red balls does Bag B contain?
- Suppose you choose Bag A and the green ball is drawn, how much do you win?
- Suppose you choose Bag B and the red ball is drawn, how much do you win?
- *etc.*
- So, we are going to ask you to make a decision for each of the eight rows: Bag A or Bag B.
- Note that your choice should really be guided by your attitudes. There are no wrong or right decisions.
- *Then, participants are informed that only one row would be selected for payment and that only one person wins the prize.*
- How will we determine the amount of money you will win for participating in this task? Now, we will explain the payment for this task.
- Only one person will receive a payment for one of the choices he/she made in this task. However, you do not know yet for which of the choices the selected person will receive the payment, so you will want to think about each choice very carefully. You will only find out at the end of this task for which of these choices the selected person is going to receive a payment.
- The payment in this game comprises three draws:
  - The first draw is to determine the person who wins a prize. Remember, in the beginning of today's workshop, you got a personal number. We will ask one of you to draw a number between one and six out of a bag. The number that is picked from the bag will determine the winner of one of the prizes.
  - The second draw is to determine the row for which you will get paid. We will ask the selected person to draw a number between one and eight out of a bag. The number that is picked from the bag will be the choice that counts for him/her.

- If the person chose bag A, which means he/she decided to take the money for sure, he/she will get that amount of money. If the person chose bag B, he/she will draw a ball out of the bag to determine whether he/she receives 10,000 UGX or nothing. The ball that is picked from the respective bag will be the choice that counts for the selected person.
- Are there any questions before we start?
- *Then, decisions will be made.*
- Which bag do you choose? Choose your preferred bag by marking either Bag A or B in each row.
- *The enumerators ask their participants for each of the eight rows which bag they prefer. The participants make their choice by pointing to the bag they prefer, and their enumerators record the choice/tick the relevant box.*

V. Summary and Discussion

The papers of the dissertation focus on decision making under uncertainty of farmers in developed and developing countries and apply experimental approaches in order to investigate farmers' risk attitude and investment behavior. The first paper experimentally examines the investment and disinvestment behavior of German farmers using an investment situation in an agricultural context, while the second paper analyzes the investment behavior of Ugandan farmers using an investment situation in a non-agricultural framing with and without the presence of a price floor. In the third paper, individual risk attitudes of Ugandan farmers are measured and compared using different risk elicitation methods. The following research questions have been examined within the three different papers of the dissertation:

1st Paper: Analysis of the investment and disinvestment behavior of German farmers

- *How well can the real options approach (ROA) or the net present value (NPV) account for the investment and disinvestment behavior of German farmers?*
- *Do German farmers approximate optimal exercise of the ROA if they are given a chance to learn from past experience in investment and disinvestment decisions?*
- *Do specific socio-demographic and socio-economic factors influence the investment and disinvestment behavior of farmers?*

2nd Paper: Analysis of the investment behavior of Ugandan farmers

- *How well can the real options approach (ROA) or the net present value (NPV) account for the investment behavior of Ugandan farmers?*
- *Does the presence of a price floor have an effect on farmers' investment behavior?*
- *Do Ugandan farmers approximate optimal exercise of the ROA if they are given a chance to learn from past experience in investment decisions?*

3rd Paper: Elicitation of the individual risk attitudes of Ugandan farmers

- *Do different methods for eliciting the individual risk attitude affect the results?*
- *Does the modified Brick lottery outperform the modified Holt and Laury lottery in reducing the inconsistency rates in the response behavior?*
- *Do specific socio-demographic and socio-economic factors influence the individual risk attitude and are these factors consistent across different elicitation methods?*

The different papers of the dissertation come to the following research results regarding the main research questions:

1ˢᵗ Paper:

In the first study, a within-subject designed experiment with a sample of German farmers was conducted to answer the research questions mentioned above. In the experiment, farmers were faced with the option to invest and disinvest in irrigation technology. Both decision situations are repeatedly conducted by the participants and within each repetition, participants should decide to realize or to postpone an investment or disinvestment. They were also faced with a lottery to elicit the individual risk attitude and a survey that captured socio-demographic and farm-specific information. The observed investment and disinvestment decisions in the experiment are contrasted with normative benchmarks, which are derived from the NPV and the ROA. The results show that both theories do not explain exactly the observed investment and disinvestment behavior. Farmers invest later than predicted by the NPV but earlier than suggested by the ROA and they disinvest later than predicted by the NPV and even later than suggested by the ROA. However, the results suggest that the ROA can predict actual investment and disinvestment decisions better than the NPV. Furthermore, farmers accumulate knowledge through repeated decision making in investment situations, and approximate the predictions of the ROA, and do not further deviate from the ROA benchmark in disinvestment situations. Specific socio-demographic and farm-specific variables also affect the investment and/or disinvestment behavior of farmers, namely age, gender, economic background in education, household size, farm size, and risk attitude.

2ⁿᵈ paper:

In the second study, another within-subject designed experiment with a sample of Ugandan farmers was conducted to answer the research questions elaborated above. The experiment consists of two investment situations stylizing the option to purchase the right to participate in a coin tossing game. The participants were also faced with a lottery to elicit the individual risk attitude and a survey that covered information on household demographics and economic characteristics. The two investment situations differ with regard to the presence of a price floor, which ensures a minimum investment return. The respective decision situations are repeatedly conducted by the participants and within each repetition, participants should decide to realize or to postpone an investment. The observed

investment decisions in the experiment are also contrasted with normative benchmarks, which are derived from the NPV and the ROA as already mentioned in the study above. The results show that Ugandan farmers invest later than predicted by the NPV but earlier than suggested by the ROA regardless with or without the presence of a price floor. However, the results suggest that the ROA can predict actual investment decisions better than the NPV. The investment behavior does not differ significantly with respect to the presence of a price floor, which coincides with the theoretical predictions of the ROA. This finding implies that the consideration of temporal flexibility of an investment decision is necessary for policy impact analysis. Learning from past experience during the experiment does not significantly affect the investment behavior. However, specific socio-demographic and socio-economic factors, such as risk attitude, education, household size, total land owned, access to a savings account, and membership of a farmer group, affect the investment behavior of farmers.

With respect to both the investment and disinvestment experiments conducted with farmers in Germany and Uganda, it has to be considered that participants may behave differently in the experimental situation than they do in a similar situation in reality. Decision makers who are faced with real investment or disinvestment decisions often have multiple objectives, and they require more time to prepare and to make these far-reaching decisions. The ROA is not individually sufficient in order to explain completely the investment and disinvestment behavior, even though the results suggest that the ROA can predict farmers' investment and disinvestment behavior in Germany and Uganda better than the NPV. A common criticism of experiments is the question whether experimental results are likely to provide reliable inferences outside the laboratory and can be extrapolated to reality (Levitt and List 2007; Roe and Just 2009). This lack of external validity is considered to be the major disadvantage of laboratory experiments (Loewenstein 1999). Actually, there is an intensive debate on the trade-off between the internal and external validity of economic experiments (Camerer 2003; Guala 2005). However, there is a widespread consensus that the benefits of internal validity are more important than the lack of external validity if the experiments aim to test economic theories such as the explanatory potential of the ROA in both of our studies (Schram 2005).

Several opportunities present themselves for future research in order to better understand what exactly drives an individual's decision making in investment and disinvestment situations and to predict this behavior in the future. It is possible that potential drivers of

psychological inertia also play a role when explaining investment and disinvestment behavior. A behavioral phenomenon that might influence the intuitive choice of investment triggers towards postponement of this decision is the escalation of commitment effect (Staw 1981; Denison 2009). This effect describes the phenomenon that it is difficult to dissuade someone from a course that the person had previously adopted. That would mean that decision makers have the tendency to persist on a failing course of action. It would also be interesting to reveal the heuristics, which participants apply in order to make investment and disinvestment decisions. Furthermore, a comparison of the studies conducted with farmers in Germany and Uganda could be conducted. This would allow identifying potential differences in the decision-making behavior of farmers in developed and developing countries.

3rd Paper:

In the third study, two different methods for eliciting the risk attitudes of smallholder farmers in Uganda were used for comparison. The risk attitude elicitation methods are based on the incentive-compatible lotteries used in Holt and Laury (2002) and Brick et al. (2012) and differ in the variation of probabilities and the fixing of payoffs or vice versa. Furthermore, the two methods are modified from the original lottery-choice experiments by replacing probabilities expressed in percent with images of bags of colored balls to represent probabilities of different payoffs in order to apply them to individuals in a rural developing country setting. The results show that both methods reveal high proportions of farmers who are classified as risk averse. However, the comparison of the different risk attitude categories shows that the two elicitation methods yield significantly different results. That means that risk attitude measures are affected by the type of method used, even though the tendency of participants being risk averse is the same. Furthermore, the inconsistency rates in the response behavior for the two methods are relatively low compared to other studies in the past. The rate of inconsistent decisions in the modified Holt and Laury lottery (modified HLL) is even slightly lower compared to the modified Brick lottery (modified BL). This finding may be an indication that the version and implementation of the modified HLL and the modified BL was well understood by the participants and thus, an appropriate elicitation method within a developing country context. Specific socio-demographic and socio-economic characteristics also affect farmers' risk attitudes, namely education, district, annual per capita household expenditure, quiz test score, and winner of the modified BL. Although these factors are consistent

across the two applied regression models, they are not consistent across the two different elicitation methods. This shows that one has to be cautious in making meaningful conclusions about the impact of these factors on the risk attitude and therefore policy recommendations.

Given the low inconsistency rates in the response behavior in the results, it would be interesting to conduct and compare the original lottery-choice experiment design with probabilities expressed in percent and the modified lottery-choice experiment design with probabilities expressed in bags of colored balls using the same sample of subjects. An extension of the present study regarding different sample groups by testing whether farmers in developed countries show similar risk attitudes and inconsistency rates in the two lottery-choice experiments as farmers in developing countries or by conducting the lottery-choice experiments with farmers in another developing country might further verify the validity of the results.

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List of publications

Accepted papers:

Ihli, H.J., Maart-Noelck, S.C., and Musshoff, O. (2013). Does Timing Matter? A Real Options Experiment to Farmers' Investment and Disinvestment Behaviours. *The Australian Journal of Agricultural and Resource Economics* (in press).

Working papers:

Ihli, H.J., and Musshoff, O. (2013). Investment Behavior of Ugandan Smallholder Farmers: An Experimental Analysis. *GlobalFood Discussion Paper Series No. 21*, Transformation of Global Agri-Food Systems: Trends, Driving Forces, and Implications for Developing Countries, Goettingen.

Ihli, H.J., Chiputwa, B., and Musshoff, O. (2013). Do Changing Probabilities or Payoffs in Lottery-Choice Experiments Matter? Evidence from Rural Uganda. *GlobalFood Discussion Paper Series No. 24*, Transformation of Global Agri-Food Systems: Trends, Driving Forces, and Implications for Developing Countries, Goettingen.

Conferences:

Ihli, H.J., and Musshoff, O. (2013). Investment Behavior of Ugandan Smallholder Farmers: An Experimental Analysis. *Agricultural & Applied Economics Association' s AAEA & CAES Joint Annual Meeting*, August 4-6, 2013 in Washington DC, US.

Ihli, H.J., Chiputwa, B., Bauermeister, F.-G., and Musshoff, O. (2013). Measuring Risk Attitudes of Smallholder Farmers in Uganda: How Consistent Are Results of Different Methods? *The Second International Agricultural Risk, Finance, and Insurance Conference (IARFIC)*, June 16-18, 2013 in Vancouver, Canada.

Ihli, H.J., Maart-Noelck, S.C., and Musshoff, O. (2013). Investment and Disinvestment under Uncertainty: A Real Options Experiment. *Annual Meeting of the SCC-76 'Economics and Management of Risk in Agriculture and Natural Resources Group'*, March 14-16, 2013 in Pensacola, US.

Ihli, H.J., Maart, S.C., and Musshoff, O. (2012). Investment and Disinvestment in Irrigation Technology: An Experimental Analysis of Farmers' Decision Behavior. *Annual Meeting of the Agricultural & Applied Economics Association (AAEA)*, August 12-14, 2012 in Seattle, US.

Curriculum vitae

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Other skills

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Communication skills German (native)   English (business fluent)

Spanish (very good)   French (basic)

Declaration on the proportion of own work performed

I, hereby, declare the proportion of own work performed in the scientific papers, which are included in this Ph.D. dissertation.

In the first paper titled '*Does Timing Matters? A Real Options Experiment to Farmers' Investment and Disinvestment Behaviors*', which is co-authored by Dr. Syster Christin Maart-Noelck and Prof. Dr. Oliver Musshoff, the following parts have been performed by me: conceptualization and design of the experiment and the survey in close cooperation with Dr. Syster Christin Maart-Noelck and Prof. Dr. Oliver Musshoff, implementation of the experiment, analysis and interpretation of the research results in cooperation with Dr. Syster Christin Maart-Noelck and Prof. Dr. Oliver Musshoff, revision of the paper with all participating authors.

In the second paper titled '*Investment Behavior of Ugandan Smallholder Farmers: An Experimental Analysis*', which is co-authored by Prof. Dr. Oliver Musshoff, the following parts have been performed by me: conceptual development of the research project with advice from Prof. Dr. Oliver Musshoff, design and implementation of the experiment, implementation of model calculations and analysis, interpretation of the research results in close collaboration with Prof. Dr. Oliver Musshoff.

In the third paper titled '*Do Changing Probabilities or Payoffs in Lottery-Choice Experiments Affect the Results? Evidence from Rural Uganda*', which is co-authored by Brian Chiputwa and Prof. Dr. Oliver Musshoff, the following parts have been performed by me: idea and design of the experiment in collaboration with Prof. Dr. Oliver Musshoff, implementation of the experiment, collection of household survey data with the assistance of Brian Chiputwa, analysis and interpretation of the research results in cooperation with Brian Chiputwa and Prof. Dr. Oliver Musshoff.

Declarations

1. I, hereby, declare that this Ph.D. dissertation has not been presented to any other examining body either in its present or a similar form.

   Furthermore, I also affirm that I have not applied for a Ph.D. at any other higher school of education.

   Göttingen, ...

   ....
   (Signature)

   ....
   (Name in block capitals)

2. I, hereby, solemnly declare that this dissertation was undertaken independently and without any unauthorised aid.

   Göttingen,...

   ....
   (Signature)

   ....
   (Name in block capitals)