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Does timing matter? A real options experiment to farmers' investment and disinvestment behaviours*

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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 (ROA) and the classical investment theory can predict farmers' (dis) investment behaviour. We consider a problem of optimal stopping, stylising 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 ROA 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 characterised 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 nonmonetary 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

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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 realising 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 improve 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 recognised 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 analysing 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 realised 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 realised if the disinvestment is

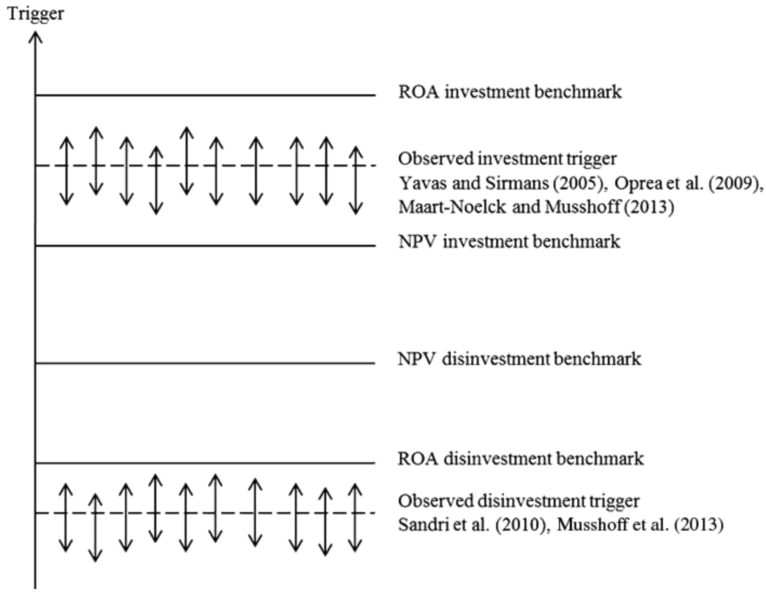

Figure 1 Stylized representation of (dis)investment choices in other experimental (dis) investment studies in relation to normative benchmarks.

postponed; that is, the disinvestment trigger is shifted downwards. Figure 1 stylises (dis)investment choices derived from experimental results of various 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 recognise the benefit of the option to wait. However, their willingness to pay for an investment included an option 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 nonentrepreneurs (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 analysed 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.

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

Therefore, our last hypothesis is as follows:

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.

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 randomised treatments. These two treatments stylise 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 realise 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 1200 €. 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 1400 € with a probability of 50 per cent or decrease to 1000 € 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.

The present values of investment returns corresponded to the gross margins, which could be earned in the respective years assuming an infinite

[1] The parameter values in the (dis)investment experiment (i.e. investment cost, salvage value, gross margin, standard deviation and interest rate per year) 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 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%

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

useful lifetime of the investment object. Moreover, it was assumed that the gross margin observed in the year after the investment realisation 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 1400 € per year resulted in a present value of 14,000 €, while an annual gross margin of 1000 € per year resulted in a present value of 10,000 €.

In treatment A, each participant had three options: First, a participant could invest immediately, that is, he/she paid the investment cost of 10,000 € in year 0 and received 1400 € (=present value of 14,000 €) or 1000 € (=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 whether 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, that is, he/she saved the investment cost of 10,000 €. The deposit and the present value of the investment returns minus the investment cost realised 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 5000 € (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.

In treatment B, each participant had three options: First, a participant could disinvest immediately in year 0, that is, he/she received the initial gross margin of 400 € and the salvage value of 5000 €. Second, a participant could decide to postpone the disinvestment decision and could disinvest at any time between year 1 and year 9, that is, 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, that is, 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 realised gross margins and the realised salvage value increased by the risk-free interest rate of 10 per cent for every year left in the tree.

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%

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

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 1155 or 30 € with the same probabilities as in alternative 1. In the second row, the probabilities raise to 20 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 1155 €.

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 zero 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

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.

5 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 S1 (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 min and ranged from 25 to 63 min. All participants received a show-up fee of 10 € as a compensation

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

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 2500 € achieved in the selected repetition. The potential earnings varied between 270 and 1900 € for the investment treatment and between 0 and 1900 € 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 1155 €.

4. Normative benchmarks

For the evaluation of the observed (dis)investment behaviour in the experiment, we have to derive normative benchmarks that 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 annualising 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 S2 analytically and numerically describes the derivation of the normative benchmark for the last two investment periods.

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 1444 and 166 € for the investment and the disinvestment treatment, respectively. The curves coincide with the NPV at 1100 and 500 € at year 9, respectively.

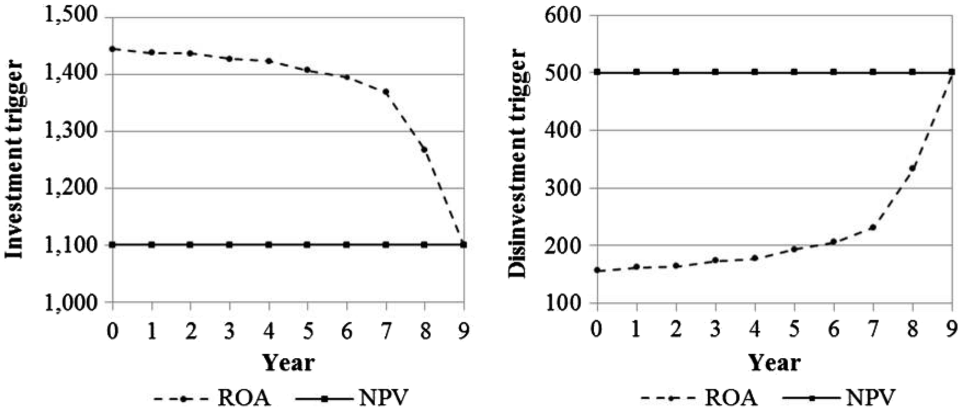

Figure 4 Investment (left figure) and disinvestment (right figure) triggers for a risk-neutral decision maker (in €).

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, and 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, that is, from which gross margin it would be optimal to realise the (dis)investment. Appendix S3 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

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	32.1 years (11.9 years)	
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	228.9 ha (452.4 ha)	
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)	
Investment and (dis)investment behaviour		
Experimentally observed year of (dis)investment without repetitions of non-investment and disinvestment	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 10 expresses risk aversion.

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 to 3600 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.

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 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 2700 random realisations (two 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 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

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

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*.

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 realised 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.

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

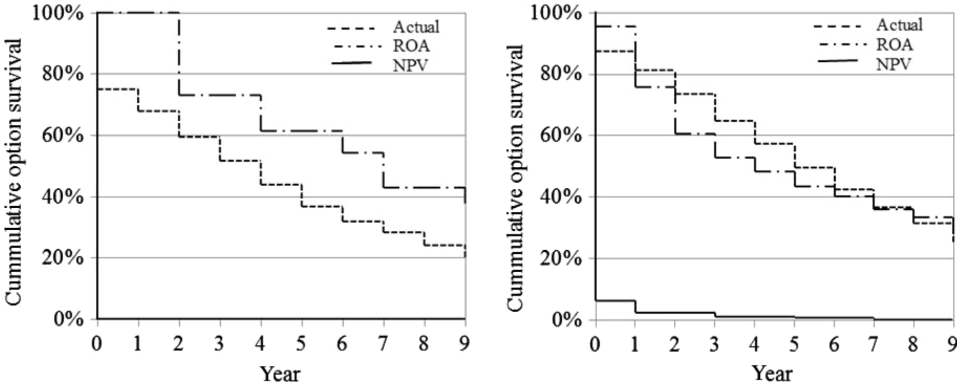

Figure 5 Survival functions of observed and optimal investment (left figure) and disinvestment (right figure) decision making according to the net present value and the real options approach.

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

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.

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.

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 nonsignificance 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 modelled 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 policymaker'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 policymakers 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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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Appendix S1. Experimental instructions.
Appendix S2. Normative benchmarks.
Appendix S3. Risk-adjusted discount rate.