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**Deviations from the real options benchmark –  
An experimental approach to (non) optimal  
investment decisions of conventional and organic hog  
farmers**

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## Abstract

This study analyses the influencing variables on deviations of German hog producers' investment behaviour from optimal investment decisions according to the real options approach (ROA). Therefore, an experiment is carried out wherein hog farmers have the opportunity to invest in a conventional and in an organic hog barn. Theoretical optimal benchmarks according to the ROA are calculated and compared to the observed investment decisions. To examine which factors influence the deviations from ROA, a mixed multinomial model is used. Our results show significant effects of non-monetary variables. First, a significant framing effect becomes obvious, meaning that the deviations from ROA change when farmers have the possibility to invest in the production method they are currently using or in the other one. Second, a learning effect is observed. Increasing experience with investment decisions leads to later investments and a more appropriate incorporation of the value of waiting. Finally, we have found that farm-specific and socio-demographic variables influence the deviations.

**Keywords:** experimental economics, farmers' decisions, hog production, investment behaviour, real options

## 1. Introduction

The proper use of the net present value (NPV) criterion is subject to a number of conditions. However, in real investment situations these conditions are mostly not fulfilled. Here the real options approach (ROA) might be necessary (Abel and Eberly, 1994; Dixit and Pindyck, 1994; Trigeorgis, 1996). The ROA considers that it could be economically advantageous when investments with uncertain returns and high sunk costs are not carried out directly when achieving a positive NPV. The reason for this is that there may be new information available about the uncertain investment returns while waiting (Dixit and Pindyck, 1994, p. 6). The loss of both the option and the flexibility due to the implementation of the investment represent opportunity costs which have to be considered in addition to the investment costs (Pindyck, 1991).

An example of investment situations that comprise requirements for the application of the ROA is an investment in hog production. These investments are very capital intensive and associated with specific sunk costs. Furthermore, such an investment is typically not a now-or-never decision; it may be deferred for a period of time. The explanatory potential of the ROA concerning investments in hog production is described by Odening *et al.* (2005). They find that normative determined investment thresholds according to the ROA are considerably

higher than the thresholds calculated in accordance to the NPV. The explanatory power of the ROA for the reluctance to invest in hog production is shown by Hinrichs *et al.* (2008) on the basis of single farm accounting data. One difficulty of this empirical verification on the validity of the ROA, however, is that investment thresholds are not directly observable. In addition, investors' expectations about the prospective and uncertain investment returns are not known. This kind of data can be obtained by experiments under controlled and identical framework conditions for all participants (Yavas and Sirmans, 2005).

For this reason, the explanatory power of the ROA is investigated with economic experiments. For instance, Yavas and Sirmans (2005) and Oprea *et al.* (2009) carry out experiments with students. They find that students differ from the optimal behaviour according to the ROA; however, approximations to theoretical optimal behaviour can be observed. Ihli *et al.* (2014) experimentally test the validity of the ROA with real agricultural decision-makers in the context of irrigation technologies. Furthermore, Maart-Noelck and Mußhoff (2013) investigate the investment behaviour of farmers in arable land and also in non-agricultural investment possibilities. The studies of Ihli *et al.* (2014) and Maart-Noelck and Mußhoff (2013) indicate that while the ROA has an explanatory power for the investment behaviour of farmers, the investment behaviour, however, cannot be predicted exactly using the ROA. Both aforementioned experiments indicate that farmers have a clear tendency to premature investments.

So far it has not been investigated why the timing of investments deviates from the optimal investment time according to the ROA. As the ROA is a fairly new approach to explain investment behaviour, it can be assumed that farmers have a relatively low theoretical knowledge about this 'new' investment theory. This raises the question if agricultural decision-makers intuitively recognize the value of waiting. Ihli *et al.* (2014) and Maart-Noelck and Mußhoff (2013) find evidence that agricultural decision-makers approximate the optimal investment timing according to the ROA with increasing repetitions in an experiment.

Further studies in the field of behavioural economics reveal that the exclusive consideration of monetary factors influencing the decision behaviour is not sufficient (Kahneman, 2003). These observations can also be made in the agricultural context (Willock *et al.*, 1999). For instance, this is discussed in the context of the conversion of farmers from conventional to organic production. Here, in addition to economic indicators (Koesling *et al.*, 2008; Kuminoff and Wossink, 2010) non-monetary factors, e.g. attitudes towards environmental issues as well as farm-specific and socio-demographic factors in the context of the choice of the production

method (Burton *et al.*, 2003; Laple and Kelley, 2013), are identified that also affect the decisions of farmers.

Against this background, our objective is to analyse the investment behaviour of conventional and organic hog farmers with an incentive-compatible investment experiment. We investigate the factors influencing the deviations of the empirical investment timing from the optimal investment timing according to the ROA. This article provides three contributions to the existing literature. To begin with, we are the first to apply an experimental approach in order to check if the frame of an investment option as ‘conventional’ or ‘organic’ has an influence on the deviations of empirical investment timing from the optimal investment time according to the ROA. Therefore, we conduct a within-subject experiment with real decision-makers. Second, we detect whether multiple consecutive investment decisions have an influence on the deviations from the ROA. Third, we examine the influence of farm-specific and socio-demographic variables on these deviations.

In the following section 2, we derive the hypotheses underlying this paper from the relevant literature. Thereafter, we describe the design of the experiment in section 3. In section 4 the calculation of the normative benchmark for the investment thresholds and the econometric model are explained. Section 5 gives an overview of the socio-demographic characteristics of the participating hog farmers, and the validity of the hypotheses is tested. The paper ends with a discussion and conclusions in section 6.

## **2. Derivation of hypotheses**

Tversky and Kahneman (1981) demonstrate that the preferences of subjects can be influenced by a different description of the same decision situation. Applied to investment decisions, this means that not only are economic indicators of an investment relevant but also the frame, i.e. the context in which the investment possibilities are embedded, is important for the decision.

In the literature it is indicated that conventional farmers are sceptical of the organic production method, which is based, for example, on the disapproval of organic farming by the social environment (Gardebroek, 2006; Defrancesco *et al.*, 2008; Laple and Kelley, 2013). Against this, in the opinion of organic farmers, conventional farming has negative effects on the environment, and they, therefore, refuse this production method (McCann *et al.*, 1997). Based on the reservations about the respective non-used production method, we assume that the description of the investment possibility as conventional or organic influences the decision of hog farmers and alters the conformity with the ROA. With this in mind, we formulate the first hypothesis:

*H1 'Framing': The consistency with the ROA differs when conventional and organic hog farmers have the possibility to invest in the non-used production method for the same economic indicators.*

The decision-making behaviour can be influenced by experience acquired from the past, what is typically referred as a learning effect. In previous experiments, participants have been faced with recurring decision situations in order to analyse whether the subjects adapt their behaviour according to their experience from previous repetitions (Loewenstein, 1999). For example Oprea *et al.* (2009) reveal in an experiment with students that initially they underestimate the value of waiting; however, on average they adjust their decisions towards the optimal behaviour according to the ROA with additional repetitions. A comparable behaviour has also been observed by Yavas and Sirmans (2005). For conventional and organic hog farmers learning effects have not been investigated resulting in hypothesis two:

*H2 'Learning effect': Hog farmers adjust to their behaviour if they are given a chance to learn from past experience.*

Furthermore, it is pointed out in the literature that farm-specific and socio-demographic variables influence investment decisions. Savastano and Scandizzo (2009) show that an increasing farm size leads to subsequent investment decisions, and Adesina *et al.* (2000) determine that full-time farmers invest later than part-time farmers. Thus, the question whether investment decisions of conventional and organic farmers differ from each other arises. Organic farmers act significantly more value-oriented and have a greater environmental awareness than their conventional counterparts (Mzoughi, 2011). However, organic farmers attach significantly less importance to the reduction of production costs and associated risks and show a less pronounced profit orientation (McCann *et al.*, 1997; Lappler, 2013).<sup>1</sup>

In terms of socio-demographic variables, Gardebroek and Oude Lansink (2004) indicate that with increasing age of the decision-maker he/she has a growing delay to invest, whereas with higher education, the opposite is the case. Furthermore, Jianakoplos and Bernasek (1998) have found that women invest later than men. According to Viscusi *et al.* (2011), a greater risk aversion is accompanied by a more hesitant investment. This finding leads to our final hypothesis:

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<sup>1</sup> Evidence for the influence of the attitude on the behaviour of farmers is shown by Vogel (1996) and Willock *et al.* (1999)



*H3 'Farm-specific and socio-demographic variables': Farm-specific and socio-demographic variables affect the compliance of hog farmers' investment decisions with the ROA.*

### **3. Experiment**

The aforementioned hypotheses are tested using a computer-based experiment that is carried out with organic and conventional farmers. The experiment consists of four parts. In the first part, information about the participants' farms is gathered. Afterwards, an investment experiment with two consecutive treatments, namely the investment in an organic and in a conventional hog barn, is conducted. Each participant decides in both treatments.<sup>2</sup> According to the employed production method indicated in the first part of the experiment, the participants are divided into two groups (organic and conventional farmers) to ensure a guaranteed randomized order of treatments in each group.<sup>3</sup>

In the third part, the participants' risk attitude is determined using a Holt and Laury lottery (HLL) (Holt and Laury, 2002). Both the investment experiment and the lottery involve financial incentives. Subsequently, socio-economic data of the participants is collected. The structure of the core elements of the experiment is described in detail in the following.<sup>4</sup>

#### **3.1 Structure of the investment experiment**

The investment experiment consists of two times ten repetitions of decision situations with the same underlying structure. One repetition is composed of five periods in which the participants can decide for or against an investment in a hog barn. Within the 5 periods a participant can only invest once. The investment costs of €300 000 remain constant over the five periods. Participants start each repetition with liquid assets in the amount of €300 000. For the liquid assets available, participants receive a risk-free interest rate of 10 per cent at the end of each period.<sup>5</sup> In each repetition, participants have the following options available: They can either

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<sup>2</sup> We obtain observations from each participant which facilitates the comparison of the different behaviour an individual shows in the two treatments (within-subject design) which, therefore, results in a stronger statistical power of the research findings (Charness *et al.*, 2012).

<sup>3</sup> The randomization is carried out as follows: If one participant in a group starts with the conventional treatment, the next participant starts with the organic treatment, the next with the conventional, etc. This sequence is valid for both groups: organic and conventional farmers. The randomization of the treatments avoids the bias of possible learning effects when we compare the results of both treatments.

<sup>4</sup> A detailed description of the experimental instructions is available from the authors.

<sup>5</sup> For simplicity reasons we fix the risk-free interest rate at 10 per cent.

invest in the hog barn in period 0 or once within the following periods 1 to 4. Alternatively, participants can also decide against the investment over all periods. If participants invest in a hog barn, they can realize the investment returns that correspond to the uncertain present value of the annual returns from the hog barn over its useful lifetime of 20 years. In accordance with Dixit and Pindyck (1994, p. 26), it is assumed for simplification reasons that the annual returns, in the case of an investment, are hedged by a corresponding insurance over the whole production period. However, the investment returns are realized in the period following the period of the investment implementation and therefore, they are uncertain at the time of implementing the investment. In each repetition, participants are supposed to earn as much capital as possible since the total capital forms the calculation basis of possible real payouts for the participants.

The binomial tree shown in Figure 1 visualizes all possible developments of the uncertain present value of the returns from the investment in the hog barn starting from investment returns of €300 000 in period 0 in each repetition. The investment returns are realizations of an arithmetic Brownian motion (Dixit and Pindyck, 1994, p. 59) without a drift and with a standard deviation of €60 000 per period. The probability that the uncertain investment returns increase by €60 000 in the subsequent period is 50 per cent.

Period 0	Period 1	Period 2	Period 3	Period 4	Period 5
					<b>€600 000</b> (3.12%)
			<b>€480 000</b> (12.5%)	<b>€540 000</b> (6.25%)	<b>€480 000</b> (15.62%)
	<b>€360 000</b> (50%)	<b>€420 000</b> (25%)	<b>€360 000</b> (37.5%)	<b>€420 000</b> (25%)	<b>€360 000</b> (31.25%)
<b>€300 000</b> (100%)	<b>€240 000</b> (50%)	<b>€300 000</b> (50%)	<b>€240 000</b> (37.5%)	<b>€300 000</b> (37.5%)	<b>€240 000</b> (31.25%)
		<b>€180 000</b> (25%)	<b>€120 000</b> (12.5%)	<b>€180 000</b> (25%)	<b>€120 000</b> (15.62%)
				<b>€60 000</b> (6.25%)	<b>€0</b> (3.12%)

**Figure 1** Binomial tree of the potential present values of the returns from the investment in the hog barn (probabilities of occurrence in parentheses)

In the course of the experiment, the same binomial tree was shown to the participants and it adjusts automatically to the decisions made and the stochastic development of the investment returns. Furthermore, the possible investment returns and the recalculated probabilities of occurrence are displayed to the participants.

In the investment experiment, decisions to invest in organic and conventional hog production are to be made during ten repetitions, respectively. Organic and conventional hog produc-

tion does not differ in economic parameters; there are only differences with respect to the decision-making situation, namely the framing. Before the ten repetitions start, participants are made aware of whether they deal with the organic or conventional treatment. This is illustrated by using figures of a conventional or an organic hog barn, respectively. After the participants have finished all ten repetitions of one treatment, they are passed on to the other treatment. The two investment treatments appear in a randomized order. This randomization should help to improve the internal validity and reliability (Harrison *et al.*, 2009).

Before the investment experiment starts, all participants are informed about the underlying assumptions and values as well as the calculation of financial incentives. The participants' understanding regarding the framework conditions is tested using control questions. Moreover, they are made familiar with the experiment in a trial run.

### **3.2 Structure of the lottery**

Data about the participants' risk attitudes is collected using a variant of the HLL (Holt and Laury, 2002; Viscusi *et al.*, 2011). Here, participants can choose from a lottery A and B. In lottery A, participants can win either €200 or €160 with a given probability, while in lottery B, they can earn €385 and €10 with a given probability. Thus, lottery B is riskier than lottery A. The probabilities are systematically varied in steps of 10 per cent so that the expected value changes each time. The more often a participant chooses lottery A, the higher the HLL value (number of safe choices) and the more risk-averse is the participant. In accordance to Holt and Laury (2002), three types of risk attitudes can be distinguished: A HLL value of 0 to 3 stands for a risk-seeking attitude, 4 represents risk neutrality, and a value of 5 to 10 means that a participant is risk-averse.

### **3.3 Financial incentives**

Before the experiment started, participants were informed about the probability to win, the range of possible earnings, and the decisions influencing the amount of earnings. In our experiment we use a combination of fixed, and cash payouts depended on the success in the experiment. This is a recognized procedure for financial incentives in experiments (Abdellaoui *et al.*, 2008; Maart-Noelck and Mußhoff, 2014). For completing the experiment, each participant received an expense allowance of €10. The investment experiment and the lottery had an incentive-compatible design and were linked to real payouts. The payout of the investment experiment results from the total capital achieved in a randomly selected repetition divided by 750. The possible earnings from the lottery arise from the task formulation. One random par-

ticipant is selected out of 100 to receive a cash payout. If a participant won, his/her earnings from the investment experiment were added to those from the lottery. The potential earnings varied between €96 and €1590. The amount of the possible earnings is determined by chance and by the decisions made by the participants in the investment experiment and lottery.

## 4. Approach to data analysis

### 4.1 Normative benchmark for a risk-neutral decision-maker

To evaluate the observed investment behaviour, normative benchmarks are calculated that reflect the optimal investment behaviour according to the ROA. Consecutively, the computation of investment triggers for the last two investment periods 4 and 3 is described. Exemplarily, a risk-neutral decision-maker is assumed who discounts the future returns with a risk-free interest rate of  $r = 10$  per cent. According to the experimental design, the investment costs ( $I$ ) for the hog barn are constant at €300 000 over all periods.

By period 5, the observed present value in period 4 ( $V_4$ ) will either increase by  $h = €60\,000$  with the probability of  $p = 50$  per cent or decrease by  $l = €60\,000$  with the probability of  $1 - p$ . As period 4 is the last possible investment period, the flexibility to postpone the investment expires. Thus, the value of the investment in period 4 is defined as the maximum of 0 which corresponds to no investment and the expected net present value ( $NPV$ ) of the investment in period 4 that is denoted alternatively as the intrinsic value of the investment:

$$\tilde{F}_4 = \max(E(NPV_4); 0) \quad (1)$$

$$\text{with } E(NPV_4) = \left( (p \cdot (V_4 + h) + (1 - p) \cdot (V_4 - l)) \cdot q^{-1} \right) - I$$

$E(\cdot)$  designates the expectation operator and  $q^{-1} = \frac{1}{1+r}$  is a discount factor. The critical present value ( $\tilde{V}_4$ ) which indicates the threshold value above which it is optimal to invest is calculated by equating the expected present value in period 4 with the investment costs  $I$ :

$$\tilde{V}_4 = h - 2 \cdot p \cdot l + I \cdot q \quad (2)$$

This means for the assumptions in the investment experiment:

$$\tilde{V}_4 = 60\,000 - 2 \cdot 0.5 \cdot 60\,000 + 300\,000 \cdot 1.1 = 330\,000$$

According to this, a participant should invest in period 4 if the expected present value exceeds €330 000.

In period 3, the participants have to decide whether they invest or whether they postpone the investment to period 4. Deferring the investment could have an advantage because new information on the expected investment returns could be available. From the viewpoint of period 3, the expected present value in period 5 can have the following three values:  $V_3 + 2 \cdot h$

with the probability  $p^2$ ,  $V_3 - 2 \cdot l$  with the probability  $(1 - p)^2$ , or  $V_3 + h - l$  with the probability  $2 \cdot p \cdot (1 - p)$ . A rational risk-neutral decision-maker would only invest if the expected actual net present value exceeds the expected discounted net present value of the following period. The expected discounted net present value of the following period is also called continuation value. Therefore, it is formulated alternatively that the value of the investment is equal to the maximum of the intrinsic value and the continuation value:

$$\tilde{F}_3 = \max(E(NPV_3); E(NPV_4) \cdot q^{-1}) \quad (3)$$

$$\text{with } E(NPV_3) = \left( (p \cdot (V_3 + h) + (1 - p) \cdot (V_3 - l)) \cdot q^{-1} \right) - I \text{ and}$$

$$E(NPV_4) \cdot q^{-1} = \left( p \cdot \left( (p \cdot (V_3 + 2 \cdot h) + (1 - p) \cdot (V_3 + h - l)) \cdot q^{-1} - I \right) + (1 - p) \cdot 0 \right) \cdot q^{-1}$$

The investment trigger  $\tilde{V}_3$  is calculated by equating  $E(NPV_3)$  and  $E(NPV_4) \cdot q^{-1}$ :

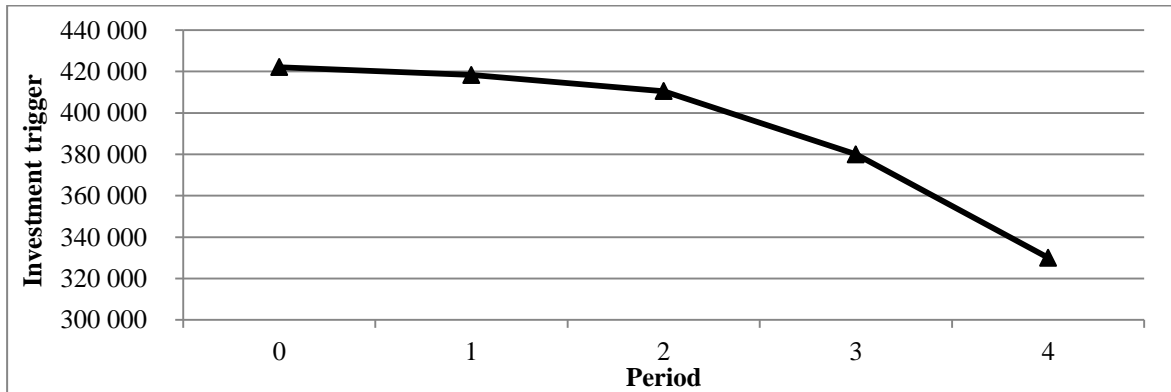
$$\tilde{V}_3 = \frac{q \cdot h - 2 \cdot p \cdot q \cdot l + I \cdot q^2 + 2 \cdot p^2 \cdot h - p \cdot I \cdot q}{q - p} \quad (4)$$

This means for the used example:

$$\begin{aligned} \tilde{V}_3 &= \frac{1.1 \cdot 60\,000 - 2 \cdot 0.5 \cdot 1.1 \cdot 60\,000 + 300\,000 \cdot 1.1^2 + 2 \cdot 0.5^2 \cdot 60\,000 - 0.5 \cdot 300\,000 \cdot 1.1}{1.1 - 0.5} \\ &= 380\,000 \end{aligned}$$

According to this, a participant should only invest in period 3 if the expected present value exceeds €380 000.

The calculation of the critical values according to the ROA for the remaining periods 2 to 0 is done by stochastic dynamic programming (Trigeorgis, 1996, p. 312). The critical exercise threshold for a risk-neutral agricultural decision-maker which is visualized in figure 2 is decreasing exponentially. The diminishing value of waiting is the reason for this development.



**Figure 2** Optimal investment triggers according to the ROA for a risk-neutral decision-maker (in €)

## 4.2 Normative benchmark considering risk attitudes

In addition to this exemplary calculation of the normative benchmark for a risk-neutral decision-maker, optimal benchmarks which consider individual risk attitudes investigated on the

basis of the HLL are computed. This is necessary because the determined trigger values are not a decision rule for non-risk-neutral decision-makers as investment decisions are influenced by risk attitudes (Knight *et al.*, 2003; Viscusi *et al.*, 2011).

The consideration of individual risk attitudes is done by the use of risk-adjusted discount rates. According to Holt and Laury (2002), a power risk utility function is assumed which implies decreasing absolute risk aversion and constant relative risk aversion:

$$U(V) = \frac{V^{1-\theta}}{(1-\theta)} \quad (5)$$

$U$  indicates the utility, and  $\theta$  is the relative risk aversion coefficient. If  $\theta < 0$ , the participant is risk-seeking and  $\theta = 0$  indicates risk neutrality.  $\theta > 0$  represents risk aversion. The relative risk aversion coefficient is established using participants' HLL values. Following this, the certainty equivalent  $CE$  is calculated:

$$CE = V \left( E(U(V)) \right) = [E(U(V)) \cdot (1-\theta)]^{\frac{1}{1-\theta}} = E(V) - RP \quad (6)$$

$E(V)$  denotes the expected present values of the investment returns, and  $RP$  represents a risk premium. The present value of the certainty equivalent  $CE_0$  at time  $T$  is defined as follows:

$$CE_0 = CE_T \cdot (1+r)^{-T} = (E(V_T) - RP_T) \cdot (1+r)^{-T} \quad (7)$$

The risk adjusted interest rate is equal to  $r^* = r + v$ :

$$(E(V_T) - RP_T) \cdot (1+r)^{-T} = E(V_T) \cdot (1+r+v)^{-T} \quad (8)$$

From this it follows:

$$v = (1+r) \cdot \left( \left( \frac{E(V_T)}{E(V_T) - RP_T} \right)^{\frac{1}{T}} - 1 \right) \quad (9)$$

It is difficult to apply dynamic programming for the calculation of the normative benchmarks with the risk-adjusted discount rates according to equation (9) since the problem of a non-recombining binomial tree can occur.<sup>6</sup> This is because the certainty equivalent and the discount rate are not constant over time. Therefore, the level of investment returns is fixed at its initial amount when the risk-adjusted discount rate is determined from equation (9). Moreover,  $T$  is set to one period. Additionally, compliant with Holt and Laury (2002), the values for the extrema HLL 0 and 1 as well as HLL 9 and 10 are summarized to one value, respectively. In this way, nine discount rates are calculated which represent the different individual risk preferences. The discount rates range from 6.78 per cent (HLL = 0-1) to 13.12 per cent (HLL

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<sup>6</sup> This implies that the number of potential states increases exponentially if the number of periods rises (cf. eg. Longstaff and Schwartz (2001)).

= 9-10). The shape of the curve of the risk-adjusted benchmarks for the ROA changes only slightly in comparison to the risk-neutral benchmark. With increasing risk aversion the curves have a steeper slope.

### 4.3 Econometric model

Based on the calculated normative benchmarks according to the ROA the optimal investment times for every investment period are determined. The optimal investment times are compared to the empirical investment times in the experiment. Thus, any decision to invest can be divided into one of three categories compared to the ROA: ‘too early’, ‘exact’, or ‘too late’. This results in a categorical target variable  $Y_i$  with three categories. Due to this scaling, a multinomial logit model is estimated with  $x_i$  as explanatory variables. The aim of this model is to estimate the probability of belonging to one of the mentioned disordered groups  $m$  (Fahrmeir *et al.*, 2013, p. 330):

$$P(Y_i = m) = \pi_{im} = \frac{\exp(\eta_{im})}{1 + \sum_{s=1}^c \exp(\eta_{is})} \quad (10)$$

$$\text{with } m = 1, \dots, c \text{ and } \eta_{im} = \mathbf{x}'_i \boldsymbol{\beta}_m = \beta_{m0} + x_{i1}\beta_{m1} + \dots + x_{ik}\beta_{mk}$$

The alternative depiction

$$\frac{\pi_{im}}{\pi_{i,c+1}} = \exp(\mathbf{x}'_i \boldsymbol{\beta}_m) = \exp(\beta_{m0}) \cdot \exp(x_{i1}\beta_{m1}) \cdot \dots \cdot \exp(x_{ik}\beta_{mk}) \quad (11)$$

expresses that the linear predictor  $\eta_{im}$  specifies the Odds ratio or the relative risk between category  $m$  and the reference category with an exponentially multiplicative model (Fahrmeir *et al.*, 2013, p. 329). The model is estimated Bayesian.

Due to the 20 repetitions of the investment experiment, we have 20 observations for each participant which cannot be seen as independent. Hence, the model is extended to a mixed multinomial logit model by including a random term  $\boldsymbol{\gamma}_m$  (Fahrmeir *et al.*, 2013, p. 392). It is estimated as a random intercept model:

$$P(Y_{ij} = m | \boldsymbol{\gamma}_m) = \frac{\exp(\eta_{ijm})}{1 + \sum_{s=1}^c \exp(\eta_{ijs})} \text{ with } m = 1, \dots, c \quad (12)$$

$\eta_{ijm} = \mathbf{x}'_{ij} \boldsymbol{\beta}_m + \mathbf{u}'_{ij} \boldsymbol{\gamma}_m$  denotes the category-specific predictor with random effects  $\boldsymbol{\gamma}_m$  and the category-specific fixed effects  $\boldsymbol{\beta}_m$ .  $Y_{ij}$  represents the observations of the target variable of farmer  $i$  in repetition  $j$ , and the vector  $\mathbf{x}'_{ij}$  contains the observed values of the covariates of each participant in the particular repetition. As a rule,  $\mathbf{u}'_{ij}$  is a subset of the covariate vector and for random intercept models  $\mathbf{u}'_{ij}$  is equal to 1 (Fahrmeir *et al.*, 2013, p. 362). The random effects  $\boldsymbol{\gamma}_{i1}, \dots, \boldsymbol{\gamma}_{ic}$  are assumed to be i.i.d. multivariate normal distributed,  $\boldsymbol{\gamma}_{im} \sim N(0, \mathbf{Q}_m)$ , whereas the elements of the diagonal of the covariance matrix  $\mathbf{Q}_m$  show the variability of the

farmer-specific random effects around the global parameters  $\beta_m$  (Fahrmeir *et al.*, 2013, p. 358, 392). The selection of the covariates is done according to the improved Akaike information criterion (AIC) corresponding to Burnham and Anderson (1998).

## 5. Results

### 5.1 Descriptive statistics

In spring 2013, a computer-based experiment was conducted with 84 hog farmers. Their socio-demographic and farm-specific characteristics separated by the production method are outlined in Table 1. The processing time of the experiment is 30.8 minutes on average.

Mann-Whitney-U-tests show that conventional and organic farmers do not differ significantly concerning HLL values, farm land, and age. However, the number of hogs and sows is significantly different between both groups.

**Table 1** Descriptive statistics

	Conventional ( $n=51$ )		Organic ( $n=33$ )	
	Mean	Standard deviation	Mean	Standard deviation
Farm land (ha)	99.6	60.8	91.9	93.8
Number of hogs	1684.3 †	1560.4	179.6	236.1
Number of sows	236.0 ‡	155.5	58.0 §	55.1
Full-time farmers (%)	92.2		81.8	
Farm managers (%)	78.4		84.8	
Participants with agricultural qualification (%)	100.0		84.8	
Participants holding a university degree (%)	51.0		51.5	
Age of farmers (years)	38.9 †	8.9	42.0	10.5
Female participants (%)	3.9		12.1	
Risk attitude (HLL value 0-10) ¶	6.1	2.4	5.3	2.2
Participants with investment intention in reality (%)	68.6		54.5	

†  $n = 50$

‡  $n = 26$

§  $n = 14$

¶ HLL = 0-3: risk-seeking, HLL = 4: risk-neutral, HLL = 5-10: risk-averse (cf. Holt and Laury (2002))

Altogether, there are 1680 investment decisions (84 farmers  $\cdot$  20 repetitions). Compared to the ROA, 428 decisions were made at the exact time. 1086 investments were realized too early and 166 too late in relation to the ROA recommended investment timing.



## 5.2 Hypotheses testing

To test the formulated hypotheses a mixed multinomial Logit model is estimated whose results are shown in Table 2.

A positive sign indicates in the model ‘too early’ and also in the model ‘too late’ that the probability of deviating from the ‘exact’ time of investment rises, whereas a coefficient with a negative sign reduces the probability of deviations from the optimal investment timing according to the ROA. If there is no coefficient for the covariate, it has not been included in the model due to the variable selection according to improved AIC. In Table 2, the 95 per cent-confidence intervals are shown. If a confidence interval does not contain 0, the coefficient is significantly different from zero with an error probability of 5 per cent.

**Table 2** Results of the mixed multinomial Logit model to explain the deviations of the agricultural decision-makers’ behaviour in comparison to the optimal behaviour according to the ROA (N= 1680)

Covariate	Too early		Too late	
	Coefficient <i>b</i>	95% confidence interval <i>b</i>	Coefficient <i>b</i>	95% confidence interval <i>b</i>
Constant	<b>2.226</b>	[ <b>0.051</b> ; <b>3.975</b> ]	<b>-1.919</b>	[ <b>-2.735</b> ; <b>-0.740</b> ]
Organic in conventional †	<b>-1.741</b>	[ <b>-2.215</b> ; <b>-1.474</b> ]	<b>0.640</b>	[ <b>0.395</b> ; <b>1.126</b> ]
Conventional in organic ‡	<b>-1.324</b>	[ <b>-1.607</b> ; <b>-1.042</b> ]	<b>0.775</b>	[ <b>0.338</b> ; <b>1.056</b> ]
Conventional in conventional §	<b>-0.634</b>	[ <b>-1.179</b> ; <b>-0.384</b> ]	---	---
Repetition (1-20)	<b>-0.020</b>	[ <b>-0.037</b> ; <b>-0.006</b> ]	<b>0.031</b>	[ <b>0.002</b> ; <b>0.049</b> ]
Farm land (ha)	<b>-0.002</b>	[ <b>-0.004</b> ; <b>0.000</b> ]	---	---
Full-time farmer ¶	---	---	<b>-0.866</b>	[ <b>-1.676</b> ; <b>-0.248</b> ]
Farm manager ¶	---	---	-0.322	[-0.890; 0.095]
Agricultural qualification	-0.826	[-1.565; 0.208]	---	---
University degree ¶	<b>-0.458</b>	[ <b>-0.595</b> ; <b>-0.315</b> ]	<b>-0.559</b>	[ <b>-0.702</b> ; <b>-0.088</b> ]
Age	-0.013	[-0.027; 0.004]	---	---
Gender	0.331	[-0.278; 0.826]	<b>-0.345</b>	[ <b>-1.316</b> ; <b>-0.041</b> ]
Risk attitude ††	0.020	[-0.022; 0.069]	<b>0.167</b>	[ <b>0.095</b> ; <b>0.342</b> ]
Investment intention ¶	<b>0.530</b>	[ <b>0.366</b> ; <b>0.909</b> ]	-0.500	[-0.868; 0.036]

Improved AIC of the starting model with all variables: 2110.6;

Improved AIC of the final model: 2083.0

Significant variables ( $p < 0.05$ ) are printed in bold.

† 1 = *organic* farmer decides in *conventional* treatment, 0 = all other combinations

‡ 1 = *conventional* farmer decides in *organic* treatment, 0 = all other combinations

§ 1 = *conventional* farmer decides in *conventional* treatment, 0 = all other combinations

¶ 1 = yes, 0 = no

|| 1 = male, 0 = female

†† HLL = 0-3: risk-seeking, HLL = 4: risk-neutral, HLL = 5-10: risk-averse (cf. Holt and Laury (2002))

### *H1 ‘Framing’*

To test this hypothesis, on one hand, the investment behaviour of organic farmers who invest in the organic treatment is compared to the decisions of organic farmers in the conventional

treatment. On the other hand, conventional farmers who decide in the conventional treatment are confronted with the investment decisions of conventional farmers in the organic treatment.

Evidence for the validity of H1 becomes obvious by comparing the proportions of investment decisions that were ‘too early’, ‘exact’, or ‘too late’ in comparison to the ROA, depending on production method and treatment. As it can be seen in Table 3, the proportions of ‘too early’ investments decline if the investment is done in the non-used production method. Simultaneously, the shares of ‘exact’ and ‘too late’ investment decisions increase.

**Table 3** Shares of investment possibilities exercised ‘too early’, ‘exact’, or ‘too late’ as predicted by the ROA depending on the production method and treatment

Production method	Treatment	In comparison to the ROA		
		Too early	Exact	Too late
Organic	Organic	84.8%	11.8%	3.3%
	Conventional	52.1%	32.1%	15.8%
Conventional	Conventional	69.0%	25.5%	5.5%
	Organic	55.3%	30.0%	14.7%

For further validations of H1, the results of the mixed multinomial Logit model are used (Table 2). It is examined whether the probability of a ‘too early’ or ‘too late’ exercise of the investment option changes if a hog farmer decides on an investment in the non-used instead in their currently used production method, although economic indicators are identical. The effects of the variables ‘organic in conventional’, ‘conventional in organic’, and ‘conventional in conventional’ have to be interpreted with ‘organic in organic’ as the reference group.

The effect of the covariate ‘organic in conventional’ is significantly negative for ‘too early’ investments. This means that the probability of ‘too early’ investments compared to the ROA decreases if an organic farmer opts for the conventional instead of the organic treatment. The same holds true for conventional farmers if they have the possibility to invest in an organic hog barn instead a conventional one. This is derived from the comparison of the coefficients of the variables ‘conventional in conventional’ and ‘conventional in organic’. Since the posterior distributions are normal for both coefficients and since the difference between the expected values as well as the variances are known for both coefficients, it is possible to test according to Lee (2012) whether the coefficients differ significantly. It becomes obvious that this is the case on a significance level of 5 per cent.

For ‘too late’ investments the variable ‘conventional in conventional’ was not selected for the model according to improved AIC. This means that the probability of ‘too late’ investments of conventional farmers in the conventional treatment is not significantly different from the probability of ‘too late’ investments of the reference group of organic farmers in the or-

ganic treatment. Thus, the significant positive coefficients of the covariates ‘conventional in organic’ and ‘organic in conventional’ show that both conventional farmers in the organic treatment and organic farmers in the conventional treatment have a higher probability for ‘too late’ investments compared to the investments in the used production method.

Summarized, it is concluded that it is **not possible to reject H1**.

### *H2 ‘learning effect’*

The variable ‘repetition’ has a significant negative effect on a ‘too early’ exercise of the investment option compared to the ROA from which it follows that the likelihood of a ‘too early’ investment decreases from repetition to repetition. Thus, it is concluded that hog farmers invest later and with a higher accordance to the ROA with each repetition. At the same time, the probability of ‘too late’ investments increases with each repetition. This indicates an increasing overestimation of the value of waiting, which expands the knowledge from previous studies. Until now, it was known from experiments with farmers (Ihli *et al.*, 2014) as well as with students (Oprea *et al.*, 2009) that the participants of the experiments learn from their decisions and that the value of waiting is considered more in repeating investments. To conclude, it is **not possible to reject H2**.

### *H3 ‘farm-specific and socio-demographic variables’*

To check the influence of the production method, investment decisions of conventional farmers in the conventional treatment are compared to those of the organic farmers in the organic treatment. For this, the variable ‘conventional in conventional’ is used. The coefficient of this variable is significantly negative, implying that conventional farmers have a lower probability, in terms of the ROA, of ‘too early’ investments compared to organic farmers. Since the variable ‘conventional in conventional’ is not selected for ‘too late’ investments in the course of variable selection subject to improved AIC, we conclude that the production method does not have an influence on the probability of ‘too late’ investments compared to the ROA.

Additionally, the farm size, measured based on the proxy-variable ‘farm land’, affects significantly negative the likelihood of ‘too early’ investments. Both Ihli *et al.* (2014) and Savastano and Scandizzo (2009) also find that there is a tendency for later investments with an increasing farm size.

In contrast, the variable ‘full-time farmer’ has a significant negative effect on the probability of ‘too late’ investment decisions. This means that full-time farmers tend more to optimal decisions according to the ROA compared to their colleagues who are part-time farmers. This

result is not consistent with the study of Adesina *et al.* (2000) who observed that full-time farmers invest later.

In the context of socio-demographic variables it is apparent that farmers holding a university degree have a lower probability of ‘too early’ investments and a lower tendency for ‘too late’ investments. From this we conclude that the possession of a university degree leads to lower deviations from the ROA, and the value of waiting is considered more adequately.

Furthermore, the probability of a ‘too early’ investment is significantly higher for farmers with investment intentions than for those without. Accordingly, we note that farmers transfer their willingness to invest from reality to the experiment.

Gender has a significant negative impact on the probability of ‘too late’ investments. Hence, male hog farmers invest earlier than female hog farmers, and thus they behave more in line with the ROA. Jianakoplos and Bernasek (1998) also stress that men invest sooner than women. However, our result has to be interpreted with caution because only 6 women participated in the experiment.

In addition, the farmers’ risk attitude plays a role. With rising risk aversion, the probability of investing ‘too late’ increases, although the benchmark according to ROA considers the individual risk attitude. From this it can be concluded that in theory the entire risk aversion of a decision-maker is not covered. Viscusi *et al.* (2011) also discover that risk aversion involves later investments.

In contrast to other studies (Ihli *et al.*, 2014; Gardebroek and Oude Lansink, 2004) that emphasize the influence of the decision-makers’ age on the investment timing, no significant effect of this variable can be determined for the examined group of participants. An effect of the variable ‘farm manager’ was not found either.

In summary, it is **not possible to reject H3**.

## 6. Discussion and conclusions

The explanatory power of the ROA for investments made in a dynamic-stochastic context is still proven. Nevertheless, deviations from the optimal behaviour according to the ROA are observed, but so far it was not clear which factors influence the deviations. In addition, differences in investment decisions of conventional and organic hog farmers are not clear. To verify these questions, an investment experiment is carried out, and the observed investment timing of conventional and organic hog farmers is compared to the theoretically optimal investment timing according to the ROA benchmarks. Subsequently, we examine which factors influence the deviations from optimal investment behaviour according to the ROA. This sci-

entific contribution is particularly useful for policy-makers since the knowledge of the reasons for deviations from the optimal behaviour provide helpful hints for policy recommendations.

In the literature it is stated that decision-makers invest too early. Our results confirm this claim but going beyond that, we find that the deviations from the optimal behaviour according to the ROA vary significantly when hog farmers have the possibility to invest in a hog barn framed with the production method they are not currently using on their farm. This is the case even though the investment possibility has the same economic indicators. Moreover, we ascertain that hog farmers learn from previous investment decisions and thus invest in repetitive investment decisions later. Less surprisingly, farm-specific and socio-demographic variables also affect the deviations from the ROA.

From these results it is apparent that non-monetary factors affect investment decisions. In the interpretation of the observed framing effect it has to be noted that the results are ambivalent. On one hand, the conformity of the observed investment timing with the optimal investment timing according to the ROA increases if hog farmers have the possibility to invest in the production method they are not currently using on their farm. On the other hand, with the investment possibility in the currently not used production method, the probability to invest 'too late' in a hog barn increases. If the hog farmers invest 'too late', they exceed the investment threshold according to the ROA and either invest at a higher threshold or do not exercise the investment option. Despite the economic profitability, the participating hog farmers decide with a higher probability not to invest in a hog barn in the whole repetition of the experiment if they have to decide in the treatment of the production method they are not currently using on their own farm. Here the possible reservations of the farmers against the other production method come into play. Consequently, it can be suspected that the increasing conformity with the ROA is due to the fact that farmers invest 'right for the wrong reasons', i.e. actually they invest 'too early' according to the ROA, but due to the aversion to the foreign production method they approximate to the optimal behaviour.

A direct policy implication can be derived from the fact that farmers have a higher probability of an 'exact' accordance of their investment time to the ROA if they have a university degree. It can be concluded that the optimality of the farmers' investment decisions can be enhanced by the promotion of education. Education has a direct positive consequence for the income situation and the competitiveness of agricultural enterprises. Regarding the observed framing effect, the question derives at which amount of subsidy payments farmers are willing to convert to organic farming. This is an interesting question for further research, since only

with such knowledge effective policy measures can be developed that promote the expansion of organic farming.

In further research it should be also investigated how deviations from the ROA could be influenced. A possible approach could be the education regarding the knowledge of the ROA and the value of waiting. With this knowledge, the deviations could be reduced and, consequently, economically better investment decisions would be made. Furthermore, on the basis of our results, economic models could be developed that allow a more precise modelling of reality and, therefore, lead to better forecasts. For efficient policy measures it is also necessary to know how farmers invest, as for example, structural change can be predicted better. In addition, to increase the validity of our results the experiment could be carried out with farmers whose main focus shift away from hog production, e.g. arable farming. This would lead to an insight whether the framing effect described in our study can also be observed in areas beyond hog production.

## References

- Abdellaoui, M., Bleichrodt, H. and L'Haridon, O. (2008). A tractable method to measure utility and loss aversion under prospect theory. *Journal of Risk and Uncertainty* 36, 245–266.
- Abel, A. B. and Eberly, J. C. (1994). A unified model of investment under uncertainty. *The American Economic Review* 84, 1369–1384.
- Adesina, A. A., Mbila, D., Nkamleu, B. B. and Endamana, D. (2000). Econometric analysis of the determinants of adoption of alley farming by farmers in the forest zone of south-west Cameroon. *Agriculture, Ecosystems and Environment* 80, 255–265.
- Burnham, K. P. and Anderson, D. R. (1998). *Model selection and multimodel inference. A practical information-theoretic approach*. Springer, New York, NY.
- Burton, M., Rigby, D. and Young, T. (2003). Modelling the adoption of organic horticultural technology in the UK using Duration Analysis. *Australian Journal of Agricultural and Resource Economics* 47, 29–54.
- Charness, G., Gneezy, U. and Kuhn, M. A. (2012). Experimental methods: between-subject and within-subject design. *Journal of Economic Behavior & Organization* 81, 1–8.
- Defrancesco, E., Gatto, P., Runge, F. and Trestini, S. (2008). Factors affecting farmers' participation in agri-environmental measures: a northern Italian perspective. *Journal of Agricultural Economics* 59, 114–131.
- Dixit, A. K. and Pindyck, R. S. (1994). *Investment under uncertainty*. Princeton University Press, Princeton.
- Fahrmeir, L., Kneib, T., Lang, S. and Marx, B. (2013). *Regression. Models, methods and applications*. Springer, Heidelberg.
- Gardebroek, C. (2006). Comparing risk attitudes of organic and non-organic farmers with a Bayesian random coefficient model. *European Review of Agricultural Economics* 33, 485–510.
- Gardebroek, C. and Oude Lansink, A. (2004). Farm-specific adjustment costs in Dutch pig farming. *Journal of Agricultural Economics* 55, 3–24.
- Harrison, G. W., Lau, M. I. and Elisabet Rutström, E. (2009). Risk attitudes, randomization to treatment, and self-selection into experiments. *Journal of Economic Behavior & Organization* 70, 498–507.
- Hinrichs, J., Mußhoff, O. and Odening, M. (2008). Economic hysteresis in hog production. *Applied Economics* 40, 333–340.

- Holt, C. A. and Laury, S. K. (2002). Risk aversion and incentive effects. *The American Economic Review* 92, 1644–1655.
- Ihli, H. J., Maart-Noelck, S. C. and Mußhoff, O. (2014). Does timing matter? A real options experiment to farmers' investment and disinvestment behaviours. *Australian Journal of Agricultural and Resource Economics* 58, 430–452.
- Jianakoplos, N. A. and Bernasek, A. (1998). Are women more risk averse? *Economic Inquiry* 36, 620–630.
- Kahneman, D. (2003). A psychological perspective on economics. *The American Economic Review* 93, 162–168.
- Knight, J., Weir, S. and Woldehanna, T. (2003). The role of education in facilitating risk-taking and innovation in agriculture. *Journal of Development Studies* 39, 1–22.
- Koesling, M., Flaten, O. and Lien, G. (2008). Factors influencing the conversion to organic farming in Norway. *International Journal of Agricultural Resources, Governance and Ecology* 7, 78–95.
- Kuminoff, N. V. and Wossink, A. (2010). Why isn't more US farmland organic? *Journal of Agricultural Economics* 61, 240–258.
- Läpple, D. (2013). Comparing attitudes and characteristics of organic, former organic and conventional farmers: evidence from Ireland. *Renewable Agriculture and Food Systems* 28, 329–337.
- Läpple, D. and Kelley, H. (2013). Understanding the uptake of organic farming: Accounting for heterogeneities among Irish farmers. *Ecological Economics* 88, 11–19.
- Lee, P. M. (2012). *Bayesian statistics. An introduction* (4th ed). Arnold; Wiley, London, New York.
- Loewenstein, G. (1999). Experimental economics from the vantage-point of behavioural economics. *The Economic Journal* 109, F25-F36.
- Longstaff, F. A. and Schwartz, E. S. (2001). Valuing American options by simulation: a simple least-squares approach. *The Review of Financial Studies* 14, 113–148.
- Maart-Noelck, S. C. and Mußhoff, O. (2013). Investing today or tomorrow? An experimental approach to farmers' decision behaviour. *Journal of Agricultural Economics* 64, 295–318.
- Maart-Noelck, S. C. and Mußhoff, O. (2014). Measuring the risk attitude of decision-makers: are there differences between groups of methods and persons? *Australian Journal of Agricultural and Resource Economics* 58, 336–352.



- McCann, E., Sullivan, S., Erickson, D. and De Young, R. (1997). Environmental awareness, economic orientation, and farming practices: a comparison of organic and conventional farmers. *Environmental Management* 21, 747–758.
- Mzoughi, N. (2011). Farmers adoption of integrated crop protection and organic farming: do moral and social concerns matter? *Ecological Economics* 70, 1536–1545.
- Odening, M., Mußhoff, O. and Balmann, A. (2005). Investment decisions in hog finishing: an application of the real options approach. *Agricultural Economics* 32, 47–60.
- Oprea, R., Friedman, D. and Anderson, S. T. (2009). Learning to wait: a laboratory investigation. *Review of Economic Studies* 76, 1103–1124.
- Pindyck, R. S. (1991). Irreversibility, uncertainty, and investment. *Journal of Economic Literature* 29, 1110–1148.
- Savastano, S. and Scandizzo, P. L. (2009). Optimal farm size in an uncertain land market: the case of Kyrgyz Republic. *Agricultural Economics* 40, 745–758.
- Trigeorgis, L. (1996). *Real options. Managerial flexibility and strategy in resource allocation*. MIT Press, Cambridge, Mass.
- Tversky, A. and Kahneman, D. (1981). The framing of decisions and the psychology of choice. *Science* 211, 453–458.
- Viscusi, W. K., Phillips, O. R. and Kroll, S. (2011). Risky investment decisions: how are individuals influenced by their groups? *Journal of Risk and Uncertainty* 43, 81–106.
- Vogel, S. (1996). Farmers' environmental attitudes and behavior: a case study for Austria. *Environment and Behavior* 28, 591–613.
- Willock, J., Deary, I. J., Edwards-Jones, G., Gibson, G. J., McGregor, M. J., Sutherland, A., Dent, J. B., Morgan, O. and Grieve, R. (1999). The role of attitudes and objectives in farmer decision making: business and environmentally-oriented behaviour in Scotland. *Journal of Agricultural Economics* 50, 286–303.
- Yavas, A. and Sirmans, C. F. (2005). Real options: experimental evidence. *The Journal of Real Estate Finance and Economics* 31, 27–52.