European Review of Agricultural Economics Vol **40 (3)** (2013) pp. 463–485
doi:10.1093/erae/jbs032
Advance Access Publication 5 September 2012

Inertia in disinvestment decisions: experimental evidence

Oliver Musshoff[†], Martin Odening[‡], Christian Schade[‡], Syster Christin Maart-Noelck[†]* and Serena Sandri[§]

[†]*Georg-August-Universitaet Goettingen, Germany;* [‡]*Humboldt-Universitaet zu Berlin, Germany;* [§]*German Jordanian University, Jordan*

Received November 2010; final version accepted June 2012

Review coordinated by Paolo Sckokai

Abstract

In this paper we analyse the timing of disinvestment decisions by applying a real options approach to explain the experimentally observed disinvestment behaviour of agricultural entrepreneurs. Within this framework the tendency to postpone exit and termination choices can be rationalised. The validity of the real options theory is assessed by means of economic experiments. Our results show that real options models can predict actual disinvestment decisions better than traditional investment theory. Nevertheless, the reluctance to disinvest observed in the experiments was even more pronounced than that predicted by the theory. This finding suggests that non-monetary aspects such as emotions, attachment to farming and different facets of psychological inertia should be incorporated into disinvestment models.

Keywords: disinvestment, real options, experimental economics

JEL classification: C91, D81, D92

1. Introduction

The aim of this paper is to investigate whether and to what extent real options theory can predict the disinvestment behaviour of agricultural entrepreneurs and whether these predictions are better compared with those on the basis of traditional net present value (NPV) criterion. We focus on disinvestment choices because disinvestment is an important part of the entrepreneurial process. Moreover, disinvestment is central for understanding the structural change in agriculture. Many important economic decisions, such as the termination of a project, the replacement of an older technology by a newer one or firm exits can be considered as disinvestments. Understanding these

*Corresponding author: Department of Agricultural Economics and Rural Development, Georg-August-Universitaet Goettingen Platz der Goettinger Sieben 5, 37073 Göttingen, Germany. E-mail: syster.maart@agr.uni-goettingen.de

types of decisions does not only require explaining why a disinvestment has been chosen and which factors influence the decision but also the timing of the disinvestment decision. In this regard, it can be observed that decision-makers are reluctant to disinvest. For example, previous studies found that farmers are reluctant to replace perennial crop varieties (Richards and Green, 2003) and to convert from conventional to organic farming (Kuminoff and Wossink, 2010). Perhaps the most striking example is the persistence of seemingly inefficient (from a purely monetary perspective) farms. Given that land prices are often significantly higher than the annualised returns from the land use, the question is raised as to why farmers continue to produce instead of selling their land (Plantinga, Lubowski and Stavins, 2002; Turvey, 2003; Moss and Katchova, 2005). From a policy perspective, the ability to predict disinvestment behaviour is also relevant because farm exits impact the rate of structural change (Stokes, 2006).

Since about two decades, the real options approach has been propagated as a comprehensive explanation concept for economic inertia (cf. Dixit and Pindyck, 1994).[1] Real options theory analyses irreversible decisions in a dynamic context, utilising the analogy between a financial option and a real (dis)investment. It asserts that a firm may increase its profit by deferring an irreversible investment though the expected present value of the investment cash flows exceeds the investment costs. Similarly, it may be optimal to defer an irreversible disinvestment even if the expected present value of the firm's cash flow falls below the liquidation value. The intuitive reason is that in cases of irreversible decisions, waiting has a positive value because new information about the expected cash flow arrives in subsequent periods. As long as the disinvestment has not been realised, a decision-maker has the flexibility to continue an ongoing project. Termination of the project (the firm) deletes this option and reduces the decision-maker's flexibility. The loss of flexibility must also be covered by the liquidation value before a disinvestment becomes optimal. This mechanism results in a kind of inertia that has been called a 'tyranny of the status quo' (Dixit, 1992).

The real options theory has been used intensively in agricultural economics (e.g. Purvis *et al.*, 1995; Winter-Nelson and Amegbeto, 1998; Pietola and Wang, 2000; Isik *et al.*, 2003); however, most of these applications are normative, and thus they merely indicate the *potential* explanatory value of the real options approach for observed economic inertia. A few attempts have been made to provide empirical evidence for the validity of the real options approach in an agricultural context, such as Richards and Green (2003), Wossink and Gardebroek (2006) or Hinrichs, Musshoff and Odening (2008). An empirical validation of hypotheses derived from real options

1 Note that alternative approaches exist that try to rationalise economic inertia and the postponement of decisions. Andersen *et al.* (2008) depart from a discounted expected utility model and suggest an experimental procedure that facilitates a joint estimation of elicit risk preferences and time preferences. In a recent paper, Coble and Lusk (2010) adopt this experimental design for disentangling risk and time preferences. The authors provide evidence for the somehow surprising result that people may prefer to delay the resolution of uncertainty.

models is difficult for several reasons. First of all, predictions of real options theory usually refer to the (dis)investment triggers that are not directly observable (c.f. Dixit, 1989; Odening, Musshoff and Balmann, 2005). Secondly, the real options model has been criticised because it is based on a risk neutral valuation framework that renders subjective risk preferences obsolete (Isik, 2005). The standard assumption of option pricing, which requires the existence of a riskless hedging portfolio, is rarely fulfilled in the context of real options. This, in turn, means that it is cumbersome to ascertain whether investment reluctance is caused by option effects or simply by risk aversion. Thirdly, econometric estimation of real options models is also hampered by heterogeneity. For example, multiple investment options may coexist or financial constraints as well as policy instruments may affect farms' investment decisions (Sckokai and Moro, 2009; Serra *et al.*, 2009; Huettel, Musshoff and Odening, 2010).

In view of these difficulties in econometric estimation based on field data, it seems quite natural to resort to economic experiments for a validation of the real options approach. Laboratory experiments allow data collection under controlled conditions as well as the elicitation of otherwise unobservable variables. Thereby the internal validity of empirical research can be improved (Roe and Just, 2009; Roosen and Marette, 2011). Despite these advantages, the experimental investigation of real options theory is still in its early stages. Rauchs and Willinger (1996) were among the first in testing the irreversibility effect of real options in an experimental setting. Yavas and Sirmans (2005) adopt this idea and find that participants invest earlier than predicted by the real options approach, but their willingness to pay for an investment opportunity includes an option value. In a recent study, Oprea, Friedman and Anderson (2009) investigate whether real options values in a monopolistic environment differ from those under competition. All of the aforementioned studies considered the value and the timing of investment decisions. Additionally, the experiments were conducted on students. The study closest to ours is Sandri *et al.* (2010) who experimentally analyse disinvestment decisions of (non-agricultural) entrepreneurs. They find that individuals tend to postpone disinvestments longer than predicted by real options theory.

In this paper, we run online experiments to test the validity of real options theory in the context of disinvestment decisions. The experiment considers an optimal stopping problem in a context-free framework with a stylised decision to abandon an ongoing project in exchange for a certain liquidation value. We conduct an additional experiment based on a Holt and Laury lottery to elicit the risk attitude of participants (cf. Holt and Laury, 2002).

Hence, the contributions of this article to the existing literature are threefold. First, other than most empirical studies, we focus on disinvestment decisions. Secondly, we run a laboratory experiment that allows controlling the information that decision-makers have. That is, other than Sandri *et al.* (2010), we do not assume in our formal modelling that decision-makers are risk neutral. Rather, we explicitly account for individual risk propensity when we determine the normative benchmark for the disinvestment decision. Thirdly, to the best of our knowledge, it is the first time that this type of experiment has been conducted on agricultural entrepreneurs who might have a higher involvement with disinvestment decisions than other individuals.

On the one hand, the description of our experimental conditions will demonstrate that our results cannot fully explain factors that drive real-world disinvestment decisions, particularly farm exit decisions (cf. Harrington and Reinsel, 1995), since these decisions, including sociological and psychological aspects, are too complex to be fully explicated by our experiments. On the other hand, however, the fact that we investigated those choices with real farmers will partially bring in those aspects to a certain extent since expert decision-makers have a tendency to not forget the real decision situations they are use to and may not always adapt to the new (and in our case, neutral) conditions in the experiment (Burns, 1985). We will explore this aspect in more detail in Section 6.

The rest of the article is organised as follows: in Section 2, we explain our theoretical disinvestment models in greater detail and derive normative and testable hypotheses from these models. The subsequent two sections describe the design of the experiments and explain how we derive the normative benchmarks for the optimal disinvestment time. In Section 5, we present the outcome of the experiments and the hypotheses tests. The article ends with a long discussion on the validity of theoretical disinvestment models, alternative reasons for late disinvestment and directions for further research.

2. Derivation of hypotheses

Here we describe the disinvestment decision as a simple optimal stopping problem.[2] In contrast to standard options models, we prefer a discrete time framework. Moreover, we assume an additive model of risk instead of a multiplicative one. Both assumptions ease the design of the subsequent experiments, and they do not affect the qualitative insights of the model.

Consider an already existing project with a finite lifetime of three periods that currently earns an annual cash flow X_0. The cash flow follows a binomial process, i.e. in period 1 the cash flow will either increase by a value $h > 0$ with probability p or decrease by h with probability $1 - p$. In period 2, the cash flow can take the following values: $X_0 + 2h$ with probability p^2; $X_0 - 2h$ with probability $(1 - p)^2$; and X_0 with probability $2p(1 - p)$. We first assume a risk neutral decision-maker who must decide whether to continue or to abandon the project. Termination of the project yields a salvage value L in addition to the cash flow of the current period. The project cannot be restarted once it has been terminated. In other words, the decision to

2 We employ dynamic programming to derive our hypotheses. This model covers the analogy between real options and financial options. However, a contingent claim approach would complicate the model and introduce parameters that are difficult to handle in an experiment, particularly the convenience yield.

abandon the project is irreversible. Traditional investment theory asserts that the project should be terminated if the liquidation value $L + X_0$ exceeds the continuation value $\hat{C}$. Consequently, the value of the project, $\hat{F}_0$, is

$$\hat{F}_0 = \max(\hat{C}; L + X_0) \tag{1}$$

where

$$\begin{aligned}\hat{C} = X_0 + (p \cdot (X_0 + h) + (1 - p) \cdot (X_0 - h)) \cdot q^{-1} + (p^2 \cdot (X_0 + 2h) \\ + 2 \cdot (p \cdot (1 - p) \cdot X_0) + (1 - p)^2 \cdot (X_0 - 2h) + L) \cdot q^{-2}\end{aligned} \tag{2}$$

Here $q^{-1} = 1/(1 + r)$ is a discount factor and r denotes the interest rate. By equating the continuation value $\hat{C}$ defined in equation (2) and the liquidation value $L + X_0$ we obtain the disinvestment trigger $\hat{X}_0$:

$$\hat{X}_0 = L \cdot r - h \cdot (2p - 1) \cdot \left(1 + \frac{1}{1 + q}\right) \tag{3}$$

According to the NPV, the project should be terminated if the current cash flow falls below $\hat{X}_0$.

The situation is different if the decision on the termination of the project can be deferred to period 1. Deferring the decision has the potential advantage that it allows the decision-maker to take into account information that may emerge in period 1. Of particular interest is the situation where $X_0 - h < L \cdot r < X_0 + h$, which implies that continuation (termination) is the favourable decision if the cash flow in period 1 increases (decreases). According to the real options approach, the project value is given by

$$\tilde{F}_0 = \max(\tilde{C}; L + X_0) \tag{4}$$

with a continuation value

$$\begin{aligned}\tilde{C} = X_0 + (p \cdot (X_0 + h) + (1 - p) \cdot (X_0 - h + L)) \cdot q^{-1} \\ + (p^2 \cdot (X_0 + 2h + L) + p \cdot (1 - p) \cdot (X_0 + L)) \cdot q^{-2}\end{aligned} \tag{5}$$

The optimal disinvestment trigger referring to the real options approach is

$$\tilde{X}_0 = L \cdot r - h \cdot \left(2p - \frac{q}{p + q}\right) \tag{6}$$

Thus, in general, the myopic NPV differs from the real options approach.

The difference between the two disinvestment triggers is

$$\hat{X}_0 - \tilde{X}_0 = \frac{h \cdot (1-p) \cdot (2p+q)}{(1+q) \cdot (p+q)} > 0 \tag{7}$$

Apparently, $\tilde{X}_0$ is smaller than $\hat{X}_0$ as long as $p > 0$.

A simple example may illustrate the difference between the two decision rules. Assume that an initial cash flow $X_0 = 10$, an upward movement $h = 5$ with probability $p = 0.5$, a salvage value $L = 110$ and an interest rate $r = 0.1$. The disinvestment trigger according to the NPV (equation (3)) is then $\hat{X}_0 = 11$. The initial cash flow falls below this trigger, and thus the project should be immediately terminated. In contrast, the real options approach suggests a disinvestment trigger $\tilde{X}_0 = 9.4$ (equation (6)), and thus waiting is preferable.

Based on this background, we formulate the following alternate hypotheses:

H0: The disinvestment behaviour of farmers is consistent with the NPV.

H1: The disinvestment behaviour of farmers is consistent with the real options approach.

Given the complexity of the decision problem, deviations between actual and optimal behaviour would not be very surprising. In fact, it will be unlikely to identify a normative model that exactly predicts observed disinvestment behaviour even under laboratory conditions. Furthermore, a rejection of H0 or H1 does not imply that the theoretical models do not possess *any* explanatory power for the timing of farmers' disinvestments. From a perspective of applied modelling, it is also of interest to know about the relative performance of the real options model compared with the NPV. This comparison is addressed with hypothesis H2:

H2: The real options approach outperforms the NPV in explaining the disinvestment behaviour of farmers.

Equation (6) also allows investigating the impact of increasing uncertainty on the optimal disinvestment trigger. Increasing uncertainty is considered via a mean-preserving spread of the cash flow. A mean-preserving spread can be implemented in our simple model framework by increasing the additive shock h, i.e. by using $h' > h$. The optimal disinvestment trigger now becomes

$$\tilde{X}_0' = L \cdot r - h' \cdot \left(2p - \frac{q}{p+q}\right) \tag{8}$$

Obviously, the relation $\tilde{X}_0 > \tilde{X}_0'$ holds for $p = 0.5$. This finding is reflected in the following hypothesis:

H3: Farmers tolerate lower cash flows before disinvesting if the volatility of investment returns increases.

Note that a higher level of volatility does not inevitably cause the decision-makers to terminate their projects at a later stage. The reason is that a higher volatility reduces the optimal disinvestment trigger, but at the same time the probability of passing a certain trigger level increases. Thus, the effect of the volatility on the first passage time of the stochastic process is ambiguous.

Thus far the disinvestment triggers have been derived assuming a risk-neutral decision-maker; however, there is empirical and experimental evidence questioning this assumption (e.g. Yesuf and Bluffstone, 2009). As mentioned above, risk preferences are also relevant for the valuation of real options if it is impossible to set up a replicating portfolio of traded assets, which duplicates the stochastic outcome of the investment project (Dixit and Pindyck, 1994). The valuation of a risky prospect can be conducted in an expected utility framework either by replacing uncertain outcomes with their certainty equivalent or by using risk-adjusted discount rates. Let $r^* > r$ denote the risk-adjusted discount rate and $q^* = 1 + r^*$. In this case, the modified disinvestment triggers for the NPV and the real options approach are

$$\hat{X}_0^* = L \cdot r^* - h \cdot (2p - 1) \cdot \left(1 + \frac{1}{1 + q^*}\right) \tag{9}$$

and

$$\tilde{X}_0^* = L \cdot r^* - h \cdot \left(2p - \frac{q^*}{p + q^*}\right), \tag{10}$$

respectively. Comparing equations (9) and (10) with equations (3) and (6) shows that risk aversion increases the disinvestment trigger of both decision rules. This finding leads to our final hypothesis:

H4: Risk-averse farmers disinvest earlier.

This result, based on comparative statics, does not suffice, however, to fulfil a requirement that we imposed on ourselves (see Section 1): modelling the impact of risk aversion on disinvestment choices *explicitly*. Hence, we will further analyse and explicate this relationship in Section 4.

3. Experimental design

Our experimental design follows Sandri *et al.* (2010) and consists of two parts. The first part describes an optimal stopping problem by stylising a context-free choice to abandon a project for a constant termination value. In the second part, we conducted a session of Holt and Laury (2002) lotteries with real payments to determine the risk attitudes of the participants. The Holt and Laury lottery consists of 10 pairs of choices in which the participants choose between alternative 1 (i.e. the safe lottery) and alternative 2 (i.e. the risky lottery). The participant has to select one alternative for each pair of choices. The payoffs in both lotteries are fixed over the 10 pairs. Furthermore, the probability varies systematically over the pairs and is identical for both alternatives in each of the 10 pairs. From pairs 1 to 10, the expected value increases, but the expected value of alternative 2 becomes greater than the expected value of alternative 1. The Holt and Laury lottery value represents the number of safe choices. A risk-neutral decision-maker will cross over from alternative 1 in the fourth situation to alternative 2 in the fifth situation and has a Holt and Laury lottery value of 4. For a detailed explanation and an interesting application of the Holt and Laury method to agricultural economics, see Brick, Visser and Burns (2011).

To design the optimal stopping experiment, we employed the model outlined in the previous section.[3] In each round, the respondents could decide to stop an ongoing project in one of the 10 periods. This task was repeated over multiple rounds. The returns from the project followed a binomial arithmetic Brownian motion that had a value of $p = 0.5$, no drift and two different standard deviations. Furthermore, we modelled the risk on an aggregated level and did not distinguish among different sources of uncertainty, such as price or production risk.[4] Specifically, we conducted the experiment by performing two treatments on the subjects. The standard deviation (i.e. the potential gains and losses) were 200 points in the low-volatility treatment and 500 points in the high-volatility treatment. The first period cash flows were always 1,000 points. To simplify matters for the participants, we fixed the risk-free interest rate at 10 per cent. Abandoning the project yielded a constant amount of revenue (i.e. 11,000 points). Additionally, the participants were allowed to abandon the project in each period and were forced to do so in the last period to limit their planning horizons.

The binomial tree (see Appendix in supplementary material available at *ERAE* online) visualises possible realisations of the stochastic returns and their probabilities for the high-volatility treatment. In period 0, the participant will receive 1,000 points. If the participant decides to disinvest in period 0,

3 In the Appendix (see supplementary material available at *ERAE* online), we give a translated English version of the instructions of the real options experiment which were submitted to the participants in German.

4 Actually, farmers perceive and manage risks on a more disaggregated level. However, the real options approach typically focuses on strategic decisions (e.g. investments and disinvestments) that are based on aggregated variables, such as farm cash flows or farm profits.

then he or she receives the initial cash flow of 1,000 points plus the salvage value of 11,000 points. In this case, the cash flow in the subsequent periods is irrelevant for this investor. If the participant opts to continue, then the cash flow in period 1 either increases to 1,500 or decreases to 500 points, both of which occur with a probability of 50 per cent. The binomial tree will be adjusted accordingly. The irrelevant states are removed, and the probabilities for future cash flows are updated. Unless the participant terminates the project at an earlier period, the participant repeats these steps until period 10.

Twenty repetitions of the experiment were carried out per individual as we wish to discriminate between different decision rules. For a single stochastic return, the NPV and the real options approach (or a heuristic) may lead to the same optimal decision. Hence, we could not infer which rule underlies the participant's decision-making process after conducting a single trial. Over the course of the entire experiment, each respondent was confronted with 20 different, randomly determined paths of the binomial tree. The respondents did not receive immediate payoff feedback, except in a trial round. Thus, we limited the participants' abilities to learn from the outcomes through reinforcement.

We conducted the disinvestment experiment by performing two treatments (between subjects). The size of the potential gains and losses (i.e. the volatility) differed for each treatment. Specifically, the potential gains and losses were 200 points in the low-volatility treatment and 500 points in the high-volatility treatment. We informed the participants about all of the parameters and the assumptions underlying the experimental setting.

To ensure incentive compatibility of the experiment, the hypothetical disinvestment decisions were related to an actual payment. Though psychologists believe that experimental subjects usually have sufficient intrinsic motivation to work hard even in the absence of financial rewards, we presume that the experimental subjects will work harder and more effectively if the subjects earn more money for better performances (Camerer and Hogarth, 1999). Given the limitations of the experimenters' budgets, many experimenters pay small amounts of money to each participant; an alternative is the random pay mechanism introduced by Bolle (1990). Whereas there is no general consensus in the experimental literature on which payment system is preferable,[5] random pay with high stakes is often considered to evoke a more realistic emotional state of the respondents. If respondents consider being the one playing for real money, they become aware that potential outcomes will be substantial (for a recent application of the random pay mechanism in a relatively extreme form and for this line of argument see Schade, Kunreuther and Koellinger, 2011). In our case, after conducting all of the experiments, we randomly selected two different participants as the respective winners of the real options experiment and the Holt and Laury lottery.

5 Laury (2005) compares the two alternatives explicitly in an experiment. She finds that the decisions of the participants did not differ significantly under the two payment systems.

Depending on the scores, the reward in the real options experiment varied between 300 and 1,000 euros. The payoff in the Holt and Laury lottery depended on the participant's risk preference and varied between 10 and 385 euros. Following the two experiments, we asked the participants some questions about their characteristics (e.g. gender, education and age). The whole experiment took approximately 60 min for each individual. The choices made by the participants were not constrained by time. A trial round gave the participants the opportunity to become acquainted with the experiment. The experiment was conducted online in 2009. In total, 63 agricultural entrepreneurs participated in the study. We observed a total of 1,260 decisions (i.e. 20 repetitions for each of the 63 participants).

4. Normative benchmarks

To evaluate the disinvestment behaviour observed in the experiments and to evaluate our hypotheses, we have to derive normative benchmarks that reflect the NPV and the real options approach, respectively. Equations (9) and (10) can be used for this purpose but given the experimental design, an extension is necessary. Specifically, the equations have to be adapted to a planning horizon of 10 periods. Doing so is straightforward for the NPV, but for the real options approach, the single disinvestment trigger has to be replaced by a time-varying exercise frontier. Moreover, we must determine the risk-adjusted discount rate r^*. We briefly describe these two steps in the next section.

4.1. Determination of the risk-adjusted discount rate

We determine the risk-adjusted discount rate based on the results of a Holt and Laury lottery. Following Holt and Laury (2002) we assume a power risk utility function, which implies decreasing absolute risk aversion (DARA) and constant relative risk aversion (CRRA):

$$U(X) = X^{1-\theta} \tag{11}$$

Here U denotes utility and θ is the risk aversion coefficient. Based on equation (11), θ can be inferred for each individual from his/her choices in the Holt and Laury lottery. With this information, the certainty equivalent (CE) of a risky prospect can be determined as follows:

$$CE = X(E(U(X))) = E(U(X))^{-1/\theta-1} = E(X) - RP \tag{12}$$

where $E(\cdot)$ denotes the expectation operator and RP is the risk premium. However, in our context of present value calculation, it is more convenient to work with expected values of the project cash flows and to discount them with a risk-adjusted discount rate. From the definition of the present value of the certainty equivalent CE_0 of an uncertain payment X_T at time T:

$$CE_0 = CE_T \cdot (1+r)^{-T} = (E(X_T) - RP_T) \cdot (1+r)^{-T} \tag{13}$$

one can derive an equivalent risk-adjusted discount rate $r^* = r + v$ using the following equation:

$$(E(X_T) - RP_T) \cdot (1+r)^{-T} = E(X_T) \cdot (1+r+v)^{-T}$$
$$\Rightarrow v = (1+r) \cdot \left(\left(\frac{E(X_T)}{E(X_T) - RP_T} \right)^{1/T} - 1 \right) \tag{14}$$

Here, r is a risk-free interest rate. Obviously, the risk loading v and, thus, the risk-adjusted discount rate r^* depends on the level of uncertainty and the length of the discounting period.

4.2. Calculating the exercise frontiers

Although we can easily calculate the normative benchmark for the NPV with equation (9), we have to determine the exercise frontier of the real options approach by performing backward dynamic programming (cf. Trigeorgis, 1996: 312). When applying dynamic programming to the binomial tree, one faces the problem that the certainty equivalent of the up and down movements and, thus, the risk-adjusted discount rates are not constant over time (see equation (14)). This leads to a non-recombining binomial tree for the present value of the project in which the number of potential states grows exponentially with the number of time periods (cf. Longstaff and Schwartz, 2001). We impose two simplifications making the calculation of the exercise frontier tractable. First, we fix the level of the cash flow at its initial value when determining the risk-adjusted discount rate via equation (14). Secondly, we fix T at five periods in equation (14). These simplifications leave us with 10 different discount rates representing different risk attitudes for each of the two volatility scenarios (see Table 1). In the high-volatility scenario, the risk-adjusted discount rate varies between 6.4 per cent (Holt and Laury lottery value = 0–1) and 14.5 per cent (Holt and Laury lottery value = 9–10) and in the low-volatility scenario, its range is from 9.3 per cent (Holt and Laury lottery value = 0–1) to 10.6 per cent (Holt and Laury lottery value = 9–10).

The resulting normative benchmarks, i.e. the 'optimal' solutions for the disinvestment trigger according to the NPV and the real options approach, are presented in Figures 1 and 2. Figure 1 depicts the exercise frontiers for a risk-neutral decision-maker. The exercise frontiers of the real options approach increase exponentially, reflecting the diminishing time value of the disinvestment option. The trigger values start at 858 and 495 points for the low- and the high-volatility scenario, respectively. Both curves coincide with the NPV criterion (1,100 points) at maturity, as it is required by theory.

Table 1. Risk-adjusted discount rates for different Holt and Laury lottery values

Holt and Laury lottery value	Critical CRRA coefficient	Risk-adjusted discount rate: High-volatility scenario (%)	Risk-adjusted discount rate: Low-volatility scenario (%)
0–1	−1.71	6.4	9.3
2	−0.95	7.7	9.6
3	−0.49	8.7	9.8
4	−0.14	9.6	9.9
5	0.15	10.4	10.1
6	0.41	11.3	10.2
7	0.68	12.1	10.3
8	0.97	13.1	10.4
9–10	1.37	14.5	10.6

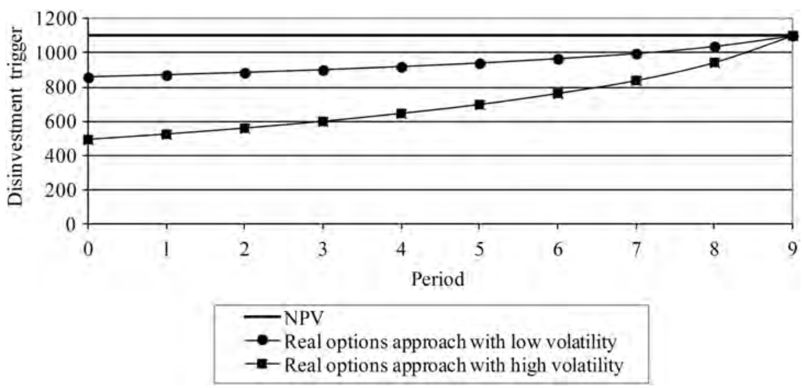

Fig. 1. Disinvestment trigger for a risk neutral decision maker.

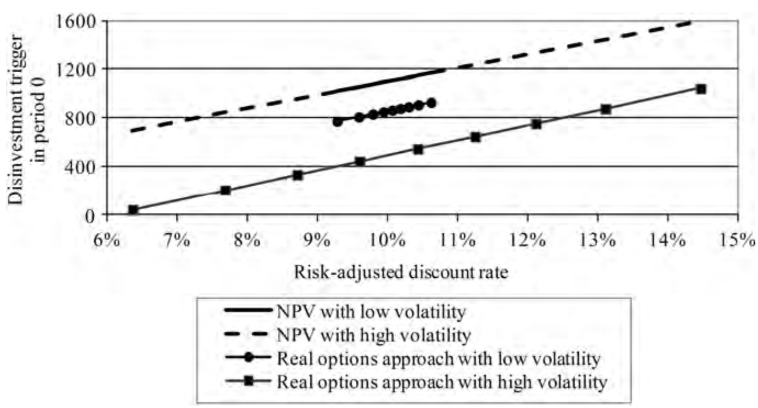

Fig. 2. Disinvestment trigger in period 0 for different risk-adjusted discount rates.

Figure 2 illustrates the sensitivity of the optimal disinvestment triggers in period 0 with respect to the risk-adjusted discount rates. The graphs show the expected positive slope (i.e. the higher the participant's aversion to risk, the lower is his or her tolerance against a decline in the project's cash flows). Note that the disinvestment triggers of the NPV and the real options approach are affected in the same way. In other words, the hypothesised differences between both decision rules persist, regardless of the decision-makers' individual risk propensities.

As mentioned earlier, a higher volatility of the cash flow leads to a lower disinvestment trigger for the real options approach. However, this difference does not necessarily translate into a later disinvestment time. Actually, when simulating the binomial tree and applying the optimal decision rule for a risk-neutral decision-maker, we found that an optimal disinvestment should take place in period 4.1 in the low-volatility scenario and in period 4.2 in the high-volatility scenario. However, the difference in the optimal disinvestment times widens if the calculation is based on the participants' aversion to risk.

5. Results

Table 2 summarises the main results of our experiments and provides information about the characteristics of the participants.

In total, 63 farmers participated in the experiments, and 80 per cent of the participants were executive farm managers. The remaining 20 per cent were either retired or prospective farm managers. Participants were recruited through alumni networks of German universities. The alumni provided us with addresses of active farmers who were invited to participate in the online experiments. The participating farmers were relatively young with an average age of 30 years, a minimum of 21 years and a maximum of 65 years. The proportion of farmers with academic backgrounds was relatively high (72 per cent). The composition of the sample can be explained by the manner in which participants were recruited and the fact that the experiments were conducted online. On average, the participants were slightly risk-averse. Nevertheless, Figure 3 shows that the individual risk attitudes vary between risk seeking and strong risk aversion.

The aforementioned disinvestment rules were applied to 1,260 random realisations of the discrete arithmetic Brownian motion. The NPV criterion predicts a risk-adjusted disinvestment time of 0.9 periods on average in the high-volatility scenario and an immediate disinvestment in period 0 in the low-volatility scenario. The corresponding predictions from the real options approach amount to 4.8 and 4.1 periods, respectively. The actual disinvestment time chosen by the participants was 6.4 periods in the high-volatility scenario and 6.1 periods in the low-volatility scenario. In the following section, we discuss whether these findings support our hypotheses regarding disinvestment behaviours.

Table 2. Descriptive statistics

	High volatility ($n = 30$)		Low volatility ($n = 33$)		Total ($n = 63$)	
Variable	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
Normative disinvestment following NPV	0.9	2.5	0	0	0.4	1.8
Normative disinvestment following real options approach	4.8	3.8	4.1	3.8	4.4	3.8
Experimentally observed time of disinvestment	6.4	3.4	6.1	3.7	6.2	3.6
Deviation between observation and NPV	5.5	4.1	6.1	3.7	5.8	3.9
Deviation between observation and real options approach	1.6	4.6	2.0	4.6	1.8	4.6
Correlation between observation and real options approach (Kendall's Tau)	0.3	0.3	0.3	0.3	0.3	0.3
Risk attitude of participants (Holt and Laury lottery value)	4.9	2.0	5.1	1.7	5.0	1.8
Age of participants	30	10	31	11	30	10
Percentage of farmers studied	72	–	81	–	77	–
Percentage of female participants	24	–	22	–	23	–

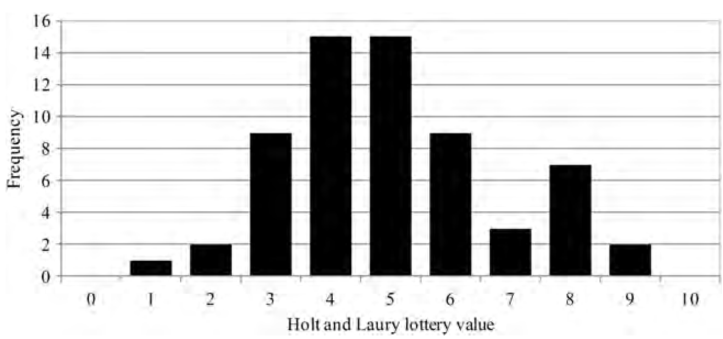

Fig. 3. Results of the Holt and Laury lottery. Holt and Laury lottery value: 0–3 risk-seeking; 4 risk-neutral; 5–9 risk-averse; 10 control question.

5.1. Tests of hypotheses H0, H1 and H2

The disinvestments took place in the period suggested by the NPV in only 8.1 per cent of the 1,260 observations. In the majority of the cases, the farmers chose to disinvest later. The average deviation between the predicted and the actual disinvestment time is 5.8 periods. This difference in the mean disinvestment times is statistically significant ($p < 0.001$, two-sided t-test). On this basis, we reject H0 and conclude that the NPV criterion is not appropriate for predicting the actual, experimentally observed disinvestment behaviours.

According to the real options approach, the average deviation between the observed and optimal disinvestment time amounts to 1.8 periods. This deviation is also significantly different from zero ($p < 0.001$, two-sided t-test). In 51.8 per cent (22.1 per cent) of the cases, the farmers decided to disinvest later (earlier) than optimal. Thus, we have to reject H1 as well. However, the deviation between the actual and predicted disinvestment periods is, on average, smaller in the real options model than in the NPV model (i.e. 1.8 periods vs. 5.8 periods, respectively). A one-sided t-test indicates that this deviation is significantly higher for the NPV than for the real options model ($p < 0.001$). In 26.1 per cent of the observations, the real options approach correctly predicts the participants' disinvestment decisions. The share of correct predictions is three times higher in the real options model than in the NPV model (i.e. 26.1 vs. 8.1 per cent, respectively). A one-sided McNemar test confirms that this difference is also highly significant ($p < 0.001$). Thus, we are able to support H2, which states that the real options approach outperforms the NPV model.

To further investigate the predictive power of the real options approach, we calculate the rank correlation coefficients (i.e. Kendall's tau) between the optimal and actual disinvestment periods for each individual (see Figure 4).

The mean of Kendall's tau for all of the farmers is 0.3. Hence, the higher the optimal disinvestment period is, the later the observed disinvestment occurs.

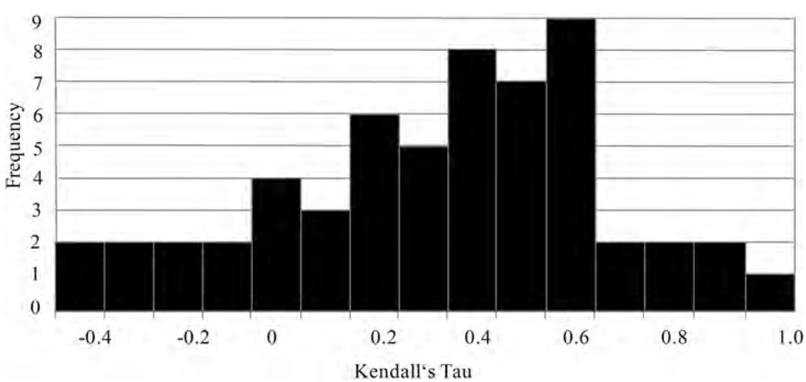

Fig. 4. Correlation between the optimal disinvestment dates according to the real options approach and the experimentally observed behaviours of individuals.

The rank correlation is positive for 87.9 per cent of the participants. Additionally, in 53.5 per cent of the cases, the correlation is significantly different from zero at a significance level of 5 per cent. Again, we find that the individuals exhibit a pronounced variability. Specifically, Kendall's tau ranges from −0.4 to 1.0. This finding shows that individual decision-making procedures are largely heterogeneous in nature.

Figure 5 provides additional information on the individuals' decision-making behaviours taking into account the panel structure of the observations. The first panel of Figure 5 depicts the empirical distribution of the average deviation between the actual disinvestment time and the optimal disinvestment time following the real options approach for all 63 participants. Means are calculated from the 20 repetitions observed per individual. The majority of the farmers (i.e. 24 people) tend to hold on for too long (i.e. for 2.5 periods on average), whereas a small group disinvests prematurely (i.e. 4 people). Interestingly, 11 farmers act, on average, in accordance with the real options approach. The differences shown in the figure are significantly different from zero for 41 farmers (i.e. 65.1 per cent) at a significance level of 5 per cent. The educational levels of the farmers had no significant influence on the deviations between the optimal and actual disinvestment time.

The second panel of Figure 5 sheds some light on the consistency of the individuals' decisions by depicting the distribution of the standard deviations of the differences in disinvestment times. Apparently, the standard deviations are rather high. Approximately 75.0 per cent of the participants have a standard deviation of 3 periods or more, indicating that the deviations of their decisions from the real options approach are rather unstable. In other words, the individuals' decision rules are not characterised by a constant bias relative to the real options approach. Instead, the same individual may both overestimate and underestimate the optimal disinvestment period.

The large standard deviations shown in the second panel of Figure 5 may cast some doubt on the reliability of our experiments. However, the finding that actual disinvestment behaviour deviates randomly from the real options predictions does not necessarily mean that decision-makers act non-reliably in a sense that they act arbitrarily and do not adhere to a specific decision

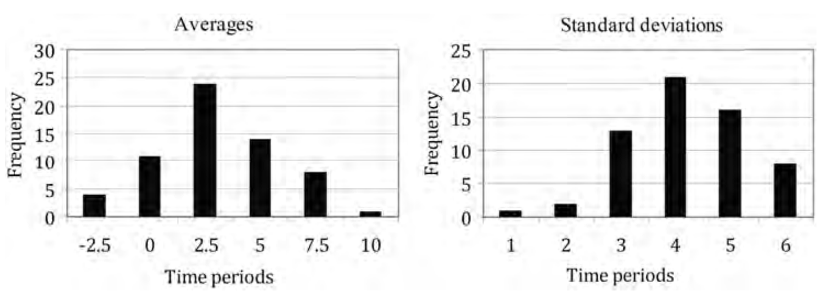

Fig. 5. Distribution of the differences between the observed and optimal disinvestment periods following the real options approach ($n = 63$).

rule (perhaps a heuristic one). To qualify this point, we specified the behavioural decision rule: 'disinvest if losses occur in two subsequent periods' as a potential simplifying heuristic that decision-makers might have followed. In a what-if analysis, we assumed the participants to have applied this rule in the experiment. We then measured the deviations between simulated disinvestment times according to the heuristic and the real options predictions using the same sample paths as in the experiment. These deviations resembled the differences generated in our experiment in terms of their mean and their standard deviation. This demonstrates that varying deviations between the actual decisions and the real options predictions do not signalise randomness of behaviour and do not rule out a consistent decision-making process.

Globally, the results of the test of H0, H1 and H2 show that the decision behaviour of participants (farmers) is not exactly predictable neither with the NPV criterion nor with the real options approach. However, our experiments found that the real options approach is superior to the NPV in explaining disinvestment behaviour.

5.2. Tests of hypotheses H3 and H4

To test H3 and H4, we ran a model in which we regressed the observed disinvestment periods on the risk aversion, the volatility of the project's cash flow and the age and genders of the farmers. A Breusch–Pagan test indicates that unobserved heterogeneity exists. Therefore, we estimated a random effects model. The results of this regression are presented in Table 3.

The estimated coefficient of the Holt and Laury lottery value is significant and has a negative sign. This result confirms our fourth hypothesis. The age and gender of the farmers did not significantly affect the disinvestment period. The sign of the dummy variable representing the volatility treatment is positive but not significant. If one recalls that the difference in the average optimal disinvestment times between the high- and the low-volatility scenarios is rather small (i.e. $4.8-4.1 = 0.7$ periods), this result appears to be quite plausible.

Table 3. Results of a random effects model of the observed individual disinvestment period ($n = 1{,}260$)[a]

Parameter	Coefficient	Robust standard error	p-value
Constant	8.52	1.84	0.000
Holt and Laury lottery value	−0.42	0.17	0.011
Volatility (0: low volatility, 1: high volatility)	0.19	0.60	0.748
Age	−0.03	0.03	0.354
Gender (0: female; 1: male)	0.57	0.77	0.457

[a] $R^2 = 0.111$.

Table 4. Validity of hypotheses on disinvestment behaviour

Hypotheses		Validity
H0	The disinvestment behaviour of farmers is consistent with the NPV.	Reject
H1	The disinvestment behaviour of farmers is consistent with the real options approach.	Reject
H2	The real options approach outperforms the NPV in explaining the disinvestment behaviour of farmers.	Supported
H3	Farmers tolerate lower cash flows before disinvesting if the volatility of investment returns increases.	Supported
H4	Risk-averse farmers disinvest earlier.	Supported

To further test H3, we compared the individual disinvestment triggers for both scenarios. Unfortunately, these disinvestment triggers are not directly observable. However, we can approximate them by measuring the minimal cash flow that each participant was willing to endure while he/she continued with the project. Clearly, this proxy lies above the true disinvestment trigger and ignores the time dependence of the exercise frontier; however, these errors prevail in both volatility treatments. As a result, the mean of the minimal cash flow is 858 for all of the farmers in the low-volatility scenario. In accordance with the theoretical arguments, the corresponding value in the high-volatility scenario is considerably lower (i.e. 587). The minimal cash flows tolerated by the farmers in the low- and high-volatility scenarios are not normally distributed (Kolmogorow–Smirnow test; $p < 0.001$). The non-parametric U-test shows that the minimal cash flows tolerated by the farmers are significantly lower in the high-volatility scenario than in the low-volatility scenario ($p < 0.001$).

Table 4 summarises the empirical results with regard to the validity of our hypotheses. Based on these results, H2, H3 and H4 could be supported.

6. Discussion and conclusions

Advocates of the real options approach have argued that uncertainty and irreversibility cause economic inertia in investment as well as in disinvestment decisions. Unfortunately, attempts to econometrically validate the real options theory are plagued by some fundamental difficulties. Among them are unobservable explanatory variables, ambiguity of explaining factors and unobserved heterogeneity. In view of these problems, we pursued a different approach in this paper and studied the disinvestment behaviour of farmers in an online experiment under controllable conditions. We contrasted the observed disinvestment decisions with theoretical benchmarks, which we derived from static (i.e. NPV) and dynamic (i.e. real options approach) investment models.

The main findings from this experimental study are first that participants (farmers) postpone taking an irreversible decision, such as project termination, even if the risk-adjusted NPV of the project cash flow falls below the liquidation value. Hence, our results rejected traditional investment theory. The tendency to defer disinvestments, which we measure for farmers, is similar to that one reported by Sandri *et al.* (2010) for students and entrepreneurs. Thus, we found no evidence that farmers differ from other entrepreneurs with regard to disinvestment decisions. This is noteworthy as farmers have been alleged to be particularly conservative and averse to change (e.g. Jose and Crumly, 1993). Additionally, our experiments found that the real options approach is superior to the NPV in explaining disinvestment behaviour, but still did not entirely capture the complexity of behaviour as observed in the experiment. The predicted disinvestment period was, on average, closer to the observed disinvestment period, and we found a significantly positive correlation between them. Moreover, our results confirmed the hypothesised impact of the volatility level and the risk aversion on the disinvestment trigger.

Basically, we do not expect individuals to carry out the computations necessary to make disinvestment choices fully consistent with real options reasoning. Nevertheless, we have evidence suggesting that many participants at least intuitively understand the value of waiting and apply decision rules resulting in choices that are somewhat consistent with the results that would have occurred if the participants had applied the real options model.[6] The reason why they are able to intuitively make choices in turn with real options reasoning might be the application of simple heuristics – as evidenced in the results section. If the cash flow falls twice in a row, go out. This is the type of heuristic Gigerenzer and his coauthors might refer to as ‘ecologically rational’ (see, e.g. Gigerenzer and Goldstein, 2002).

However, even though some heuristic way of applying a real options-type model appears to account for the individuals’ behaviours more successfully than the NPV approach, an ‘options-based’ inertia does not appear to tell the entire story. Farmers tend to disinvest even later than suggested by the real options approach. The observed bias is smaller in the real options approach than in the NPV, but this bias is still significant on average. Thus, the deviations from the predictions generated by the real options model are not only caused by idiosyncratic shocks, which may be addressed by the appropriate econometric methods. The heterogeneity of the deviations found among the respondents causes one to wonder whether a single microeconomic model based on monetary payoffs can explain the individuals’ disinvestment

6 One should be careful about drawing conclusions on the actual decision-making process because the participants may act differently in the experiments than they do in the real world. Actually, there is an intensive debate on the external validity of economic experiments (i.e. the possibility of generalising the results found in the stylised setting of a laboratory experiment) (e.g. Davis and Holt, 1993; Guala, 2005). The lack of external validity, which is considered to be the Achilles heel of laboratory experimentation (Loewenstein, 1999), is also an issue in our study. That is, real-world disinvestment problems (e.g. farm closures) involve multiple objectives, and the decision-makers require more time to prepare and to make these far-reaching decisions. 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 theories, as it is the case in our study (Schram, 2005).

behaviour. 'Psychological inertia' appears to also play a role in explaining the participants' reluctance towards making (dis)investment decisions (Sandri *et al.*, 2010). The behavioural economics literature has discussed several drivers of this phenomenon, such as the sunk-cost fallacy (Ross and Staw, 1993) and the status quo bias (Samuelson and Zeckhauser, 1988; Burmeister and Schade, 2007). Another line of reasoning would focus on the – potentially rational – consideration of non-monetary benefits of staying in agriculture. Land is a principal asset of production, and social and family ties as well as positive emotions towards this type of production may also lead farmers to exhibit disinvestment reluctance. Multi-dimensional utility considerations may also show up in a neutrally framed experiment. More specifically, since we ran our experiments with actual farmers and since experienced individuals are known to bring their background into the laboratory (Burns, 1985), all the farmers' positive attachments to their agricultural profession might have played out in a tendency to wait longer with making the final step of terminating the investment. This even applies if the experiment is per se presented in a neutral frame as it was the case in the present study. It would be interesting and challenging to disentangle these different perspectives on inertia in disinvestment decisions based on the option-based inertia that we focused on in our experiments.

As already mentioned, the process of experimentally examining and testing real options settings is in an early stage. By venturing into this new terrain, our study is a small but important first step towards a better understanding and rationalisation of termination choices. With regard to the use of simplifying heuristics, it would be interesting to test which simple heuristics can predict disinvestment behaviour best. Another interesting path to be taken is investigating the effect of framing on disinvestment choices (Bettman and Sujan, 1987; Cronk and Wasielewski, 2008; Patel and Fiet, 2010): Will farmers be even more 'attached' to a project that is described in terms that are more familiar to them? Framing might also help render a laboratory experiment more realistic and thereby increase its external validity.

Supplementary Data

Supplementary materials are available at *ERAE* online.

Acknowledgements

We gratefully acknowledge financial support from Deutsche Forschungsgemeinschaft (DFG). We further acknowledge the valuable comments of Paolo Sckokai and three anonymous referees.

References

Andersen, S., Harrison, G. W., Lau, M. I. and Rutström, E. E. (2008). Eliciting risk and time preferences. *Econometrica* 76: 583–618.

Bettman, J. R. and Sujan, M. (1987). Effects of framing on evaluation of comparable and noncomparable alternatives by expert and novice consumers. *The Journal of Consumer Research* 14: 141–154.

Bolle, F. (1990). High reward experiments without high expenditure for the experimenter? *Journal of Economic Psychology* 11: 157–167.

Brick, K., Visser, M. and Burns, J. (2011). Risk aversion: experimental evidence from South African fishing communities. *American Journal of Agricultural Economics* 94: 133–152.

Burmeister, K. and Schade, C. (2007). Are entrepreneurs' decisions more biased? An experimental investigation of the susceptibility to status quo bias. *Journal of Business Venturing* 22: 340–362.

Burns, P. (1985). Experience and decision-making: a comparison of students and businessman in a simulated progressive auction. In V. L. Smith (ed), *Research in Experimental Economics*. Greenwich, USA: JAI Press, 131–157.

Camerer, C. F. and Hogarth, R. M. (1999). The effects of financial incentives in experiments: a review and capital–labor–production framework. *Journal of Risk and Uncertainty* 19: 7–42.

Coble, K. H. and Lusk, J. L. (2010). At the nexus of risk and time preferences: an experimental investigation. *Journal of Risk and Uncertainty* 41: 67–79.

Cronk, L. and Wasielewski, H. (2008). An unfamiliar social norm rapidly produces framing effects in an economic game. *Journal of Evolutionary Psychology* 6: 283–308.

Davis, D. D. and Holt, C. A. (ed.) (1993). *Experimental Economics*. Princeton: Princeton University Press.

Dixit, A. K. (1989). Entry and exit decision under uncertainty. *Journal Political Economy* 97: 620–638.

Dixit, A. K. (1992). Investment and hysteresis. *Journal of Economic Perspectives* 6: 107–132.

Dixit, A. K. and Pindyck, R. S. (ed.) (1994). *Investment Under Uncertainty*. Princeton: Princeton University Press.

Gigerenzer, G. and Goldstein, D. G. (2002). Models of ecological rationality: the recognition heuristic. *Psychological Review* 109: 75–90.

Guala, F. (ed.) (2005). *The Methodology of Experimental Economics*. Cambridge: Cambridge University Press.

Harrington, D. H. and Reinsel, R. (1995). A synthesis of forces driving structural change. *In* D. H. Harrington, R. Bollman, P. Ehrensaft, D. Freshwater and L. Whitener (eds), *Farms, Farm Families, and Farming Communities, Canadian Journal of Agriculture Economics*, Special Issue: 3–14.

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. *American Economic Review* 92: 1644–1655.

Huettel, S., Musshoff, O. and Odening, M. (2010). Investment reluctance: irreversibility or imperfect capital markets? *European Review of Agricultural Economics* 37: 51–76.

Isik, M. (2005). Incorporating decision maker's risk preferences into real options models. *Applied Economics Letters* 12: 729–734.

Isik, M., Coble, K. H., Hudson, D. and House, L. O. (2003). A model of entry-exit-decisions and capacity choice under demand uncertainty. *Agricultural Economics* 28: 215–224.

Jose, D. H. and Crumly, J. A. (1993). Psychological type of farm/ranch operators: relationship to financial measures. *Review of Agricultural Economics* 15: 121–132.

Kuminoff, N. V. and Wossink, A. (2010). Why isn't more US farmland organic? *Journal of Agricultural Economics* 61: 240–258.

Laury, S. (2005). Pay one or pay all: random selection of one choice for payment. Research Paper Series 06–13, Andrew Young School of Policy Studies, Georgia State University, Atlanta.

Loewenstein, G. (1999). Experimental economics from the vantage-point of behavioural economics. *The Economic Journal* 109: F23–34.

Longstaff, F. A. and Schwartz, E. S. (2001). Valuing American options by simulation: a simple least-squares approach. *Review of Financial Studies* 14: 113–148.

Moss, C. B. and Katchova, A. L. (2005). Farmland valuation and asset performance. *Agricultural Finance Review* 65: 119–130.

Odening, M., Musshoff, O. and Balmann, A. (2005). Investment decision 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. *The Review of Economic Studies* 76: 1103–1124.

Patel, P. C. and Fiet, J. O. (2010). Enhancing the internal validity of entrepreneurship experiments by assessing treatment effects at multiple levels across multiple trials. *Journal of Economic Behavior and Organization* 76: 127–140.

Pietola, K. S. and Wang, H. H. (2000). The value of price and quantity fixing contracts. *European Review of Agricultural Economics* 27: 431–447.

Plantinga, A. J., Lubowski, R. N. and Stavins, R. N. (2002). The effects of potential land development on agricultural land prices. *Journal of Urban Economics* 52: 561–581.

Purvis, A., Boggess, W. G., Moss, C. B. and Holt, J. (1995). Technology adoption decisions under irreversibility and uncertainty: an ex ante approach. *American Journal of Agricultural Economics* 77: 541–551.

Rauchs, A. and Willinger, M. (1996). Experimental evidence on the irreversibility effect. *Decision and Theory* 40: 51–78.

Richards, T. J. and Green, G. (2003). Economic hysteresis in variety selection. *Journal of Agricultural and Applied Economics* 35: 1–14.

Roe, B. E. and Just, D. R. (2009). Internal and external validity in economics research: tradeoffs between experiments, field experiments, natural experiments and field data. *American Journal of Agricultural Economics* 91: 1266–1271.

Roosen, J. and Marette, S. (2011). Making the 'right' choice based on experiments: regulatory decisions for food and health. *European Review of Agricultural Economics* 38: 361–381.

Ross, J. and Staw, B. M. (1993). Organizational escalation and exit – lessons from the Shoreham Nuclear Power Plant. *Academy of Management Journal* 36: 701–732.

Samuelson, W. and Zeckhauser, R. (1988). Status quo bias in decision making. *Journal of Risk and Uncertainty* 1: 7–59.

Sandri, S., Schade, C., Musshoff, O. and Odening, M. (2010). Holding on for too long? *Journal of Economic Behavior and Organization* 76: 30–44.

Schade, C., Kunreuther, H. and Koellinger, P. (2011). Protecting against low-probability disasters: the role of worry. *Journal of Behavioral Decision Making* (in press). DOI: 10.1002/bdm.754.

Schram, A. (2005). Artificiality: the tension between internal and external validity in economic experiments. *Journal of Economic Methodology* 12: 225–237.

Sckokai, P. and Moro, D. (2009). Modelling the impact of the CAP single farm payment on farm investment and output. *European Review of Agricultural Economics* 36: 395–423.

Serra, T., Stefanou, S., Gil, J. M. and Featherstone, A. (2009). Investment rigidity and policy measures. *European Review of Agricultural Economics* 36: 103–120.

Stokes, J. R. (2006). Entry, exit, and structural change in Pennsylvania's dairy sector. *Agricultural and Resource Economics Review* 35: 357–373.

Trigeorgis, L. (ed.) (1996). *Real Options*. Cambridge: MIT Press.

Turvey, C. G. (2003). Can hysteresis and real options explain the farmland valuation puzzle? In A. B. Moss and A. Schmitz (eds), *Government Policy and Farmland Markets: The Maintenance of Farmer Wealth*. Ames, IA: Iowa State University Press, 179–207.

Winter-Nelson, A. and Amegbeto, K. (1998). Option values and agricultural price policy: application to terrace construction in Kenia. *American Journal of Agricultural Economics* 80: 409–418.

Wossink, A. and Gardebroek, C. (2006). Environmental policy uncertainty and marketable permit systems: the Dutch phosphate quota program. *American Journal of Agricultural Economics* 88: 16–27.

Yavas, A. and Sirmans, C. F. (2005). Real options. Experimental evidence. *The Journal of Real Estate Finance and Economics* 31: 27–52.

Yesuf, M. and Bluffstone, R. A. (2009). Poverty, risk aversion, and path dependence in low-income countries: experimental evidence from Ethiopia. *American Journal of Agricultural Economics* 91: 1022–1037.