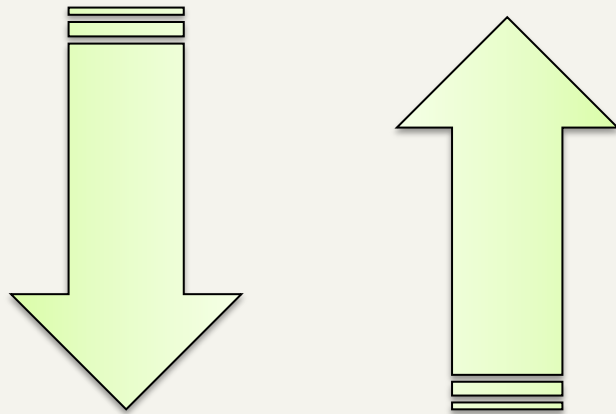# The role of the natural hedge in organic farming – an adoption barrier?

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The role of the natural hedge in organic farming – an adoption barrier?

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Abstract

The market for organic agriculture in Germany and other parts of the world has been substantially growing in the past. This raises interest of policymakers and economists in the conversion decision from conventional to organic agriculture. As one major effect of the difference in production methods between conventional and organic agriculture is the assumedly higher production risk in organic agriculture this seems to be a major determinant for the conversion decision of risk averse farmers. Natural hedge, i.e. the price-yield correlation of a crop, has been shown to be a natural risk management tool. The role of natural hedge in the conversion decision has though not explicitly been investigated yet. Using a net present value investment model and means of data simulation this research finds that natural hedge has an effect on the mean and variance of outcomes, and therefore on the conversion decision. Conversion preferences for wheat, barley, rye, potatoes, maize, field beans and sugar beets for the province of Bavaria in Germany are assessed. Assuming different levels of risk aversion of farmers one finds for the given data that a more positive (weaker) natural hedge makes cropping options more attractive. Addressing especially farmers downside risks with the introduction of a revenue insurance, results indicate that the introduction of revenue insurance for organic farming makes conversion more attractive. The more positive the natural hedge is, the greater is the possible effect of introducing insurance. Analysing natural hedge for Germany on a national and a provincial level, results point towards a more positive natural hedge for organic than for conventional crops. Given theoretical results natural hedge in Germany therefore favours conversion and makes the introduction of revenue insurance for organic farmers comparably efficient. A major obstacle in the analysis was scarce availability of data on organic agriculture. Results should therefore rather be interpreted qualitatively than quantitatively.

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List of tables and figures

List of variables

X_{it} = Yield of crop i in period t (in 100kg/ha).

P_{it} = Selling price of crop i in period t (in €/100 kg).

VC_{it} = Per period variable costs of crop i (in €/ha).

i = Discount rate.

IC_i = (Sunk) singular investment costs for conversion from conventional to organic crop i.

R_{it} = Revenue of crop i in period t (in €/ha).

DR_{it} = Difference between revenues of organic and conventional crop i in period t.

GI_{it} = Gross income of crop i in period t (in €/ha).

DGI_{it} = Difference between gross income of organic and conventional crop i in period t.

$PV_{t=n}(X)$ = Present Value of income stream X for period t=n (in €/ha).

$PV_{t=n}^{adj}(X)$ = Adjusted present value of income stream X for period t=n (in €/ha).

r_a = Arrow-Pratt coefficient of absolute risk aversion.

r_r = Arrow-Pratt coefficient of relative risk aversion.

Ind_t = Indemnity payment in period t.

$LIns$ = Level of insurance (in percentage).

IP = Fair insurance premium.

CG_i = "Correlation gap" for crop i.

1. Introduction

Background

The share of organic products in the agricultural markets has developed rapidly in recent years, e.g. in Germany the market for organic food grew from 5.8 bn. € in 2008 to 7.55 bn. € in 2013, which relates to per capita expenses of 71.2 € and 92.2 € respectively (AMI Markt Bilanz Öko-Landbau, 2014). Explanations of this development are supporting policies, a higher demand from the consumer side, partly due to increased consumer awareness for sustainable production (Grunert, 2005), and premium prices for organic products. Higher risks and transaction costs are though still a barrier for switching from conventional to organic farming. For organic farming risk plays an even more pronounced role than for conventional farming. Production risks through weather fluctuations and diseases may be harder to control than in conventional agriculture as the possibility to intervene with herbicides, pesticides or fertilizers are more restricted. Weather risks may increase with climate change. If this also results in higher income risks, and therefore market entrance barriers to organic farming, depends on the use of risk management tools, costs and prices (market risks). El Benni and Finger (2012) found for a sample of 3000 (conventional) Swiss crop farmers that price and yield risks are of "outmost importance and very crop specific"(p.2) in determining income variability, whereas costs only "play a minor role". In the study they found that "In general, natural hedge plays a substantial role in reducing revenue risk at farm level" (p.11). The existence of a so-called "natural hedge", namely a (negative) price-yield correlation, is important for risk management because low yields may be compensated with high prices. Therefore natural hedge could be a major determinant of income risks for conventional farmers and of major importance regarding the design of income supporting schemes/insurances.

Research questions

The question therefore arises if the natural hedge for organic products has a similar importance for income risks as in conventional agriculture. Especially in the context of the higher production risks in organic farming this could be of major importance for farmers willing to switch to organic farming. Held and Bahrs (2007) analyzed historical accounting data of German farmers and were able to find indications that natural hedge for organic potato and wheat farmers was not as strong as for conventional farmers. Indications on the functioning of the market for organic products might be drawn as well from such an analysis. The presence of a natural hedge can point to local markets that are not well connected to larger national or international markets. Especially findings of positive price-yield correlations, which indicate that price rises with supply, could point to special market structures. Problems for the analysis arise from the scarce availability of data on prices and yields of organic products, especially on lower aggregation levels[1], which make it necessary to use means of data simulation. The general objective of this research therefore can be stated as: How does natural hedge influence adoption of organic agriculture by conventional farmers. And: How do results apply to German agriculture, based on the available data?

Research motivation

Conventional farmers can be assumed to be risk averse in business decisions; although organic farmers were shown to be less risk averse (Gardebroek, 2006). Yield, price and income risk should therefore be considered when analyzing the adoption decision of organic farming by conventional

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[1] The importance of aggregation for the analysis of price-yield correlations is discussed by Finger (2012).

farmers. There is a considerable literature on the farmers' adoption decision, facing uncertainty. Recent studies have pointed out that one important determinant of risk in agriculture is the correlation structure between prices and yields. An example is Abadi Ghadim (2000) who points out that adoption of organic farming will be more likely if organic and conventional yields are positively correlated. Würriehausen et al. (2014) investigate the relation between organic and conventional prices and predict that individual price setting of organic farmers will be restricted in the future. Finger (2012) and others have shown which role the correlation between prices and yields ("natural hedge") plays for farmers income risks and insurance schemes. The significant influence of natural hedge on the farmers risk management is therefore widely accepted. It has so far though not explicitly been examined which role natural hedge plays in the conversion decision towards organic farming. This will therefore first be analyzed, modelling the adoption decision with a simple investment model. Influences of changing natural hedge on mean, variance and downside risk will be examined. In this regard not only negative correlation of prices and yields plays a role, but especially the difference in correlations for conventional and organic crops. This is important as in data not only negative price yield correlations, but also positive correlations are observed sometimes. The theoretical investment model is explained in chapter 2. An overview of the data used for the analysis is given in chapter 3, and chapter 4 presents the results of the model simulation. To relate theoretical results to reality it will further be interesting to analyze the magnitude of natural hedge found in organic and conventional crop farming in Germany. This is done in chapter 5. Finally, a conclusion is drawn in chapter 6.

2. The theoretical model

This chapter starts with an explanation of the investment model used in section 2.1. To introduce risk aversion of decision makers the model is then extended to an expected utility framework in section 2.2. Following this the effects of a changing natural hedge on the adoption decision are examined theoretically and expectations for the simulation runs are formulated (section 2.3). Finally, at the end of the chapter, in section 2.4, it is described how revenue insurance can be introduced to the model.

2.1 The net present value model

The conversion decision from conventional to organic farming might be driven by various factors. Research (Padel, 2001; Griliches, 1957; Pietola and Oude Lansink, 2001) though has shown that monetary motives are dominating in the decision for most farmers. To gain insights in the effects of the natural hedge on the conversion decision an investment model will therefore be used. In this model the farmer compares monetary benefits of staying in conventional farming and switching to organic farming. This can be done in various ways. Assuming that the farmer will use common calculation tools (as available on www.stmelf.bayern.de/idb) and no major policy changes[2] in support of conventional and organic farming on German and EU level occur in the near future, the model of choice is a simple net present value (NPV) model. It is additionally assumed that farmers switching to organic farming will have to pay a certain amount of investment costs (IC) for conversion (for new machinery, seeds, fertilizer, knowledge etc.) and that these investment costs are sunk (as in Musshoff and Hirschauer (2008) among others). Variable costs include costs for seeds, fertilizer, herbicides, pesticides, variable machine costs and other variable costs, and occur every period.

Defining revenue (R_{it}) as the product of per period (subscript "t") yields (X_{it}) and prices (P_{it}), the difference in per period revenues (DR_{it}) between organic (superscript "o") and conventional (superscript "c") farming of crop "i" is

$$(1) DR_{it} = R_{it}^o - R_{it}^c.$$

Defining gross income (GI_{it}) as the difference between revenue and variable costs (VC_{it}), the difference in gross income (DGI_{it}) is represented by

$$(2) DGI_{it} = DR_{it} - VC_{it}^o + VC_{it}^c.$$

The present value ($PV_{t=n}(X)$) of the difference in gross incomes can then be achieved by discounting to the present period

$$(3) \ PV_{i,t=0}(DGI_i) = \sum_{t=1}^{t=n} \frac{DGI_{it}}{(1+i)^t} \ .$$

The difference in present values of gross income represents the possible benefits from the investment in organic farming over the investment period *t=1* to *t=n*, discounted to the present period *t=0*. Evaluating an investment decision in period 0 then means to compare the investment costs IC_i with benefits $PV_{i,t=0}(DGI_i)$ from the investment. If benefits are greater than investment

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[2] The European Union has just agreed on a CAP reform for the years 2014-2020 implying a move towards further decoupling and a flat rate (European Commission, 2013). The CAP provides the framework of Agricultural Policy in the EU and harmonizes Agricultural Policy in the EU member states in main issues. Looking at the CAP reform therefore allows to foresee major changes in European Agricultural Policy for the coming years. Climate change and a higher consumer acceptance of organic products are further assumed to keep organic farming on the agenda.

costs the farmer will convert to organic farming. As already mentioned above such a NPV model simplifies the farmer's decision significantly as it only compares the monetary reward of farming systems. Non-monetary incentives such as idealism (Roberts and Swinton, 1996), social pressure (Schulze Pals, 1994), regional factors (Musshoff and Hirschauer, 2008), extensive versus intensive farming (Pietola and Oude Lansink, 2001), personal attributes of the farmer, marketing structures (Spahn et al., 2002) or different crop rotations in organic and conventional farming (Köpke, 1995; Olesen et al., 1996) are not considered in the model. Such additional factors though might differ in importance per region and individual farmer, whereas monetary rewards of the conversion can be assumed to be an important criterion for the vast majority of farmers. Having reduced the number of impact factors on the conversion decision in the model to only monetary rewards then allows to more concisely answering the research question of this paper: To what extent natural hedge influences the conversion decision? The basic model might then be used as a starting point for the analysis of an extended number of impact factors in later research.

EU regulations require a transition period from conventional to organic farming. In the EU this transition period is two to three years long for crops (Commission Regulation (EC) No 889/2008). A transition period of three years is assumed to not underestimate this effect. Only after this transition period the farmer has the right to label products as organic. Simplified, this transition period usually implies two types of ''costs" for the converting farmer. Firstly, the farmer already produces with organic methods, and therefore organic yields during the transition period, but prices are still the ones paid for conventional products. Adjusting $PV_{i,t=0}(DGI_i)$ for the transition period leads to

(4) $PV_{i,t=0}^{adj}(DGI) = \sum_{t=1}^{t=n} \frac{DGI_{it}}{(1+i)^t} - \sum_{t=1}^{t=3} \frac{(p_{it}^o - p_{it}^c)*x_{it}^o}{(1+i)^t}$.

Secondly, lower than usual organic yields due to an adoption of new technologies during the transition period can be assumed (Martini et al., 2004). These differences in yields will though be individual and depend for example on the education or experience of the farmer. To account for these kinds of costs is therefore difficult. To still take these costs into account an assumption about the level of these costs is made. Under German federal and provincial law farmers switching to organic farming receive higher than normal per hectare subsidies during a transition period of up to 5 years, depending on the province (Nieberg et al., 2011). This increase in subsidies was installed to reduce the additional threshold for conversion due to lower yields through the transition period. It therefore seems to be reasonable to assume that the increase in subsidies covers for losses due to the yield adoption process in the transition period, on average, and these costs can therefore be ignored in the model, when increases in subsidies are ignored as well.

2.2 An expected utility framework
Net present value models, as described in section 2.1, usually do not consider risk attitudes of decision makers, nor do they consider higher moments than the mean in the investment decision (NPV of benefits is compared to investment costs). This coincides with the behavior of a risk neutral individual. Risk aversion is though often observed in the behavior of farmers. Therefore, in a second step, uncertainty is introduced to the theoretical model, as the decision maker is assumed to be an expected utility maximizer. Expected utility theory was developed in response to critique on expected value as a decision criterion. It assumes that the decision criterion for the decision maker no longer is the simple net present value (the expected value when prices and/or yields are non-stochastic) but its expected utility. The utility of outcomes is therefore calculated in a first step, and

then its expected value is calculated. This makes it possible to include stochastic yields and/or prices and at the same time, according to the utility function used different risk preferences of the decision maker. Nowadays the concept of expected utility is also under criticism (Allais, 1984; Rabin, 2000) and other concepts (see Starmer, 2000 for an overview) have emerged. Expected utility theory is though still widely used as it allows assessing outcomes under different risk preferences relatively easily. Especially in a scenario as in this research where hypothetical outcomes of a changing variable (i.e. natural hedge) are assessed expected utility theory provides, combined with a sensitivity analysis, useful insights. Hardaker et al. (2004a, p.254) further argue that "[...] the expected utility hypothesis remains the most appropriate theory for prescriptive assessment of risky choices." The utility function used here is the exponential utility function, which shows constant absolute risk aversion (CARA):

$$(5) U(PV_i) = e^{-PV_i * r_{a,i}}.$$

The level of relative risk aversion ($r_{r,i}$) is defined as the absolute risk aversion ($r_{a,i}$) multiplied by the average present value of the crop at stake (equation 6). The strength of this concept is that the level of relative risk aversion can be alternated to show effects of diverging levels of risk aversion on the expected utility of present values, and therefore the investment decision. Following Anderson and Dillon (1992) $r_r = 0$ represents risk neutrality, $r_r = 1$ represents normal risk aversion, $r_r = 2$ represents rather risk averse behavior, $r_r = 3$ represents very risk averse behavior and $r_r = 4$ almost paranoid risk averse behavior. The magnitude of the coefficient of absolute risk aversion ($r_{a,i}$) is calculated for each crop and level of relative risk aversion from one to four, respectively, according to:

$$(6) r_{a,i} = \frac{r_{r,i}}{mean(PV_i)}.$$

Expected utility is measured in utils, which makes it hard to assess and compare this measure. A more convenient measure to compare outcomes is the certainty equivalent (*CE*). The certainty equivalent is defined as the risk free (or sure) amount of money, which is equal in utility to the risky gamble (here the present value). The difference between certainty equivalent and the expected value of the risky gamble is the risk premium. The more certainty equivalent and expected value are apart from each other, the more the decision maker would pay to evade risk, given utility stays the same. Outcomes of the expected utility model will be given as certainty equivalents, as they are measured in €/ha as well, and therefore easily comparable.[3]

2.3. Effects of changing natural hedge

The aim of this research is to show possible effects of the natural hedge on the conversion decision of farmers. The natural hedge is defined as the correlation between per period yields and prices. When the correlation is negative high prices are accompanied by low yields, and vice versa. Such a negative correlation can be seen as a "natural hedge" against fluctuations in revenues, which explains the name of the phenomenon.

When per period prices and yields are assumed to be uncertain (follow a stochastic process) it is important to understand which influence the correlation between the two correlated random variables price and yield has on their product, revenues. This is due to the fact that the decision

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[3] For a short introduction to risk aversion and the expected utility model see Appendix II.

criterion in the NPV model is the present value of a stream of revenues (and variable costs). Looking at the first two moments of the product, namely mean and variance, one finds (Rinne, 1997):

$$(7) E(X_{it} * P_{it}) \approx E(X_{it}) * E(P_{it}) + Cov(X_{it}, P_{it}) = E(X_{it}) * E(P_{it}) + Cor(X_{it}, P_{it}) * \sigma_{X_{it}} * \sigma_{P_{it}}.$$

And for a bi-variate normal distribution (otherwise higher moments are included in the formula, see Bohrnstedt and Goldberger, 1969) variance equals:

$$(8) V(X_{it} * P_{it}) = E^2(X_{it}) * V(P_{it}) + V(X_{it}) * E^2(P_{it}) + 2 * E(X_{it}) * E(P_{it}) * Cor(X_{it}, P_{it}) * \sigma_{X_{it}} * \sigma_{P_{it}} + V(X_{it}) * V(P_{it}) + (Cor(X_{it}, P_{it}) * \sigma_{X_{it}} * \sigma_{P_{it}})^2.$$

Where $E()$ stands for the expected value, $V()$ for the variance, $Cov()$ for the covariance, $Cor()$ for the correlation coefficient and σ for the standard deviation. One sees that an increase in natural hedge (more negative correlation) decreases the mean of revenues due to the second term in the product equation of expected values (see equation 7). If it is additionally true that:

$$(9) \mid 2 * E(X_{it}) * E(P_{it}) * Cor(X_{it}, P_{it}) * \sigma_{X_{it}} * \sigma_{P_{it}} \mid > (Cor(X_{it}, P_{it}) * \sigma_{X_{it}} * \sigma_{P_{it}})^2$$

then an increase in natural hedge reduces variance of revenues at the same time. To simplify terminology let the "correlation gap" then be the difference in natural hedge between conventional and organic agriculture or the correlation coefficient between conventional crop yields and prices minus the correlation coefficient of its organic counterparts

$$(10) CG_i = Cor(X_i^c, P_i^c) - Cor(X_i^o, P_i^o).$$

Given the above reasoning one sees that an increase in the correlation gap will reduce the mean of present values of organic crops compared to conventional crops, ceteris paribus. This is the case as an increase in the correlation gap always means a more negative correlation coefficient of organic crops compared to conventional crops. But a more negative correlation coefficient will lead to a lower mean as well, as shown in equation 7. Or a more positive correlation coefficient of conventional crops to a higher mean, respectively. Increasing the correlation coefficient of the organic crop, compared to the conventional crop will further reduce variance of the organic crops compared to conventional crops ceteris paribus, following the same reasoning and equations 8 and 9[4]. A risk averse decision maker prefers higher means and lower variances (see Chavas, 2004). Results of a changing natural hedge on the conversion decision of farmers are therefore ambiguous, as mean and variance of present values are expected to change in the same direction as a response. Which effect will outweigh the other will depend on the extent to which mean and variance change, as well as the preference structure of decision makers (modelled here by utility function and degree of risk aversion).

2.4. Introducing revenue insurance

A widely used tool for risk management nowadays, is revenue insurances. Such insurance tools are already being offered to farmers in the USA (see the U.S. Federal Agricultural Improvement and Reform Act in 1996, see also Barnett (2000)) or Canada (see in 1991 the Gross Revenue Income Program) for example. In the recent CAP reforms such tools were also on the agenda of European Common Agricultural Policy (European Commission, 2013). Revenue insurances insure the farmer against revenues falling below a certain percentage of the historical mean revenues. It is therefore a

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[4] A simple numerical example to illustrate this reasoning can be found in Appendix A1.

tool to reduce downside risks of farmers. The indemnity paid in period t for crop i ($Ind_{i,t}$), amounts to the difference between the insured level in percentage ($LIns$) of the historical mean revenue for crop i ($mean(R_{i,hist})$) and the realized revenue for each period.

(11) $Ind_{i,t} = LIns * mean(R_{i,hist}) - R_{it} , \forall R_{it} < LIns * mean(R_{i,hist})$.

A fair insurance premium for crop i (IP_i), paid every period, is the sum of (predicted) indemnity payments divided by the number of periods the insurance runs. The premium paid each period therefore exactly covers (predicted) indemnity payments throughout the insurance contract

(12) $IP_i = \frac{\sum_{t=1}^{t=n} Ind_{it}}{n}$.

If this fair insurance premium is now calculated for the investment period and added to the variable costs in the basic net present value model, it is implicitly taken account of the possible downside risk aversion of farmers.

(13) $VC_{it}^{O,IP} = VC_{it}^{O} + IP_i$

An insured farmer will always realize revenues above the insured threshold and therefore reduce his downside risk in revenues (the downside variance is reduced by introducing a lower boundary to revenues). For greater downside risks in the realizations of revenues this premium will be larger, and vice versa. The magnitude of the fair insurance premium therefore quantifies the downside risks for a risk-averse farmer present in predicted revenues. In the context of this analysis it will be interesting to find out if revenue insurance will change the results of the NPV model. Assuming three cases, namely a conventional farmer, a farmer converting to organic farming without insurance, and a farmer converting to organic farming with revenue insurance, the effect of an introduction of revenue insurance on the results will be assessed. This is done in a practical and convenient way. For the organic farmer with revenue insurance, deviations from the mean of NPV below the insured threshold will be compensated. In return, the fair insurance premium (IP_i) will be added to per period variable costs as shown in equation 13.

3. The data

In this chapter an overview over the data used for simulation of the model, simulation techniques and possible restraints to simulation will be given. Farmers usually rely on short term historical data for their investment decision, when local experience is lacking. In Germany online-platforms such as www.stmelf.bayern.de/idb of the Bavarian "Landesanstalt für Landwirtschaft" provide data of prices, yields and costs of various organic and conventional crops, as well as calculation tools. For the investment analysis yield and price data supplied by the Bavarian "Landesanstalt für Landwirtschaft"(2009-2013), are available to the public, are therefore taken to determine basic statistics as means and standard deviations of organic and conventional crops. An overview of means and coefficient of variation is given in Table 1 (where dt is a common German abbreviation for deci-tons, equal to 100 kg).

Table 1. Benchmark data used for simulation (mean and coefficient of variation)

	Conventional		Organic	
	Yields (dt/ha)	Prices (€/dt)	Yields (dt/ha)	Prices (€/dt)
Wheat	70 (0.05)	20 (0.22)	41 (0.11)	38 (0.13)
Barley	59 (0.05	16 (0.27)	33 (0.05)	33 (0.07)
Rye	49 (0.14)	18 (0.30)	32 (0.09)	28 (0.25)
Maize	99 (0.10)	17 (0.30)	66 (0.08)	35 (0.14)
Sugar beets	760 (0.09)	5 (0.20)	485 (0.07)	8 (0.09)
Potatoes	411 (0.15)	16 (0.44)	246 (0.16)	48 (0.33)
Field Beans	34 (0.05)	21 (01.3)	30 (0.06)	40 (0.13)

Own calculations, summary statistics for 2009-2013, and data from www.stmelf.bayern.de/idb.

Working with data for only five years will not give a reliable estimate of the "true moments". It though seems reasonable as farmers in real life also rely on such short data series for their investment decision. Prices and yields may follow stochastic (or deterministic) developments and accordingly they are allowed to differ per period. El Benni and Finger (2012) show that a major source of variance in farmer's income stems from price and yield uncertainty, whereas costs (fertilizer, seeds, pesticides; e.g. variable costs) only play a minor role. Variable costs are therefore assumed not to vary substantially. Additionally there is no data on variation of variable costs available. Given the above, it therefore seems to be reasonable to assume constant variable costs during all periods, in contrast to prices and yields, which are allowed to follow a stochastic process.

Based on the benchmark data, predicted yields and prices for organic and conventional crops over an investment horizon of twenty years are simulated 5000 times with a Monte Carlo simulation in R. To give an overview over different types of crops, simulation is performed for wheat, barley, rye, maize, field beans, sugar beets and potatoes (for consumption). It is troublesome to select a distribution family for simulation, as evidence for distribution of agricultural yields is ambiguous. Just and Weninger (1999) point out that a normal distribution cannot be rejected so far. Atwood et al. (2003) find negative skewness in their response to Just and Weningers paper. Data series of the above mentioned crops are therefore first tested for normality with the Shapiro-Wilk test. If longer than 5 years data series were available from the Bavarian "Landesanstalt für Landwirtschaft", those were used. The Shapiro-Wilk test is known for its high test power, especially with small sample sizes as in this case, and therefore seems to be especially suitable to test for normality here. Using a

significance level of alpha equal to five percent, normality was only rejected [5]for yields of conventional field beans, as well as prices of organic field beans[6]. Based on the results of individual Kolgorov-Smirnov tests Weibull distributions were found to be the best-fitting distributions, and were used for simulation of these two items (i.e. conventional and organic field beans), respectively. Data for (over time not varying) variable costs are taken from the Bavarian "Landesanstalt für Landwirtschaft", as well. The correlation between yields and prices of the organic crop is then varied for all simulations of organic crops, holding standard deviation and means of prices and yields equal all the time. This makes it possible to show the effects of differing levels of natural hedge (in the here introduced terminology: an increase in the correlation gap, ceteris paribus) on the adoption decision. This shows the advantage of using simulated data. While in real data a change in natural hedge would most probably go along with a change in prices or yields, simulation tools make it possible to show the effects of a change in natural hedge ceteris paribus. The long term risk free interest rate is set to be 6.75 %, following Musshoff and Hirschauer (2008).

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[5] The normality test for organic barley was first rejected as well. This was though due to an extreme outlier in 2009/2010. Neither organic barley on national level, nor conventional barley on provincial or national level or other crops showed sign of a similar decrease in yield for this year. Yield for organic barley in 2009/10 was therefore replaced by a nationwide average. Normality was not rejected anymore after this replacement.

[6] A table of the respective p-values of the Shapiro-Wilk tests and the number of observations per series can be found in the appendix in Table 12.

4. Simulation results

This chapter presents results of the simulation runs and briefly discusses them. Section 4.1 starts with the basic model, whereas section 4.2 and 4.3 follow with the expected utility framework and the revenue insurance component, respectively.

4.1. Basic NPV model

The resulting adjusted net present values per hectare for the example of Bavaria are summarized in Table 2.

Table 2. Means of simulated Net Present Values for Bavarian crops

	NPV organic (€/ha)	NPV conventional (€/ha)	Difference (€/ha)
Wheat	5368	7155	-1787
Barley	2005	1097	908
Rye	1339	2957	-1618
Maize	7452	4550	2902
Sugar beets	15494	22752	-7258
Potatoes	69801	40572	29229
Field Beans	3928	511	3417

Own calculations. Data from Bayerische Landesanstalt für Landwirtschaft. i=0.0675.

Adjusted net present values for an investment horizon of twenty years are simulated 5000 times for each crop with a Monte Carlo simulation. Means of the adjusted net present value are then calculated. The difference between organic and conventional adjusted net present values is the decision variable for the farmer in this model. A negative value (wheat, rye, sugar beets) indicates that a conversion to organic farming does not pay off. A positive value (barley, maize, potatoes, and field beans) indicates that a conversion pays off if the difference is greater than initial investment (conversion) costs in organic farming. This research is not meant to analyze the business economics of the conversion decision, but the effect of natural hedge on the decision. Conversion as an investment decision is therefore not modeled explicitly enough to analyze results quantitatively. As mentioned above, differing crop rotations, marketing structures, extensive/intensive farming and other factors are not considered. It is though possible to draw qualitative conclusions. Conversion seems to rather pay off for potatoes, maize, field beans and barley, whereas it rather not pays off for sugar beets, wheat and rye. Another reason why it is hard to draw quantitative conclusions from these results is aggregation bias. The benchmark data was taken on a provincial level. On farm level risk might though be higher (Finger, 2012a). It could therefore be the case that such crops, for which conversion is paying off, also incur greater yield risks on farm level. This is though not possible to analyze with the given data.

In a second step the price-yield correlation (natural hedge) of the organic crops has been varied from -0.1 to -0.5, maintaining mean and variance. A Monte Carlo simulation with 5000 runs has been performed for every deviation of natural hedge and mean and coefficient of variation are calculated again. From equations (7) and (8) it is clear that a change of the correlation between two stochastic variables will affect mean and variance of the product (revenues). These effects are clearly visible in the outcomes of the simulation runs. Changing the natural hedge from -0.1 to -0.5 has clearly a mean decreasing effect for adjusted Net Present Values (NPV) of all crops (see Table 3).

Table 3. Mean NPV (€/ha) and standard deviation (sd) for differing levels of natural hedge

Natural hedge	Wheat	Barley	Rye	Maize	Sugar beets	Potatoes	Field Beans
-0.1	5344 (321)	1998 (192)	1354 (319)	7399 (575)	15420 (740)	71425 (4754)	3959 (161)
-0.2	5323 (318)	1995 (191)	1338 (318)	7398 (566)	15413 (735)	71093 (4669)	3951 (158)
-0.3	5305 (314)	1992 (191)	1321 (316)	7388 (559)	15406 (731)	70759 (4575)	3942 (154)
-0.4	5288 (310)	1989 (190)	1305 (315)	7374 (553)	15399 (726)	70421 (4472)	3934 (150)
-0.5	5271 (306)	1986 (189)	1289 (313)	7359 (546)	15393 (720)	70079 (4360)	3925 (147)
Δ sd from -0.1 to -0.5	-5%	-1%	-2%	-5%	-3%	-8%	-9%

Own calculations. Data from Bayerische Landesanstalt für Landwirtschaft. i=0.0675.

On the other hand, a more negative price-yield correlation should reduce variance of adjusted NPVs according to equations (8) and (9). This is clearly visible in the outcomes. The Standard deviation is decreasing in natural hedge for all crops. The greater standard deviation is the more it decreases in natural hedge, in absolute, as well as relative terms. The biggest decrease in relative terms occurs for field beans, where prices have not been simulated under the assumption of a normal distribution but a Weibull distribution (see chapter 3).

Looking at the probability density functions (pdf) of adjusted net present values for the differing levels of natural hedge[7] the two results that an increase in natural hedge has a mean and variance reducing effect, from above, can clearly be confirmed. Pdfs of the simulation runs are entirely shifted towards lower values (lower means) with increasing natural hedge, whereas the distribution curve becomes more centered at the same time, indicating a lower variance.

4.2. Expected utility framework

The basic NPV model, as described in section 2.1.does not consider risk attitudes of decision makers. A decision maker would therefore always prefer the option with the higher mean, not taking the differences in variance into account. A risk averse decision maker on the other hand has a preference for higher means but also lower variance. An approach often used in such situations is therefore the mean-variance approach (Hardaker et al., 2004b). Here we will though model risk aversion of the decision maker explicitly, using the expected utility model. This approach is restrictive in the sense that it demands the selection of a utility function for the decision maker. Adopting the idea of expected utility with respect to a function (SERF) (see Hardaker et al., 2004a) the outcomes are assessed under differing levels of relative risk aversion. The advantage of this approach is that no assumption regarding the risk aversion of the decision maker has to be made, as outcomes are assessed for a predefined range of possible risk aversion (here 1 to 4, see section 2.2). As a utility function the exponential utility function, exhibiting CARA properties, with diverging levels of relative risk aversion ($r_{r,i}$) is used. The above results of the simulations of adjusted NPVs under differing natural hedge are therefore used to calculate the respective certainty equivalents under differing

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[7] See Figure 1 in Appendix III.

levels of risk aversion. Table 4 shows certainty equivalents for a relative risk aversion coefficient of 1 and 4, respectively[8].

Table 4. Certainty equivalents in €/ha for $r_r=1$ (and for $r_r=4$ in parenthesis)

Natural hedge	Wheat	Barley	Rye	Maize	Sugar beets	Potatoes	Field Beans
-0.1	5334 (5305)	1989 (1961)	1316 (1205)	7377 (7310)	15402 (15349)	71267 (70795)	3956 (3946)
-0.2	5314 (5285)	1986 (1958)	1300 (1189)	7376 (7311)	15395 (15343)	70940 (70483)	3948 (3938)
-0.3	5295 (5268)	1983 (1955)	1284 (1173)	7367 (7303)	15389 (15337)	70611 (70170)	3939 (3930)
-0.4	5278 (5251)	1980 (1953)	1267 (1156)	7353 (7291)	15382 (15331)	70280 (69856)	3931 (3922)
-0.5	5262 (5236)	1977 (1950)	1251 (1140)	7339 (7278)	15376 (15325)	69944 (69539)	3923 (3914)

Own calculations. Data from Bayerische Landesanstalt für Landwirtschaft. i=0.0675.

As outcomes are uncertain, certainty equivalents are lower for higher levels of risk aversion. The expected utility analysis was performed because means were increased and variance was decreased through a more negative natural hedge. In the first NPV model only means were considered as decision variables. A risk averse decision maker, as now modeled in the expected utility framework though prefers higher means and lower variance. It was therefore unsure which effect would outweigh the other. From the above results it can be seen that for all levels of risk aversion and all crops certainty equivalents are higher for less negative correlation coefficients. For the chosen crops, province (Bavaria), levels of risk aversion and utility function it can therefore be stated that the mean decreasing effect outweighs the variance reducing effect of a more negative natural hedge. Under the above assumptions it can therefore be reasoned that for risk averse farmers (maximizing expected utility) adoption of organic farming is more likely when the correlation gap is smaller.

4.3. Revenue insurance

A policy measure often discussed in agricultural risk management is the subsidization of revenue insurances (Meuwissen, 2003; Skees, 1998; Gray, 2004). In the USA and Canada such insurances are already common (see above), in the EU they have been discussed in the new CAP reform (see section 2.4). With such revenue insurances downside risk for the farmer can be reduced, as the insured level of historical revenues is the lower threshold level of revenue for an insured farmer. Under the proposition that production risks are especially large for organic farmers, as they cannot use certain herbicides, pesticides and fertilizers, such insurance would especially make sense for them. It is therefore evaluated how the conversion decision would change after introduction of 90% revenue insurance. As before, adjusted NPVs for conventional and organic farming are being computed. Additionally the case of organic farming with revenue insurance, covering for losses below 90% of historical yields, is being computed. In this case farmers pay a fair insurance premium every period (which is considered to be part of variable costs, see equation 13). Fair insurance premiums are expected to be higher for a more positive natural hedge, as a more negative natural hedge reduces revenue risk. Table 5 shows the fair insurance premiums for the organic crops.

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[8] Tables for $r_r=2$ and $r_r=3$ can be found in the appendix in Table 13 and Table 14.

Table 5. Fair (revenue) insurance premiums for organic crops with different levels of natural hedge (€/ha)

Natural hedge	Wheat	Barley	Rye	Maize	Sugar beets	Potatoes	Field Beans
original	42	4	49	94	78	767	41
-0.1	38	3	52	53	31	1085	48
-0.2	34	2	49	48	26	1023	46
-0.3	29	2	46	43	21	959	44
-0.4	25	1	43	37	16	894	42
-0.5	20	1	40	31	12	825	40

Own calculations. Data from Bayerische Landesanstalt für Landwirtschaft. i=0.0675. Indemnity level of revenue insurance =0.9.

It can be seen that per hectare premiums significantly decrease with increasing natural hedge, indicating less downside risk. The magnitude of the fair insurance premiums not only depends on variance, but also on the mean of NPVs, which explains why fair insurance premiums differ so much. Next for the organic crops fair insurance premiums are now included in the variable costs and revenues are adjusted accordingly. The mean of adjusted NPVs, as well as the coefficient of variation are calculated then. Additionally CEs are calculated.

Table 6. Mean (coefficient of variation) of adjusted NPVs in €/ha

	NPV organic	NPV organic + Insurance	NPV conventional
Wheat	5368 (0.06)	5367 (0.06)	7155 (0.04)
Barley	2005 (0.10)	2005 (0.10)	1097 (0.18)
Rye	1339 (0.24)	1339 (0.21)	2957 (0.06)
Maize	7452 (0.08)	7449 (0.08)	4550 (0.11)
Sugar beets	15494 (0.05)	15491 (0.05)	22752 (0.03)
Potatoes	69801 (0.06)	69787 (0.05)	40572 (0.06)
Field Beans	3928 (0.04)	3927 (0.03)	511 (0.17)

Own calculations. Data from Bayerische Landesanstalt für Landwirtschaft. i=0.0675. Indemnity level of revenue insurance=0.9.

Table 7. CEs (in €/ha) of NPVs with r_r=1 (and r_r=4 in parenthesis) for organic crops

	NPV organic	NPV organic + Insurance	NPV conventional
Wheat	5358 (5329)	5359 (5334)	7150
Barley	1996 (1968)	1996 (1968)	1079
Rye	1302 (1191)	1309 (1219)	2951
Maize	7427 (7354)	7428 (7346)	4520
Sugar beets	15475 (15418)	15473 (15420)	22739
Potatoes	69671 (69283)	69698 (69433)	40508
Field Beans	3925 (3917)	3925 (3920)	504

Own calculations. Data from Bayerische Landesanstalt für Landwirtschaft. i=0.0675. Indemnity level of revenue insurance=0.9.

From Table 6 it can be seen that revenue insurance does not affect mean and variance of adjusted NPVs strongly. A slight decrease in mean and variance can be observed for most crops. Looking at the corresponding certainty equivalents with different levels of risk aversion, it first of all becomes apparent that all means, except for sugar beets with r_r=1, of organic crops with insurance lie higher than the ones without insurance. Additionally this difference is higher for higher levels of risk

aversion (compare r_r=4 to r_r=1). The difference is especially high when mean and variance are higher (see potatoes opposed to barley). This means that revenue insurance for organic crop farmers will make adoption more attractive, the higher variance of the crops revenue and risk aversion of the farmers. This result was already expected, as insurance helps to reduce downside risks and is therefore, the more effective, the more risky the crop and the more risk averse the farmer is. It is though interesting to see which effect natural hedge has on this result. Table 8 therefore displays the certainty equivalents for organic potatoes with and without insurance at different levels of natural hedge and a relative risk aversion coefficient of four ($r_r = 4$). This means very high risk aversion, and therefore a high efficiency of insurance.

Table 8. CEs for organic potatoes (in €/ha) with differing levels of natural hedge and r_r=4

Natural hedge	NPV organic	NPV organic + Insurance	Difference
-0.1	70795	70973	178
-0.2	70483	70656	173
-0.3	70170	70340	170
-0.4	69856	70021	165
-0.5	69539	69696	157

Own calculations. Data from Bayerische Landesanstalt für Landwirtschaft. i=0.0675. Indemnity level of revenue insurance=0.9.

One can clearly see that a more negative natural hedge reduces the efficiency of insurance, as the gap between the adjusted NPV for an uninsured and an insured potato farmer diminishes as the natural hedge becomes more negative. This confirms that natural hedge can be seen as a "natural insurance". Markets with such structures therefore have less need for revenue insurance.

5. Natural hedge in German agriculture

The theoretical effects of different natural hedge in organic and conventional agriculture on the adoption decision of organic farming have been modelled and simulated in chapters two to four. It has been found that an increase in natural hedge has a mean and variance decreasing effect and the effect of natural hedge on the adoption decision for risk averse farmers therefore relies on the magnitude of both and the risk aversion of the farmer. To evaluate which impact of natural hedge on the adoption decision can be assumed realistically, and if this effect is crop specific, the magnitude of natural hedge has to be analyzed. Natural hedge in organic and conventional agriculture has rarely been measured for Germany. This chapter therefore first evaluates and describes data for such an analysis, describes possible pitfalls in the analysis and finally gives an extensive analysis of natural hedge in Germany.

5.1 Descriptive data analysis

The chapter starts with a description of the data and a check if data fulfills expectations given in literature. The natural hedge is calculated for organic and conventional crops. Two data sets, on different aggregation levels (statewide and provincial level), were available for the analysis of natural hedge in Germany. The reason that two data sets on different aggregation levels were used is, that natural hedge was shown to differ substantially (Finger, 2012a), depending on the aggregation level. Data on farm level is therefore preferably used for the analysis. As this kind of data was not available, looking at solely provincial or state data may lead to misleading conclusions, whereas both data sets in combination provide a broader picture. The first data set consists of yield and price data for Germany, aggregated on a national level, from 1999 to 2013[9]. It is based on data collected in the Farm Accountancy Data Network (FADN)[10]. The Von-Thünen-Institut (VTI) then selected farms according to different criteria from the pool of organic and conventional farms, respectively. Averages of these "comparable groups" are then provided on a yearly basis, whereas their composition might change according to the characteristics of the pooled farms (for more information regarding the pooling procedure see Offermann et al. (undated). Data was available for wheat, rye, barley, potatoes, rapeseed and sugar beets. The second data set consists of yearly price and yield data for the province of Bavaria (located in the south of Germany) from 2001 to 2014. It is based on monthly reports of producer organizations for the price data and data from the statistical bureau of the province ('' Bayerisches Landesamt für Statistik und Datenverarbeitung'') for the yield data. The data is then processed and summarized by the institute for agriculture of the province ("Bayerische Landesanstalt für Landwirtschaft")[11]. Data for wheat, rye, barley, potatoes, sugar beets, maize and field beans was used. Looking at the data points, there seem to be some patterns and trends in the data, which suggests de-trending of the series. One finds especially low yields and high prices in period 2003/2004 and especially high yields and low prices in period 2009/2010 for most crops, both indications for a natural hedge. One would expect to find extreme weather conditions in these periods explaining this negative correlation between yields and prices.

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[9] Not for all crops data was available from 1999 on. Table 15 and
Table 16 in the appendix indicate the number of available observations per crop.
[10] Data is publicly available on ''http://www.bmelv-statistik.de/de/service/publikationen-und-archive/archiv-testbetriebsnetz-buchfuehrungsergebnisse/'' (accessed on 21.2.2015).
[11] The data is not publicly available and was kindly provided by the Bayerische Landesanstalt für Landwirtschaft.

This research focuses on differences in revenue risks, i.e. the natural hedge, between conventional and organic crops. Therefore mean, standard deviation, coefficient of variation and correlation coefficients for conventional and organic yields and prices from the given data series[12] will be compared. Furthermore these statistics will be compared to expectations given in literature. It is usually assumed (Seufert, 2012) that conventional agriculture is able to generate higher yields on average. The means of organic and conventional per hectare yields are therefore compared. The latter is expected to be larger. Another assumption regarding production, found in literature, is that organic agriculture is more risky in the sense that the farmer's tools to counter threats like diseases are limited compared to conventional agriculture (Smith et al., 2007). One would therefore expect to find more variation in organic agriculture per hectare yields than in conventional agriculture. Finally prices are expected to be higher for organic products due to price premiums for the producers. The mean of prices is therefore expected to be higher for organic crops.

First looking at per hectare yields of conventional crops one finds the mean to be higher than their conventional counterparts (see Table 15 and

Table 16). The lowest difference in yields was found for sugar beets. This criterion therefore meets expectations. Further looking at the coefficient of variation for per hectare yields of conventional crops, it shows to be lower for conventional crops as expected. One exemption is barley, where the organic barley shows a slightly lower coefficient of variation than conventional barley (as well as sugar beets in Bavaria). Finally looking at mean prices, the expectation of an organic price premium was met for all crops. Mean prices were though not as uniformly different between conventional and organic crops as mean yields. Whereas mean prices were only 37% higher for rapeseed, they were 216% higher for potatoes on a state level. This shows that there are most probably other important factors determining the price differences for organic and conventional crops apart from the yield gap. This could be cost components, market structures or policies. In summary the data behaved as expected, except for small exemptions. Mean yields for organic crops were lower and mean prices higher than for conventional crops. Organic yields also showed a higher variation. Looking at differences between German and Bavarian data one finds higher yields, as well as higher prices for the Bavarian crops. This might be explained by different fertility of the soil, climatic conditions, farm sizes or other factors explaining yields and different market structures, among others, for prices.

5.2 Methodology and pitfalls in analysis

This research aims to examine possible differences in correlation between organic and conventional crop yields and prices (the "natural hedge") in Germany, and relate findings to its influence on farmer's adoption decisions of organic farming. Correlation is a vague concept and may be defined in different ways. Most common measures are the Pearson correlation coefficient and non-parametric measures like Spearman's rho and Kendall's tau. Like Finger (2012) mentions, the Pearson correlation coefficient only measures linear relations and is sensible to outliers. Therefore additionally to the Pearson correlation coefficient Spearman's rho is calculated, which also accounts for non-linear relations. The results of these calculations will be discussed after addressing the issue of trends and aggregation bias in the data.

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12 Table 15 and
Table 16 summarize descriptive statistics for Germany and Bavaria.

Two important issues in the analysis of natural hedge are possible deterministic trends in the data and aggregation bias. Aggregation bias is a well-known problem in yield analysis on an aggregated level. It refers to the difference in yield variation on different aggregation levels. Yield variation is typically underestimated on higher aggregation levels (Finger 2012b). Reasons are differences in variation between farms or regions which level each other out. Finger (2012a) further investigated which effects aggregation bias has on the strength of the natural hedge. The idea of aggregation bias is extended and it is shown that larger farms show a stronger natural hedge. Facing the fact that this paper uses data on a national and a provincial level, results for the natural hedge therefore might not be quantitatively comparable to studies based on data on farm level. A qualitative comparison of natural hedge between conventional and organic crops however is possible. Variation in crop yields and prices over time can be influenced by deterministic and/or stochastic factors. Typical examples for crop yields are technological change as a mainly deterministic factor and weather fluctuations as a mainly stochastic factor (Conradt et al., 2012). For risk analysis only stochastic factors like weather fluctuations are of interest. It is therefore important to eliminate deterministic trends from the time series before correlation coefficients are calculated. The growing importance of organic agriculture in the last two decades might have led to trends due to technological advancement especially in this sector. This underlines the importance of de-trending in this regard. The here used procedure follows Conradt et al. (2012). Linear and quadratic models are estimated with an OLS estimator and compared. The best fitting models according to F-values are then used for de-trending. After de-trending a Breusch-Pagan test for homoscedasticity was performed, rejecting homoscedasticity only for one price variable. Robust standard errors were used accordingly. Pearson's correlation coefficient and Spearman's rho, representing the natural hedge, are then calculated for both aggregation levels. They are summarized in Table 9.

Table 9 Correlation coefficients for different crops and aggregation levels

		Pearson coefficient		Spearman coefficient	
		Germany	Bavaria	Germany	Bavaria
Wheat					
	Conventional	-0.38	-0.06	-0.42	-0.08
	Organic	-0.37	0.11	-0.46	0.14
Rye					
	Conventional	-0.21	-0.66	-0.25	-0.49
	Organic	0.50	0.02	0.63	-0.19
Barley					
	Conventional	-0.51	-0.34	-0.59	-0.35
	Organic	-0.68	-0.50	-0.32	-0.66
Potatoes					
	Conventional	-0.09	-0.55	-0.15	-0.52
	Organic	-0.78	-0.59	-0.70	-0.61
Sugar beets					
	Conventional	-0.48	0.35	-0.50	0.26
	Organic	0.04	0.85	-0.31	0.80
Rapeseed					
	Conventional	-0.57	na	-0.75	na
	Organic	-0.41	na	-0.46	na
Maize					
	Conventional	na	0.10	na	0.19
	Organic	na	0.77	na	0.59
Field Beans					
	Conventional	na	-0.03	na	-0.32
	Organic	na	-0.47	na	-0.18

Own calculations. Data from Von-Thünen-Institut (German FADN data found on http://www.bmelv-statistik.de/de/service/publikationen-und-archive/archiv-testbetriebsnetz-buchfuehrungsergebnisse/), and Bayerische Landesanstalt für Landwirtschaft (unpublished data for Bavarian agriculture. Na values indicate that data was not available.

5.3 Results

From the results it is apparent that price-yield correlation for some crops seems to be positive, which is not in line with the expectation of a negative natural hedge. There are several possible reasons why this is the case. Some markets might have special market structures due to the availability or lack of substitutes, the integration in the European or world market and/or dependencies on other large supplier or consumer markets. Second of all differences between Pearson and Spearman correlation coefficients are quite large. For such small sample sizes as used here the impact of outliers on the calculations can be significant. As the Pearson correlation coefficient is especially sensible to outliers it seems to be recommendable to mainly rely on Spearman's rho for the analysis. A negative price yield correlation points towards more local market structures. Artavia et al. (2010) postulated that yield variation in (conventional) German wheat, rapeseed and barley is not strongly

correlated to prices anymore as they are determined on the world market for liberalized countries. The data shows that Spearman's rho is negative for all conventional crops on state level, except organic rye. On provincial level this was not true for sugar beets and maize. Natural hedge on state level ranges from -0.75 for sugar beets to -0.15 for potatoes. On provincial level it ranges from -0.52 for potatoes to 0.26 for sugar beets. This already shows the large difference between an analysis on state and provincial level. Comparing natural hedge of conventional and organic crops it seems that for the majority of crops (rye, sugar beets, rapeseed, maize, field beans, and wheat in Bavaria) the correlation coefficient is more positive for organic crops than for conventional crops (results are therefore in line with Held and Bahrs, 2007).

As the difference between natural hedge of conventional and organic crops ("correlation gap") plays a key role in the theoretical analysis performed above, it is additionally tested if differences are statistically significant. The test used, implemented in R, is based on a Fisher transform, as suggested by Steiger (1980). The resulting z and p-values are reported in

Table 17 in the appendix. It becomes apparent that differences in natural hedge of organic and conventional crops are only significant at the 5% level for barley and the 10% level for potatoes on a state level, and are not significant at all on a provincial level. This seems surprising as differences seem to be large, given a first impression of the data. But sample sizes are also rather small (with a maximum of 15 observations), explaining the low significance. This and the large differences between the state and provincial level show that quantitative results can hardly be deduced from the given data sets. On-farm level data and longer time series would be needed for significant results. It though seems that the sign of the correlation gap is crop dependent. For the majority of crops correlation coefficients seem to be more positive for organic crops. In chapter 4 it has been found that a greater (positive) correlation has a mean increasing and variance (as well as semi-variance) increasing effect on the net present values of gross income. For the reasonable assumptions made about risk preferences and magnitude of data the effect on the mean outweighed the effect on the variance. The here performed analysis of natural hedge therefore points to the fact that adoption of organic farming is supported by the level of natural hedge in organic and conventional crops in Germany.

6. Discussion and conclusions

Analyzing natural hedge in conventional and organic agriculture is a topic that has received little attention so far. The growing market for organic produce has raised interest of researchers and policymakers in the conversion process from conventional to organic farming. For risk averse farmers differences in production risks play assumedly an important role in this decision. Natural hedge, i.e. the correlation of crop prices and yield, has been shown to have importance for risk management, as a natural risk management tool. The effect of differences in natural hedge on the conversion decision has though not been analyzed explicitly yet. The question therefore arises if natural hedge in conventional and organic agriculture differs, and if yes, which impact this difference has on the (production) risks of organic opposed to conventional agriculture and on the decision to convert to organic farming.

The farmer's conversion decision was modelled with a net present value investment model. A farmer chooses to convert if differences in NPV are larger than his investment costs in this model. Only prices and yields were modelled as stochastic, as there was evidence for only weak variation in the variable costs. Adjustment costs in the first years of conversion to organic farming were introduced. Aspects like non-monetary incentives, personal attributes or differing crop rotations in organic and conventional farming, which influence the conversion decision, were not considered, but focus was laid on the monetary aspects of conversion. This seems to be reasonable, since monetary aspects were found to be the main drivers of farmers conversion decisions in literature. Further the model was explicitly held simple to obtain straight forward insights on the effects of natural hedge on the conversion decision. A main problem in this field of the research is scarce availability of data on organic agriculture. The data found for German agriculture did not provide longer than 15-year time series of organic prices and yields on a national and a provincial (Bavaria) aggregation level. The approach chosen was therefore to assume that farmers in reality can also not rely on longer than 5-year time series, provided by Internet-portals like www.stmelf.bayern.de/idb (by the "Bayerische Landesanstalt für Landwirtschaft"), for their decision making. 5-years averages of crop prices and yields were therefore taken from www.stmelf.bayern.de/idb and used to 5000 times simulate net present values for the investment model, for a 20-year horizon. Relying on simulations of data based on only 5-years averages can be seen as a problem in analysis. Longer trends are not captured and averages might be different from long-term averages through recent shocks in the used data. Scarce availability of data though made the here used simulation the most feasible alternative. The assumption that farmers have to rely on shorter time series for their decisions in reality further seems to be reasonable. Especially when considering growing new (organic) crops, local experience is probably scarce and farmers have to rely on external data for decision making.

Expectations of the effect of changing natural hedge on mean and variance of outcomes were derived theoretically. A decreasing natural hedge is expected to lead to a decrease in mean and variance of outcomes. Simulating net present values of Bavarian crops (wheat, barley, rye, maize, sugar beets, potatoes and field beans) one finds that conversion seems to be attractive for barley, maize, potatoes and field beans, given the restrictions made. This is an interesting result as a starting point for further research. It would be interesting to investigate why these crops seem to be more attractive for conversion than other crops in Bavaria. Additional elaboration would though be needed, as the model used is simple in structure and does not consider various farm level characteristics, different cost structures or different cropping systems. The expectations for the

effect of natural hedge on mean and variance of net present values; formulated theoretically, hold in the simulations.

Risk aversion of farmers is a common assumption. Risk averse farmers (maximizing expected utility) prefer higher means and lower variances of outcomes. It was therefore interesting to see if the mean decreasing effect (reducing the mean of NPV's and therefore making the crop less attractive) or variance decreasing effect (reducing (revenue) risk of the farmer and therefore making the crop more attractive) of an increase in natural hedge would dominate for the given data. So far it was unclear if a more negative natural hedge would make a crop more attractive for the farmer. This was expected to depend on the magnitude of prices and yields, their variations and the decision makers risk aversion. Risk aversion was therefore introduced to the model with the help of an expected utility framework. The exponential utility function with diverging levels of risk aversion was used to model preferences of risk averse farmers, from normal to high risk aversion. Certainty equivalents of the derived net present values were compared for conventional and organic crops. Results show that for the crops simulated, the mean decreasing effect was dominating the variance (risk) decreasing effect for all levels of risk aversion evaluated. This means for the given data a more negative natural hedge decreased variance of net present values, making the crop more attractive. But at the same time the mean decreasing effect, making the crop less attractive, is dominating. Dominance though was weaker the more risk averse farmers were assumed to be. Concluding, attractiveness of crop options was reduced with more negative natural hedge in the given data (assuming risk aversion). This is a surprising result as one would expect a stronger natural hedge, as a natural risk management instrument, help increasing attractiveness of a crop option (especially for risk averse farmers). The model shows that this though depends on the magnitude of prices and yields and their variance and amplifies the view on possible effects of changes in natural hedge on the attractiveness of cropping options. Even though the model used is simple there seems to be no major reason why these results should not translate to more elaborate (cropping systems or farm) models.

One could argue that only downside risks in revenue or income are of concern for risk averse farmers. In a third step special attention was therefore paid to downside risks and insurances. A common instrument to reduce downside risks in income or revenues are insurances for farmers. Such insurances are already offered to farmers in countries as Canada or the USA. Revenue insurance with a fair insurance premium and an indemnity level of 0.9 was added to the model. Comparing three cases, namely conventional crops, organic crops and organic crops with revenue insurance, results of the simulation show that a risk averse farmer would rather adopt organic farming when insurance is offered than without insurance (differences are though not big enough to change the preference to convert or not convert to organic farming found for crops in the basic model). This result was already anticipated before, as risk aversion of farmers is assumed and insurances reduce risk. It is though interesting to relate this result to the magnitude of natural hedge. Simulation outcomes show that a more negative price-yield correlation can clearly be seen as a substitute for revenue or income insurances. One can therefore conclude that insurance options are more attractive for farmers, the more positive natural hedge is. This is a result which is fairly known, but has to be discussed in the given context. If an analysis of natural hedge for an agricultural sector or a group of crops points towards a more positive natural hedge, this means that insurance is especially effective in reducing downside risks for this sector. The introduction of insurance to make conversion to organic agriculture more attractive is therefore the more effective, the more positive natural hedge in organic agriculture is (and the more risk averse decision makers are).

In a fourth step the magnitude of natural hedge for conventional and organic German crops was examined. To tackle the issue of aggregation bias, which is a big problem in the analysis of natural hedge, data on the national level as well as on the provincial level (Bavaria) in Germany was analyzed. Available data sets were rather short. The longest time series available contains 15 observations. Expectations for the data, found in the literature, like higher yields in conventional agriculture than in organic agriculture, as well as more variation in yields and organic price premiums are met. Data was de-trended, possible heteroscedasticity taken care of and Pearson and Spearman correlation coefficients for price-yield correlations, i.e. the natural hedge, were calculated. Analyzing the natural hedge in Germany on provincial and national level one finds substantial, but non-significant differences between organic crops and their conventional counterparts. The non-significance of differences was due to the short length of time series for organic crops. Making the reasonable assumption that there will be no major differences in the determinants of natural hedge for organic and conventional crops in the close future in Germany, one can expect differences in natural hedge to persist and tests to become significant. A clear expectation before the analysis was that natural hedge is negative. Results though yielded positive coefficients for some crops. This is an unexpected result and might be explained by the small sample size, aggregation bias or special market structures (the national market might be strongly embedded in the European or world market and German prices therefore react to changes in the European or world market, independently from German harvest). Differences between estimates on provincial and national level are substantial for most crops, highlighting the importance of aggregation bias for the analysis. The correlation gap between organic and conventional agriculture is a key issue in this research and the determining factor in the theoretical model. For most crops analyzed natural hedge was more positive in the organic than in the conventional case. Relating to the results of the conversion model one can conclude that this favors adoption of organic crops in German agriculture. At the same time it means a relatively higher variance of net present values for organic crops and a higher attractiveness of insurances for organic farmers. This result may though only be seen qualitatively. Data availability was too constraining to achieve significant results.

Summarizing, one can state that natural hedge needs to be considered in research analyzing the conversion decision from conventional to organic farming and in the design of policies supporting conversion. The magnitude and direction of the effect of natural hedge on conversion depends on magnitude and variation of prices and yields, as well as risk aversion of the decision makers. For all analyzed crops a more negative price-yield correlation lead to a decreased attractiveness of the cropping option. This result still held when risk aversion of farmers was assumed. Relating reasoning from the theoretical part to real data can only be done qualitatively though, as the above stated obstacles and the ceteris paribus assumption prevent a direct translation. Especially the short time series available for organic crops make an assessment of the conversion decision and the influence of natural hedge on it difficult. Collection of production and market data for organic produce has though improved over the last two decades. This will make an analysis in the future more precise and statistically inference more valid. The here used model might still be used then and has the advantage that it can be extended to different cropping systems, subsidization schemes or personal and farm characteristics. For Germany there have been indications that natural hedge favors adoption of organic farming, as it is more positive for most organic than for conventional crops analyzed. At the same time natural hedge has been confirmed to be a substitute for (revenue) insurance. Given the results, revenue insurance for organic farmers could further increase the attractiveness of conversion to organic farming in Germany.

This research has raised many questions and possible topics for further research. A re-evaluation of natural hedge in Germany and its effects would make sense once longer time series are available. Then also quantitative effects of natural hedge on conversion could be derived. The used model could further be extended for differing cropping systems, farm and personal characteristics, different subsidization schemes or differing market structures. It further seems to be interesting to explore determining factors of natural hedge to further understand its influence. Finally it can be doubted that organic and conventional markets are totally independent. Natural hedge, prices and yields in both markets might therefore be related which would require an extended modelling approach.

References

Abadi Ghadim, A. K. (2000). Risk, uncertainty and learning in farmer adoption of a crop innovation. Unpublished PhD Thesis, Faculty of Agriculture, University of Western Australia, Nedlands, Western Australia.

Allais, M. (1984). The foundations of the theory of utility and risk. O. Hargen and F. Wenstrop (eds), Progress in Utility and Risk Theory, Reidel, Dordrecht, 3 –131.

Anderson, J. R., & Dillon, J. L. (1992). Risk analysis in dryland farming systems (No. 2). Food & Agriculture Org.

Artavia, M., Deppermann, A., Filler, G., Grethe, H., Häger, A., Kirschke, D., Odening, M. (2010). Ertrags- und Preisinstabilität auf Agrarmärkten in Deutschland und der EU. Vortrag anlässlich der 50. Jahrestagung der GEWISOLA „Möglichkeiten und Grenzen der wissenschaftlichen Politikanalyse", Braunschweig, 29.09-1.10.2010.

Atwood, J., Shaik, S., Watts, M. (2003). Are crop yields normally distributed? A reexamination. American Journal of Agricultural Economics, 85(4), 888-901.

Barnett, B. J. (2000). The US federal crop insurance program. Canadian Journal of Agricultural Economics/Revue canadienne d'agroeconomie, 48(4), 539-551.

Bohrnstedt, G.W. Goldberger, A.S. (1969). On the Exact Covariance of Products of Random Variables. Journal of the American Statistical Association 64 (328): 1439-1442.

Chavas, J. P. (2004). Risk analysis in theory and practice. Academic Press.

Conradt, S., Bokusheva, R., Finger, R., Kussaiynov, T. (2012). Yield trend estimation in the presence of non-constant technological change and weather effects. Paper prepared for the 123rd EAAE Seminar, Dublin, February 23-24, 2012.

El Benni, N., Finger, R. (2012). Where is the risk? Price, yield and cost risk in Swiss crop production. Selected Paper prepared for presentation at the International Association of Agricultural Economists (IAAE) Triennial Conference, Foz do Iguaçu, Brazil, 18-24 August, 2012.

European Commission (2013). Overview of CAP Reform 2014-2020. Agricultural Policy Perspectives Brief, No5*/December 2013.

Finger, R. (2012a). How strong is the natural hedge? The effects of crop acreage and aggregation levels. Paper prepared for the 123rd EAAE Seminar, Dublin, February 23-24, 2012.

Finger, R. (2012b). Biases in Farm-Level Yield Risk Analysis due to Data Aggregation. German Journal for Agricultural Economics 61(1), 30-43.

Gray, A. W., Boehlje, M. D., Gloy, B. A., Slinsky, S. P. (2004). How US farm programs and crop revenue insurance affect returns to farm land. Review of Agricultural economics, 26(2), 238-253.

Griliches, Z. (1957). Hybrid corn: An exploration in the economics of technological change. Econometrica, Journal of the Econometric Society, 501-522.

Grunert, K.G. (2005). Food quality and safety: consumer perception and demand. European Review of Agricultural Economics Vol. 32 (3), pp. 369–391.

Hardaker, J. B., Richardson, J. W., Lien, G., & Schumann, K. D. (2004a). Stochastic efficiency analysis with risk aversion bounds: a simplified approach. Australian Journal of Agricultural and Resource Economics, 48(2), 253-270.

Hardaker, J. B., Huirne, R. B., Anderson, J. R., & Lien, G. (2004b). Coping with risk in agriculture (No. Ed. 2). CABI publishing.

Held, J.-H. & Bahrs, E. (2007). Profit risks in organic farming. Jahrbuch der Österreichischen Gesellschaft für Agrarökonomie, Band 17, S. 37-47.

Just, R. E., & Weninger, Q. (1999). Are crop yields normally distributed? American Journal of Agricultural Economics, 81(2), 287-304.

Köpke, U. (1995). Nutrient management in organic farming systems: the case of nitrogen. Biological Agriculture & Horticulture, 11(1-4), 15-29.

Martini, E. A., Buyer, J. S., Bryant, D. C., Hartz, T. K., Denison, R. F. (2004). Yield increases during the organic transition: improving soil quality or increasing experience?. Field Crops Research, 86(2), 255-266.

Meuwissen, M. P., Huirne, R., Skees, J. R. (2003). Income insurance in European agriculture. EuroChoices, 2(1), 12-17.

Musshoff, O., Hirschauer, N. (2008). Adoption of organic farming in Germany and Austria: an integrative dynamic investment perspective. Agricultural Economics Vol. 39 (1), 135–145.

Nieberg, H., Kuhnert, H. & Sanders, J. (2011). Förderung des ökologischen Landbaus in Deutschland: Stand, Entwicklung und internationale Perspektive, 2. überarbeitete und aktualisierte Auflage. Sonderheft Nr. 347 der Schriftenreihe Landbauforschung. VTI Agriculture and Forestry Research.

Offermann, F., Sanders, J., Nieberg, H. (undated). Methodology for selecting organic and comparable conventional farms. Johann Heinrich von Thünen-Institut, Braunschweig.

Olesen, J. E., Olsen, P., Pedersen, L. (1996). Simulating nutrient balances in crop rotations. Aspects of Applied Biology (United Kingdom).

Padel, S. (2001). Conversion to organic farming: a typical example of the diffusion of an innovation?. Sociologia ruralis, 41(1), 40-61.

Pietola, K. S., Lansink, A. O. (2001). Farmer response to policies promoting organic farming technologies in Finland. European Review of Agricultural Economics, 28(1), 1-15.

Rabin, M. (2000). Risk aversion and expected-utility theory: A calibration theorem. Econometrica, 68(5), 1281-1292.

Roberts, W. S., Swinton, S. M. (1996). Economic methods for comparing alternative crop production systems: A review of the literature. American Journal of Alternative Agriculture, 11(01), 10-17.

Rinne, H. (1997). Taschenbuch der Statistik. 2. Aufl., Thun: Deutsch.

Schaack, D., Behr, H.-C., Rampold, C. (2013). AMI Markt Studie Strukturdaten im ökologischen Landbau in Deutschland 2012 – Bodennutzung, Tierhaltung und Verkaufserlöse. AMI, Bonn.

Schulze Pals, L. (1994). Ökonomische Analyse der Umstellung auf ökologischen Landbau. Münster: Landwirtschaftsverlag GmbH. Schriftenreihe des BMELF, Reihe A, Angewandte Wissenschaft, (436).

Seufert, V., Ramankutty, N., Foley, J. A. (2012). Comparing the yields of organic and conventional agriculture. Nature, 485(7397), 229-232.

Skees, J. R., Harwood, J., Somwaru, A., Perry, J. (1998). The potential for revenue insurance policies in the South. Journal of Agricultural and Applied Economics, 30, 47-62.

Smith, R. G., Menalled, F. D., Robertson, G. P. (2007). Temporal yield variability under conventional and alternative management systems. Agronomy journal, 99(6), 1629-1634.

Spahn, C., Richter, T., Cenkowsky, U., Haest, C., Schaer, B., Reisner, S. (2002). Der Fachhandel für Bioprodukte in Europa. Bad Wildbad.

Starmer, C. (2000). Developments in non-expected utility theory: The hunt for a descriptive theory of choice under risk. Journal of economic literature, 332-382.

Steiger, J. H. (1980). Tests for comparing elements of a correlation matrix. Psychological Bulletin, 87(2), 245.

Würriehausen, N., Ihle, R., Lakner, S. (2014). Price relationships between qualitatively differentiated agricultural products: organic and conventional wheat in Germany. Agricultural Economics.

Appendix I Numerical example

A simple numerical example for the effect of a change in the correlation gap (defined as the difference between conventional and organic natural hedge of a crop, as in equation 10) on mean and variance of the organic and conventional per hectare revenues is given here. Let the mean yield and price of the organic and the conventional crop be 100 dt/ha and 100 €/dt respectively. Let the variance of price and yield of the organic and the conventional crop be 1. Now let the natural hedge (price-yield correlation) for the conventional crop be 0.5, and let the natural hedge for the organic crop vary from 0.5 to -0.5 (in steps of 0.1), ceteris paribus. Expected means and variances of per hectare revenue are then calculated according to equation 7 and equation 8, see Table 10 for the results.

Table 10. Numerical example: means (€) and variances of revenue

	correlation	means	variances
conventional	0.5	10000.5	30001.25
organic	0.5	10000.5	30001.25
organic	0.4	10000.4	28001.16
organic	0.3	10000.3	26001.09
organic	0.2	10000.2	24001.04
organic	0.1	10000.1	22001.01
organic	0	10000	20001
organic	-0.1	9999.9	18001.01
organic	-0.2	9999.8	16001.04
organic	-0.3	9999.7	14001.09
organic	-0.4	9999.6	12001.16
organic	-0.5	9999.5	10001.25

Own calculations.

The correlation gap and differences in mean and variance (conventional minus organic) are then calculated accordingly, see Table 11 for the results.

Table 11.Numerical example: correlation gap, differences in mean (€) and variance

correlation gap	Δ mean	Δ variance
0.1	0.1	2000.09
0.2	0.2	4000.16
0.3	0.3	6000.21
0.4	0.4	8000.24
0.5	0.5	10000.25
0.6	0.6	12000.24
0.7	0.7	14000.21
0.8	0.8	16000.16
0.9	0.9	18000.09
1	1	20000

Own calculations.

One can now see what was indicated in section 2.3.: A higher correlation gap leads to a decrease in expected mean revenues and a decrease in expected variance of revenues. These are counteracting effects for a risk averse individual. It therefore has to be evaluated which effect dominates.

Appendix II Introducing risk aversion

Only comparing means of outcomes as an assessment of (investment) decisions is not in line with observed behavior. There is a broad body on literature describing that people in real life situations also value the distribution of outcomes. These can be distribution moments like variance, skewness and kurtosis additionally to the mean of outcomes. This though gives rise to two questions. How to observe and describe such behavior, and how to implement it in modelling. It is obvious that such a model will never fit behavior of every individual, as individuals show different preferences towards risk.

The concept of expected utility provides an easy and intuitive way to describe and model risk preferences. Assuming the random variable "a" represents an stochastic amount of money reward, i.e. a "risky gamble". This can for example be the expected magnitude of returns of harvest for two possible states of weather (occurring with a given probability). Additionally "w" is often added to the stochastic variable a. W is a non-stochastic variable and represents a certain level of wealth at which the risky gamble is evaluated. This is meant to show that risk perception might change with different levels of wealth. Where wealth might stand for any level of value at stake. Whereas expected values $E(w + a)$ were compared in the expected value approach, now expected utility outcomes $EU(w + a)$ are compared. U() is a von Neumann-Morgenstern utility function representing the decision makers preferences. The difference in the two evaluation techniques lies in the fact that in expected utility theory values are transformed into utils before their expectation is taken. This transformation therefore resembles how the decision maker values certain amounts of reward, and therefore determines his risk preferences. A certainty equivalent (CE) is defined as the sure amount of money which gives the same amount of utility as the risky gamble, so that the following equation is fulfilled:

(14) $U(CE) = EU(w + a)$

Given the standard case of risk aversion, one would use a concave utility function to resemble the decision makers preferences. This implies that the difference between the expected value and the certainty equivalent is positive. This difference is called risk premium (RP) as it resembles how much of the expected value of the risky gamble the decision maker is willing to give away to eliminate all uncertainty, and is positive for risk averse individuals:

(14) $E(w + a) - CE = \mathrm{RP}$

Expected utility theory therefore describes a way how to evaluate the expected value of a stochastic reward in decision making, but also provides a way to value the distribution of the value at stake in the decision makers decision. It is common to use the certainty equivalent to compare stochastic rewards, as it is measured in real life units, such as euros, instead of utils, like expected utility.

The problem remains how to model and measure risk preferences. In the expected utility framework the von Neumann-Morgenstern utility function plays a central role in determining the decision makers preferences. Such a utility function can take various shapes (convex, concave, linear). This in turn determines how values are transformed and if the risk premium is negative (risk loving), positive (risk aversion) or zero (risk neutral). The preference towards risk is therefore determined by the utility function. A more precise picture of the nature of risk preferences (dependency on levels of wealth, magnitude) determined by the utility function though is necessary to describe a decision

makers behavior. A measure commonly used is the absolute coefficient of risk aversion or Arrow-Pratt coefficient of risk aversion (r_a). Let U() be the utility function used, then the absolute coefficient of risk aversion is defined as:

$$(15)\ r_a = - \frac{U(a)''}{U(a)'}$$

Whereas the relative coefficient of risk aversion (r_r) is defined as:

$$(16)\ r_r = r_a * a = - \frac{U(a)''}{U(a)'} * a$$

In applied work a is usually evaluated at its mean value (optionally ($w+a$) is also used, where w is some level of wealth at which the risky gamble is evaluated). The change of the absolute coefficient of risk aversion with respect to a determines if the utility function used has CARA (constant absolute risk aversion), DARA (decreasing absolute risk aversion) or IARA (increasing absolute risk aversion) properties. It resembles how risk aversion changes with increases in a. Whereas CARA properties are more practical for empirical work, DARA properties are often observed in reality. The same concept exists for the relative coefficient of risk aversion. Its derivative with respect to a leads to a partition of utility functions into CRRA (constant relative risk aversion), DRRA (decreasing relative risk aversion) and IRRA (increasing relative risk aversion).

The utility function used in this research is the exponential utility function:

$$(17)\ U(a) = e^{-a*r_{a,i}}.$$

with CARA and IRRA properties (computed given equations 15 and 16). An especially useful property of the exponential utility function is that the degree of risk aversion can easily be changed as the coefficient of absolute risk aversion enters in the exponent. Using results from Anderson and Dillon (1992), who described the degree of risk aversion of decision makers for different levels of the coefficient of relative risk aversion, one can, in applied work, easily switch from a utility function resembling "normal risk aversion (rr=1)" to one with "high risk aversion (rr=3)", for example. The specific coefficient of relative risk aversion just needs to be transformed into the coefficient of absolute risk aversion, using equation 6. This makes the exponential utility function especially suitable for this research as results can easily be computed for different levels of risk aversion.

Appendix III Tables and Figures

Table 12. Shapiro-Wilk tests for normality – p-values and sample sizes

	Conventional				Organic			
	Yields	n	Prices	n	Yields	n	Prices	n
Wheat	0.39	10	0.29	10	0.59	10	0.07	10
Barley	0.69	10	0.17	10	0.83	10	0.71	10
Rye	0.90	10	0.35	10	0.56	10	0.48	10
Maize	0.67	14	0.07	14	0.11	10	0.13	11
Sugar beets	0.39	6	0.82	6	0.63	4	0.32	4
Potatoes	0.86	10	0.15	10	0.95	10	0.23	10
Field Beans	0.02	13	0.12	12	0.15	10	0.048	11

Data from Bayerische Landesanstalt für Landwirtschaft. Calculations performed with R. Highlighted fields indicate that normality has to be rejected.

Table 13. Certainty equivalents for $r_r=2$

Natural hedge	Wheat	Barley	Rye	Maize	Sugar beets	Potatoes	Field Beans
-0.1	5325	1980	1279	7354	15384	71109	3953
-0.2	5304	1976	1263	7355	15378	70787	3945
-0.3	5286	1973	1246	7345	15371	70464	3936
-0.4	5269	1971	1230	7333	15365	70138	3928
-0.5	5253	1968	1213	7318	15359	69808	3920

Own calculations. Data from Bayerische Landesanstalt für Landwirtschaft. i=0.0675.

Table 14. Certainty equivalents for $r_r=3$

Natural hedge	Wheat	Barley	Rye	Maize	Sugar beets	Potatoes	Field Beans
-0.1	5305	1961	1205	7310	15349	70795	3946
-0.2	5285	1958	1189	7311	15343	70483	3938
-0.3	5268	1955	1173	7303	15337	70170	3930
-0.4	5251	1953	1156	7291	15331	69856	3922
-0.5	5236	1950	1140	7278	15325	69539	3914

Own calculations. Data from Bayerische Landesanstalt für Landwirtschaft. i=0.0675.

Table 15 Descriptive statistics for yearly, aggregated German crop yield and price data from 1999-2013

			n	mean	standard deviation	coefficient of variation
Wheat						
	Yield	Conventional	15	65.5	3.93	0.06
		Organic	15	35.3	2.21	0.06
	Price	Conventional	15	13.9	4.21	0.30
		Organic	15	30.6	6.43	0.21
Rye						
	Yield	Conventional	9	51.2	4.90	0.10
		Organic	9	26.2	4.02	0.15
	Price	Conventional	9	9.5	1.10	0.11
		Organic	15	24.8	6.22	0.25
Barley						
	Yield	Conventional	15	56.0	3.90	0.07
		Organic	9	30.6	1.62	0.05
	Price	Conventional	15	12.8	3.41	0.27
		Organic	9	21.2	3.24	0.15
Potatoes						
	Yield	Conventional	15	341.8	40.94	0.12
		Organic	15	192.8	30.15	0.16
	Price	Conventional	15	10.4	2.04	0.20
		Organic	15	33.1	9.80	0.30
Sugar beets						
	Yield	Conventional	13	594.6	59.40	0.10
		Organic	13	537.1	59.21	0.11
	Price	Conventional	13	4.6	0.72	0.16
		Organic	13	7.9	1.28	0.16
Rapeseed						
	Yield	Conventional	15	34.2	3.95	0.12
		Organic	15	18.6	5.74	0.31
	Price	Conventional	15	26.6	9.17	0.34
		Organic	15	36.4	11.78	0.32

Own calculations. Data from Von-Thünen-Institut. All time series end in 2013. Shorter series than 15 years start earlier than 1999, accordingly.

Table 16 Descriptive statistics for yearly, aggregated Bavarian crop yield and price data from 2001-2014

			n	mean	standard deviation	coefficient of variation
Wheat						
	Yield	Conventional	10	71.8	4.63	0.06
		Organic	10	40.8	3.21	0.08
	Price	Conventional	10	17.6	5.33	0.30
		Organic	10	36.4	7.39	0.20
Rye						
	Yield	Conventional	10	51.8	6.65	0.13
		Organic	10	35.6	4.95	0.14
	Price	Conventional	10	15.3	5.84	0.38
		Organic	10	29.2	9.75	0.33
Barley						
	Yield	Conventional	10	58.9	3.24	0.06
		Organic	10	34.3	1.81	0.05
	Price	Conventional	10	14.0	4.60	0.33
		Organic	10	29.1	7.31	0.25
Potatoes						
	Yield	Conventional	10	410.1	43.08	0.11
		Organic	10	239.2	28.44	0.12
	Price	Conventional	10	13.5	6.64	0.49
		Organic	10	45.2	14.00	0.31
Sugar beets						
	Yield	Conventional	6	751.2	62.83	0.08
		Organic	4	484.5	32.81	0.07
	Price	Conventional	6	4.4	0.83	0.19
		Organic	4	8.2	0.69	0.09
Maize						
	Yield	Conventional	14	95.7	9.71	0.10
		Organic	10	62.5	9.28	0.15
	Price	Conventional	14	14.3	4.53	0.32
		Organic	11	31.7	6.45	0.20
Field Beans						
	Yield	Conventional	13	34.8	3.02	0.09
		Organic	10	32.6	3.92	0.12
	Price	Conventional	12	14.7	4.84	0.33
		Organic	11	37.2	9.04	0.24

Own calculations. Data from Bayerische Landesanstalt für Landwirtschaft. All time series end in 2014. Shorter series than 14 years start earlier than 2001, accordingly.

Table 17 Significance test for differences in correlation coefficients: z and p-values

		z-value	p-value
Wheat			
	Germany	0.14	0.89
	Bavaria	-0.40	0.69
Rye			
	Germany	-1.98	0.05
	Bavaria	-1.04	0.30
Barley			
	Germany	-0.83	0.41
	Bavaria	0.74	0.46
Potatoes			
	Germany	1.89	0.06
	Bavaria	0.34	0.73
Sugar beets			
	Germany	-0.52	0.60
	Bavaria	-1.14	0.26
Rapeseed			
	Germany	-1.20	0.23
	Bavaria	na	na
Maize			
	Germany	na	na
	Bavaria	-1.12	0.26
Field Beans			
	Germany	na	na
	Bavaria	-0.35	0.72

Own calculations. Data from Von-Thünen-Institut (data for Germany) and Bayerische Landesanstalt für landwirtschaft (data for Bavaria). Na values indicate that no data was available.
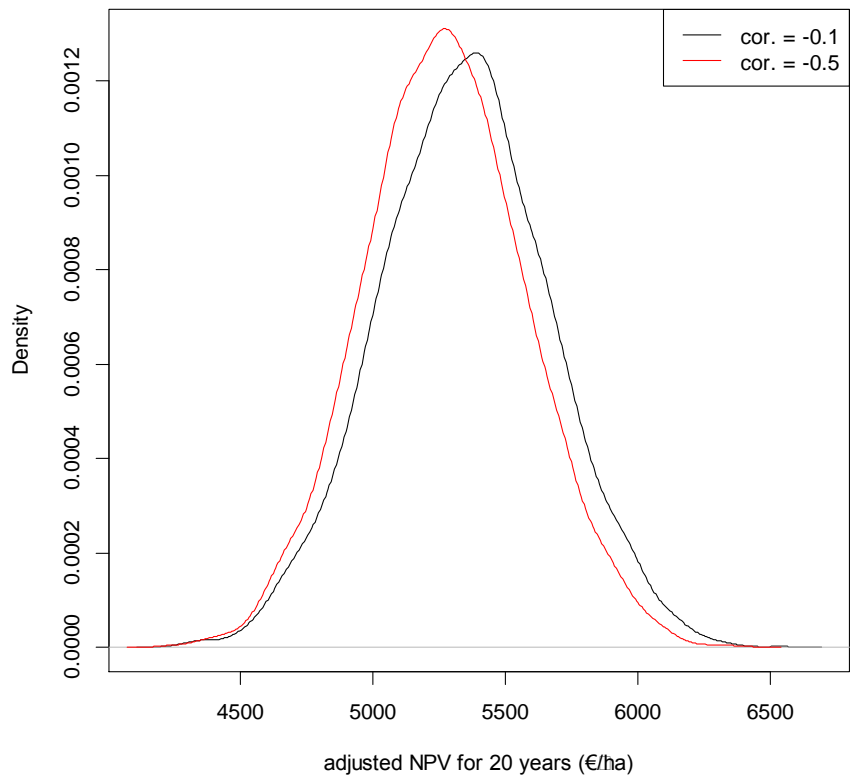
Figure 1 Pdf's of simulation runs for organic crops

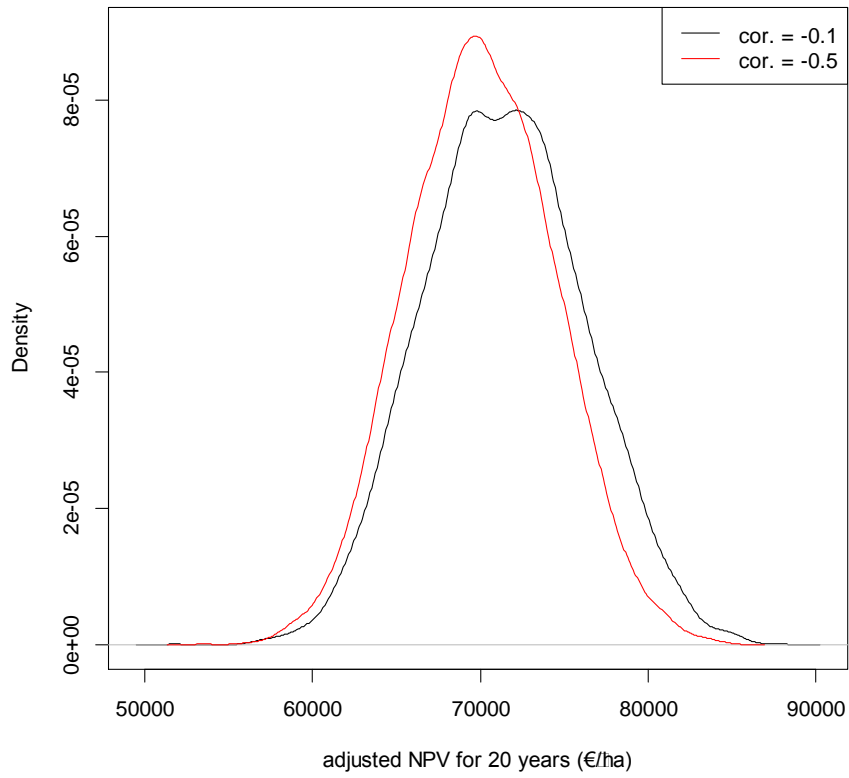**PDFs of NPV distribution of barley with different natural hedge**

adjusted NPV for 20 years (€/ha)
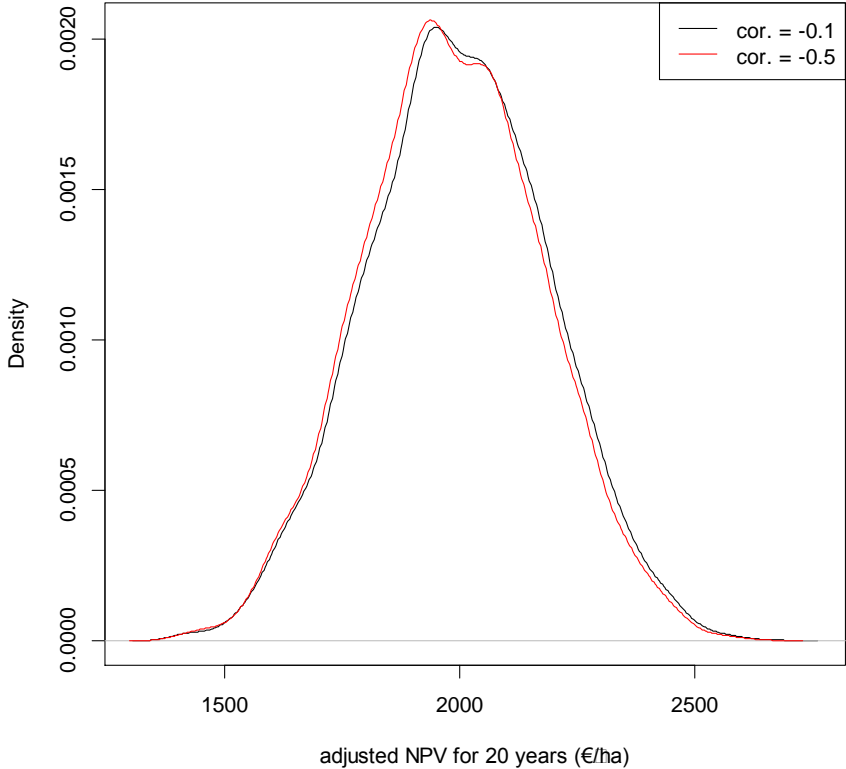
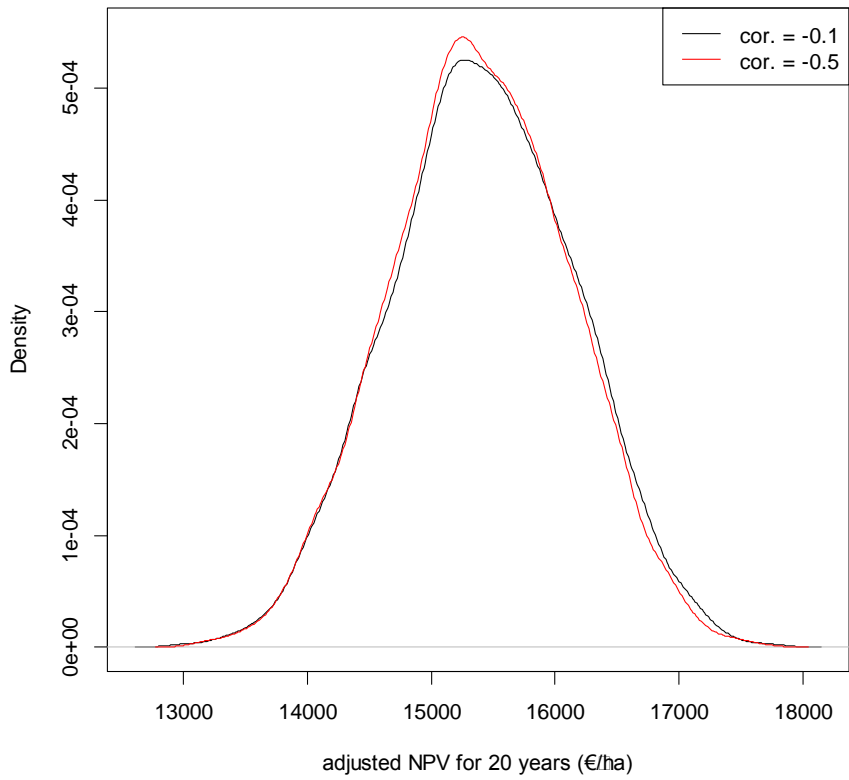**PDFs of NPV distribution of rye with different natural hedge**
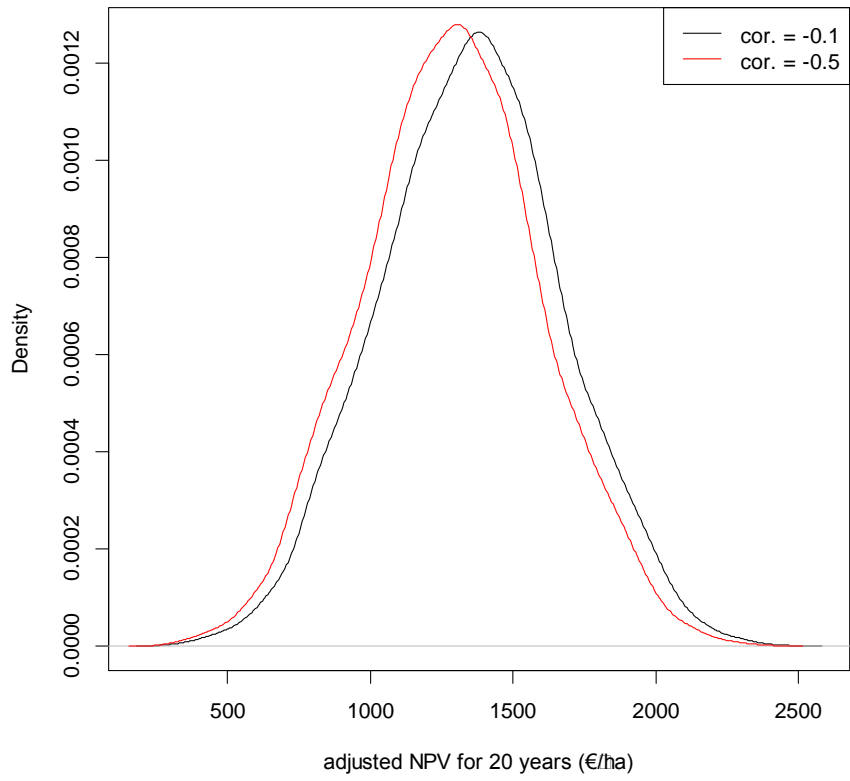
PDFs of NPV distribution of wheat with different natural hedge
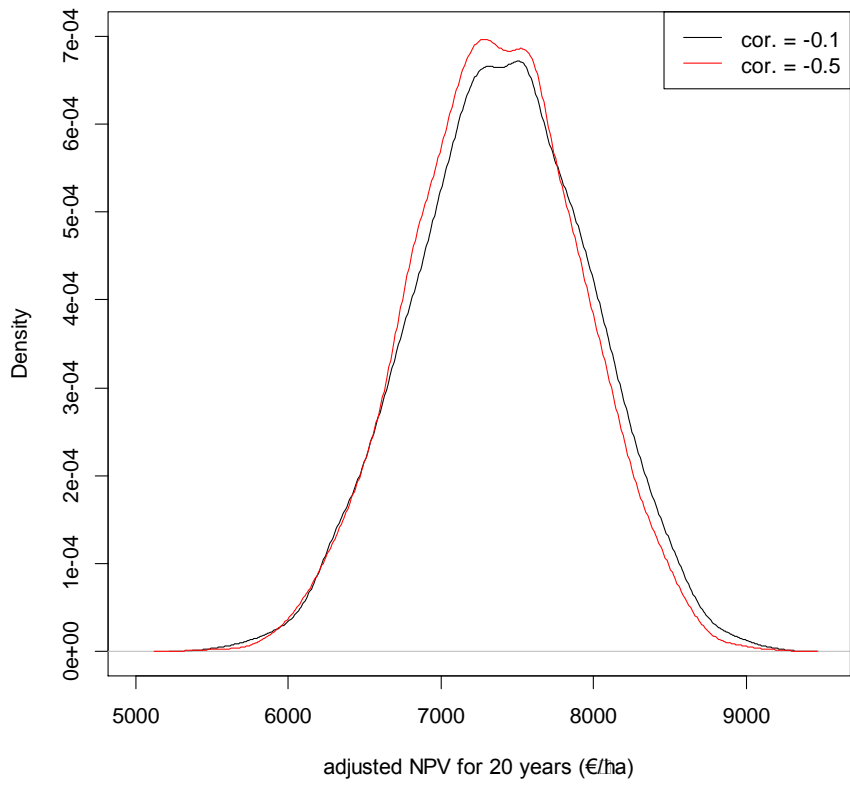
PDFs of NPV distribution of potatoes with different natural hedge

PDFs of NPV distribution of sugar beets with different natural hedge

PDFs of NPV distribution of maize with different natural hedge

PDFs of NPV distribution of field beans with different natural hedge