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Efficient farming options for German apple growers under risk – a stochastic dominance approach

RESEARCH ARTICLE

Maren B.K. Röhrig[a], Bernd Hardeweg[b], and Wolfgang Lentz[c]

[a]*Research Associate and* [b]*Researcher, Center for Business Management in Horticulture and Applied Research, Institute of Horticultural Production Systems, Leibniz University of Hanover, Herrenhäuser Straße 2, 30419 Hanover, Germany*

[c]*Professor, Faculty of Agriculture/Environment/Chemistry, University of Applied Sciences Dresden (HTW Dresden), Pillnitzer Platz 2, 01326 Dresden, Germany*

Abstract

For a sustainable economic performance of apple production, the determination of efficient farming options considering production risk is crucial. Relying on a permanent crop, apple producers are less flexible to react upon disturbances. Based on data of 134 apple producers operating in the two main production areas in Germany, we compare and determine efficient production options. Furthermore, appropriate risk management instruments (RMIs) are identified using stochastic dominance criteria. In addition, we use Stochastic Efficiency with Respect to a Function to evaluate farming options for defined ranges of relative risk aversion. The results indicate that Red Prince is the most efficient variety in the north and subsidized hail insurance with frost irrigation is superior to frost irrigation as single RMI. In the south Braeburn should be chosen by rational decision makers, but the tested insurance solutions are not as efficient as the common practice of producing apple under hail nets.

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JEL code: Q54, Q58, Q15

Corresponding author: roehrig@zbg.uni-hannover.de

1. Introduction

Apple production is a challenging business. Aspects of pests and diseases, changing market demands as well as weather conditions and volatile prices are predominant sources of risk, which have to be considered during the planning phase of an apple orchard (Catalá *et al.,* 2013; Menapace *et al.,* 2013). Due to the high complexity, this article focuses on the latter two issues of farm planning for apple production, as they represent two of the key risks (Ahmed and Serra, 2015).

Farmer organizations have repeatedly pleaded for state subsidization of multi-peril insurance for fruit production. The debate was revived most recently by the occurrence of unusually strong late frosts in April 2017 inflicting severe damage on fruit and wine production especially in Southern Germany. The debate is often based on incidental information and – even when referring to risk – mostly ignores the nature of risk, which may be due to the complexity of the phenomenon and lacking data. This paper contributes to closing this gap for apple production. Therefore, farmers' risk perception is compiled and distributions of the net present value (NPV) of different risk management strategies for apple production are calculated. The results indicate that a multi-peril insurance even with subsidies is dominated by other combinations of risk management instruments (RMIs). This explains the relatively low adoption of frost insurance in Southern Germany and provides evidence in favor of market-based solutions without government interference.

For German apple growers, available risk management strategies to cope with weather-related risks are hail nets and frost irrigation. In the north of Germany subsidies for these risk management strategies are not available, whereas in the south hail nets are subsidized up to 50% by producer organizations (Dirksmeyer *et al.,* 2014: 59-60). In addition, hail insurance that protects against revenue loss is available in both regions. For hail insurance, no governmental subsidy schemes exist (Bielza Diaz-Caneja *et al.,* 2009). Even if producer organizations subsidize insurance policies, farmers, especially in the south of Germany, often decide not to participate in hail insurance, as high premium rates are common.

Political programs to support apple growers in reducing risk require information on farmers' risk behavior. According to the subjective expected utility framework, risk perception besides risk preference, is the main factor determining risk behavior. The former is the probability an individual associates with a particular uncertain situation and the likelihood to be susceptible to a specific event (e.g. Pennings *et al.,* 2002). Knowledge of apple producers' risk perceptions provides essential information for the development of political programs (Menapace *et al.,* 2012).

Deterministic crop budgets for an economic assessment of apple production systems in Germany are available (KTBL, 2010). However, no information is available on which risk management strategies are the most promising ones and whether new strategies, for instance combined frost-hail insurances, could provide appropriate instruments for apple growers in Germany. This article aims to evaluate combinations of different production systems (i.e. choice of variety and planting density) and RMIs according to their economic performance under different levels of apple growers' relative risk aversion. The insights are also of political relevance as calculations of agricultural policy measures often rely only on cost-benefit analyses, based on weighted average values in terms of money and do not consider the effect of risk aversion. As a result, inappropriate conclusions are drawn when designing risk mitigation programs (Kaufman, 2014). For an in-depth risk analysis, a survey assessing perceived risk of German apple farmers in the two most important production regions (Altes Land, Lower Saxony and Lake Constance) has been conducted. After combining the data obtained from this survey with historical information stochastic dominance relations were applied in order to determine appropriate farming strategies.

2. Literature review

Up to now only a very limited number of studies deal with apple growers' behavior towards risk in industrialized countries. Menapace *et al.* (2014) analyzed risk perception of apple farmers in Italy in the context of climate change hazards at province level. For a long-term perspective of twenty years, respondents believing in climate change stated significantly higher probabilities for suffering from weather and disease related effects, than non-believers, whereas perceptions for the short-term view did not differ significantly (Menapace *et al.,* 2014). Results of their survey further indicate a strong effect of different heuristics in farmers' decision making processes. These are mental simplifications which reduce the complexity within decision-making processes. A significant effect was observed for availability heuristics (use of experience from the past for future decisions), representativeness heuristics (alignment of unfamiliar events with familiar ones) and biased assimilation (preexisting attitudes that lead persons to acquire indications which support their opinion and to reject indications against it) (Menapace *et al.,* 2012).

For conventional and organic apple production in the Pacific Northwest of the U.S. Chen *et al.* (2007) compare the risk reduction properties of a multi-peril crop insurance covering yield shortfalls to an income-based insurance, focusing on deviations of income as a product of yield and prices. Their analysis is based on historical price and yield data. In the context of government subsidies, they find, that an income-based insurance would be more cost efficient than multi-peril crop insurance. However, as the associated certainty equivalents (CE) reveal, the income-based insurance provides a lower welfare, with only one variety-dependent exception (Chen *et al.,* 2007).

The use of historical data as the single source for probability estimates is, however, not advisable for risk analysis that addresses an uncertain future. The predictions may be insufficient, because underlying circumstances might change over time. Therefore, an appropriate risk analysis should include subjective probability estimates as well (Hardaker *et al.,* 2004: 62-63; Lien *et al.,* 2011). The historical data approach (Hardaker *et al.,* 2004: 80-82) allows one to combine historical data and the farmers' subjective probability estimates to reproduce the correlation structure and therefore to account for stochastic dependencies (Hardaker *et al.,* 2004: 168-169). Lien and Hardaker (2001) use this technique to evaluate the appropriateness of different subsidy schemes for the Norwegian agricultural sector with a utility-efficient programming model and Lien *et al.* (2011) apply it for the calculation of gross margins of a typical Norwegian lowland farm.

For capturing risk, it is recommended to work with probability distributions (Hardaker, 2000; Lien, 2003). Clancy *et al.* (2012) use a stochastic budgeting model in their work. In comparison to deterministic models, this approach is more appropriate to consider various uncertainties, as for example volatile prices, yields, costs and weather conditions, all factors, which are simultaneously affecting revenues and profits in farmers' reality. For all variables of interest, stochastic budgeting assigns probabilities to values, resulting in probability distributions (Clancy *et al.,* 2012; Lien *et al.,* 2007a).

Ranking farming options according to their efficiency under consideration of the associated cumulative density functions (CDF) and underlying farmers' risk attitudes may be achieved by applying Stochastic Dominance (SD) criteria, Stochastic Dominance with Respect to a Function (SDRF) or Stochastic Efficiency with Respect to a Function (SERF). Presuming a positive marginal utility, a ranking based on First Degree Stochastic Dominance (FSD) is appropriate, if CDFs do not cross. If the condition $F_a(x) \leq F_b(x)$ for all x with at least one strict inequality is met, farming option a dominates option b independently of the underlying risk attitude. However, if an intersection exists, Second Order SD (SSD) needs to be applied. It requires risk aversion for all values of x, which means that the associated utility function is positive with a decreasing slope. Under SSD option a dominates option b if $\int_{-\infty}^{x^*} F_a(x)dx \leq \int_{-\infty}^{x^*} F_b(x)dx$ for all x* with at least one strict inequality (Hardaker *et al.,* 2004: 147-150; Smidts, 1990: 125-126). Similar to SSD, where limits regarding risk attitude (r) are set as $0<r<\infty$, SDRF defines also positive, but more restrictive boundaries for risk attitude ($r_1<r<r_2$), which allows a stricter discrimination (Hardaker *et al.,* 2004: 153). Harper *et al.* (2013) apply SDRF for an evaluation of apple varieties, namely Crimson Gala, Ginger Gold and Fuji, as well as training

systems with respect to their associated net returns for an eight year harvest period. Data for the analysis were obtained during a ten-year field experiment in Pennsylvania (USA). They observe that higher net returns are afflicted with higher risk. SDRF analysis further indicates that growers, independent of their risk attitude, prefer Fuji as cultivar (Harper *et al.,* 2013).

For SERF-analysis values of a utility function are converted by the inverse utility function into CE for a given range of risk aversion coefficients. CEs have the advantage that they can be expressed in monetary terms. The CE is the sure payment which provides the same utility as a risky prospect (Hardaker *et al.,* 2004: 153-155; Lien *et al.,* 2007a). Similar to SDRF, SERF relies on a range of risk aversion coefficients, but with the additional assumption that parameters of risk aversion remain constant for varying levels of payoffs (Hardaker and Lien, 2010). Recently, Schenk *et al.* (2014) applied SD as well as SERF for assessing Australian farmers' decision making concerning crop-choice, focusing on five arable crops and pasture, given uncertain amounts of water supply. Similarly, Clancy *et al.* (2012) considered the previously mentioned methods for their evaluation of the economic efficiency regarding biomass crops in Ireland.

Up to now investment decisions for apple growers in Germany have not been analyzed considering the main sources of risk, different risk management tools and alternative risk protection strategies. The objective of this study is therefore to determine the most efficient farming options by applying stochastic dominance criteria and SERF to data of net present values (NPVs) for investments in apple orchards.

3. Data and methods

To obtain a stochastic ranking of farming options, the deterministic budget is extended in order to calculate cumulative distribution functions (CDFs) of the NPV for apple orchard investments. The NPV is calculated over 16 years of full bearing for a combination of one hectare of a certain variety and the respective risk management strategies by summing up the discounted net cash flows simulated for each year. The juvenile phase of the orchard in the initial three years after planting is considered as a deterministic component of the NPV. For risk ranking, stochastic dominance criteria are subsequently applied to the CDFs.

3.1 Survey sample

Apple production on owner-operated farms in Germany is concentrated in two regions, the Altes Land, located in the north at the mouth of the river Elbe, and the Lake Constance area in the south near the Alps. As the distance between these areas amounts to 900 kilometers, climatic conditions are different. In the north especially late frosts lead to higher yield and quality reductions, whereas in the south hail events are more frequent and pose a major risk to fruit quality.

During the winter season 2013/2014, the apple growers were first contacted by local extension and research stations. A number of 500 growers in each region received an invitation letter or a call for participation in the newsletter of producer organizations. Starting with 16 volunteers in the north and 3 in the south, a pyramid scheme was used to acquire further participants. In the end, data of 66 farmers from the north and 68 from the south were collected through two-hour face-to-face interviews. Besides information on farmers' risk perception, details on their risk attitude were obtained.

3.2 Elicitation of subjective probabilities

For the elicitation of probabilities, the estimation of probabilities based on the experience technique was applied, as it only requires three values and in consequence, represents one of the simplest question frameworks (Hoag, 2010: 212-213). However, only estimations of yield under normal conditions were successfully elicited with this technique, resulting in a Program Evaluation and Review Technique (PERT) Distribution. In contrast, when focusing on losses and quality reductions due to weather related risks as well as prices, the pretest revealed, that farmers do not feel comfortable to assign a minimum, maximum and modal value. As applied in the work of Menapace *et al.* (2013), the fixed value method was used in this study in order to assess distributions. To achieve a reduction in bias, farmers were asked to recall the frequency of occurrence for different events in the past 10 years, before they stated their estimates for the upcoming decade in both frameworks. A time interval of ten years was set, since longer time intervals might result in a lower willingness to participate and a decline in attention during the interview. After recapitulation of the past, farmers were asked to indicate their expectations for the upcoming production years by allocating ten years to given intervals of losses and prices, respectively. These absolute frequencies were converted into relative ones and the midpoints of the given intervals were used for further calculations. In order to evaluate the preventive effect of RMIs, apple growers were asked to give their estimates for all circumstances, i.e. under absence and existence of the RMIs. An example is given in Figure 1.

3.3 Parameter setting for Stochastic Efficiency with Respect to a Function

SERF analysis requires the choice of a utility function, which is not a trivial task. With focus on terminal wealth constant relative risk aversion (CRRA) is recommended as it is unaffected by different levels of wealth. In contrast, constant absolute risk aversion is more convincing for transitory income, which is relatively small in relation to wealth (e.g. Hardaker and Lien, 2010). As apple farms in Germany are less diversified and wealth is predominantly determined through a long term success of the orchard, CRRA will be used in this study, represented by the following functional form of utility (Equation 1).

$$U = \frac{1}{1 - r_{r(W_T)}} W_T^{(1-r_{r(W_T)})}, \; W_T > 0 \tag{1}$$

Where
W_T is total wealth
$r_{r(W_T)}$ is relative risk aversion related to total wealth

Please state the number of years in which yield losses occurred due to hail by focusing on the last ten years:
____ No. of years

Your expectation for the next ten years:
How often will hail lead to the following losses (%).
Please allocate ten years to the given intervals:

Loss due to hail (%)	**Absolute (estimation)**	**Relative (calculated)**
0	7	0.7
1-4		
5-9		
10-19		
20-29		
30-39	2	0.2
40-49		
50-59		
60-69		
70-79	1	0.1
80-89		
90-100		

If your expectation is based on the existence of hail nets, which losses would you expect under the absence of hail nets?

Loss due to hail (%)	**Absolute (estimation)**	**Relative (calculated)**
0	5	0.5
1-4		
5-9		
10-19		
20-29		
30-39		
40-49		
50-59		
60-69		
70-79		
80-89		
90-100	5	0.5

Figure 1. Application of the fixed value method related to the survey design.

CRRA implies constant relative risk aversion and in consequence decreasing absolute risk aversion as the absolute amount of money for risk-investments increases with increasing wealth, whereas the relative proportion remains constant.

As described in Lien *et al.* (2007b) the total wealth is assumed to be $W_T=W_0+W_s$. Where W_0 is the non-stochastic wealth, equaling 45,000 € per hectare, and W_s is the stochastic wealth of apple production.

Even if the simulation is based on a one hectare level, which is relatively small compared to whole-farm wealth, annual gain from one hectare is seen as a permanent source of income. Upscaling of the area planted leads to a large portion of terminal wealth and thus, the relative risk aversion coefficient is assumed to be constant (cf. Hardaker *et al.,* 2004: 112).

The range of risk aversion coefficients of 0 to 3.00 is set according to the results of the risk attitude analysis. Risk attitude was elicited with a hypothetical, farm profit-framed Holt and Laury lottery, originally pioneered by Holt and Laury (2002). About half of apple growers exhibited risk aversion, characterized by risk aversion coefficients above zero (Table 1). In this paper we follow a normative approach in order to give advice how risk averse farmers should behave under uncertainty. Thus, only data of risk averse farmers are provided. In this context, 38% of risk averse apple growers can be described as nearly risk neutral with risk aversion coefficients close to zero, whereas the others indicated stronger tendencies to risk averse behavior.

3.4 Description of the model and calculation of key variables

The risk model was developed in MS Excel (Microsoft Corporation, Redmond, WA, USA). Regarding the key variables of the model, parameters, which are substantial risky determinants of revenue, were set as stochastic ones (cf. Clancy *et al.,* 2012). As reported by Bravin *et al.* (2009), yield and quality have an important impact on farm profit, whereas production costs are less important. Therefore, it was decided to treat production costs (except for those proportional to yield) as deterministic variables, which can be taken from the literature (KTBL, 2010), whereas yield and quality under non-hazardous conditions of production, as well as prices and weather related impacts, i.e. frosts, hail and sunburn, are considered as stochastic variables. In addition, the event of fire blight (*Erwinia amylovora*), a bacterial infection, is included as a stochastic variable in the simulation as a rare but severe event. After combining historical yield and price data with subjective probabilities, the Palisade add-in @Risk for Latin hypercube simulation (@Risk 6.0 Industrial Edition, Palisade Corporation, Ithaca, NY, USA), an advancement of the Monte Carlo simulation, is used to generate probability distributions for stochastic variables of interest. For the simulation, 5,000 iterations were performed. Figure 2 shows the program flow of the simulation model, which is described in detail, afterwards.

The historical data approach was used for implementing stochastic dependencies between subjective risk perceptions of yield and price variables (Hardaker *et al.,* 2004: 80-82). As the focus is on region-specific hazards rather than single farm simulations, the means of the subjective estimates were determined. Price data for years 1993-1996 were obtained from ZMP (1998: 77-79), for 1997-2001 from ZMP (2002: 68-

Table 1. Elicited relative risk aversion coefficients.

Risk aversion coefficient	Absolute frequency	Relative frequency (%)	Level of risk attitude
0.155	25	38	Risk aversion level 1
0.470	15	23	Risk aversion level 2
0.815	14	22	Risk aversion level 3
1.265	3	5	Risk aversion level 4
2.000	8	12	Risk aversion level 5
n	65	100	

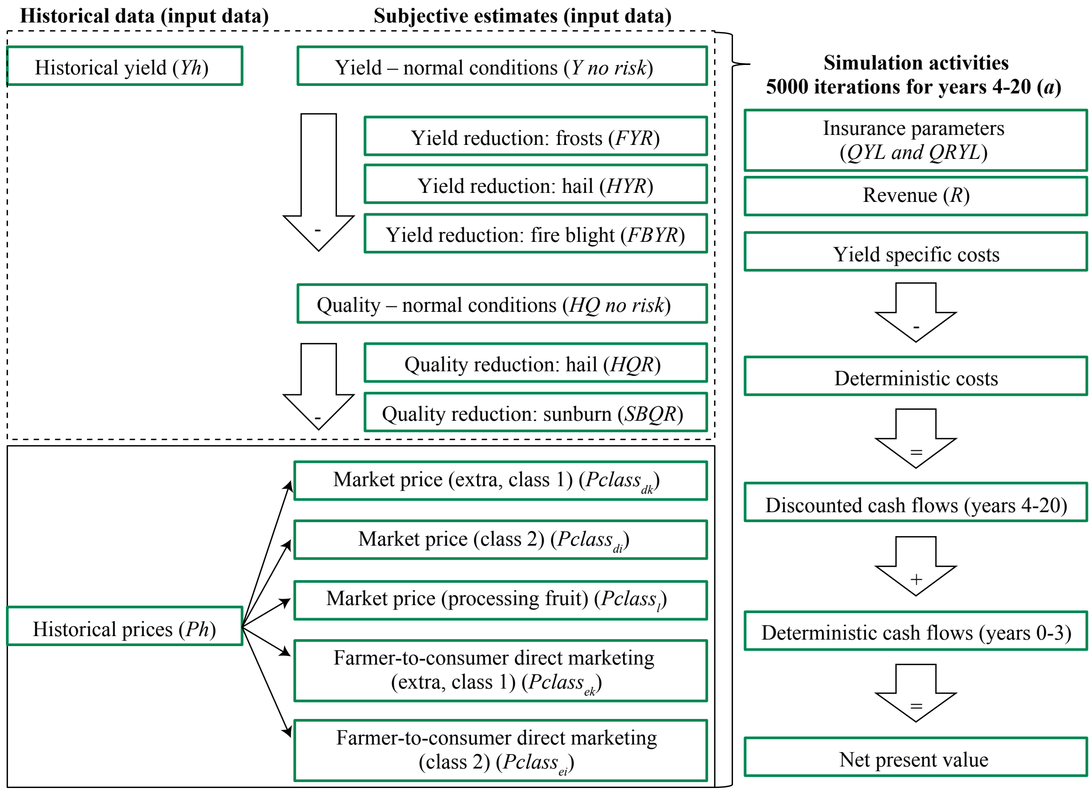

Figure 2. Schematic overview of the model's input data and stochastic calculations.

69), for 2002-2006 from ZMP (2006: 25-27), and for 2007-2012 from AMI (2013: 74-76) and adjusted for inflation, using the consumer price index with 2010 as the base year, provided by the Federal Statistical Office (2014). Yield data were taken from the Landesbetrieb für Statistik und Kommunikationstechnologie Niedersachsen (2008, 2012).

Equation 2 provides an example for the combination of historical prices with subjective estimates.

$$P_{vy} = E[Ps_v] + \{[Ph_{vy} - E[Ph_v]] / \sigma[Ph_v]\} \times \sigma[Ps_v] \tag{2}$$

Where
$E[Ps_v]$ is the expected value E of the subjective price estimation P_S of the variety v
Ph_{vy} is the historical price of variety v in year y
$E[Ph_v]$ is the expected value of the historical price P_h of the variety v
$\sigma[Ph_v]$ is the standard deviation of the historical price P_h of the variety v
$\sigma[Ps_v]$ is the standard deviation of the subjective price estimation P_S of the variety v

The following calculations of yield and qualities under the consideration of risky events are based on subjective estimates. Risk-adjusted yield ($Y_{after\ risk}$) and the percentage of high quality apples (*HQ*) of the actual year *a* are calculated as follows (Equations 3 and 4).

$$Y_{a\ after\ risk} = Y_{a\ no\ risk} \times (1 - FYR_a) \times (1 - HYR_a) \times (1 - FBYR_a) \tag{3}$$

Where frosts (*FYR*), hail (*HYR*) and fire blight (*FBYR*) may lead to yield reductions.

$$HQ_{a\ after\ risk} = HQ_{a\ no\ risk} \times (1 - HQR_a) \times (1 - SBQR_a) \tag{4}$$

Where *HQR* indicates quality reductions due to hail and *SBQR* due to sunburn.

For the yield and quality reductions due to severe weather events, two additional assumptions were made. First, events of hail may lead to a considerable decrease in revenue if quality classes extra, one and two become apples for processing purposes. However, it was assumed that hail has a similar impact on both quality classes and thus only apples for processing purposes were distinguished from *HQ*. This simplification is justified by price adjustments. If adverse weather events lead to widespread damages, the price level of class two commonly equals those of classes extra and one. Thus, it was decided not to differentiate between hail damage of classes one and two separately, but instead reduce the percentage of both quality classes equally. As a consequence, the model realizes revenue reduction and accounts for higher market prices of class two simultaneously. Second, in reality frosts affect yield and quality of apples. Nevertheless, the pretest revealed that apple growers are more concerned about yield losses due to frosts. In consequence, questions addressing quality reductions due to frosts were not answered and therefore frost-related quality reductions are not considered in the model.

Insurance indemnity payments are generally related to quantitative and qualitative losses. The actual yield after spring frost provides the basis for the calculation of quantitative yield loss (*QYL*) due to hail (Equation 5). In addition, quality-related yield loss (*QRYL*) is calculated after subtraction of frost and hail related yield loss (Equation 6).

$$QYL_a = Y_a\,(1 - FYR_a) \times HYR_a \tag{5}$$

$$QRYL_a = Y_a\,(1 - FYR_a) \times (1 - HYR_a) \times HQ_a \times HQR_a \times Q_{Quota} \tag{6}$$

Where *QRYL* indicates the amount of high quality apple HQ_a is the share that becomes processing fruit after hail (HQR_a). This value is further multiplied with Q_{Quota}, which is determined as a loss ratio of 70% and represents a common rating, applied by an insurance company in Germany (Vereinigte Hagel, 2017).

The sum of quantitative and qualitative losses due to hail, divided by expected yield after excluding the effect of losses from spring frosts, result in the total loss ratio from hail (*TLRH*). As the model is confined to the years of full harvest, the expected yield is calculated as a mean of production years four to twenty (Equation 7).

$$TLRH_a = \left[(QYL_a + QRYL_a) * \left[\frac{1}{16} * \left(\sum_{a=4}^{20} Y_a \ * \ (1 - FYR_a)\right)\right]^{-1}\right] * 100 \tag{7}$$

The total sum insured equals expected revenues as a mean of the production years four to twenty, considering the higher quality classes extra, one and two and their respective market prices. If the decision maker participates in frost insurance, indemnity payments for covering frost damages are subtracted. Multiplying the sum insured with the *TLRH* leads to the total amount of economic loss. A percentage of this economic loss represents deductibles, which are paid by the apple grower. For deductibles conventional calculations considering the *TLRH* of a single year were used (Vereinigte Hagel, 2017). After deductibles have been subtracted, the value of the economic loss equals the indemnity payment.

For the calculation of the hail insurance premium, the basic insurance premium (IP) equals 10% of the sum insured in the north and 21% in the south. As the insurance premium has to be adjusted in order to consider the extent and the variation of overall damages, it is further multiplied with a correction factor. For the first nine years of full harvest, the factor equals 100% and for the following years it is determined on the basis of the average *TLRH* observed during the ten previous years.

The calculation of parameters regarding frost insurance follows the same procedure as explained for hail. The sum insured equals the calculated sum insured for hail. Only information of yield losses due to frosts (Equation 8) and the total loss ratio of frosts (*TLRF*) (Equation 9) are required for the calculation of the insurance premium and indemnity payments.

$$QYF = Y_a \times FYR_a \tag{8}$$

$$TLRF_a = \left[QYF_a * \left(\sum_{a=4}^{20} Y_a * 16^{-1} \right)^{-1} \right] * 100 \tag{9}$$

In line with existing frost insurance schemes deductibles are not calculated. Furthermore, information on quality reduction is not available and therefore not considered in this study. For frost insurance 7 and 2% represent the basic insurance premium levels for the north and south, respectively. As for hail, the premium is multiplied with an adjustment factor, which is set at 100% for the first nine years and relies on the average *TLRF* of the previous ten years, afterwards. Finally, the amount of annual indemnity-payments is obtained as *TLRF* is multiplied with the sum insured.

Even if frost insurance as RMI has not been established for apple production in Germany, it is already available as a RMI in neighboring countries. Thus, it is suggested as an alternative to frost irrigation in the north and as a supplement in the south.

Revenues are calculated as shown in Equation 10.

$$\begin{aligned} R_a = & \sum_{c=d}^{e} \sum_{j=k}^{i} \left[\left(Y_{a\,after\,risk} * HQ_{a\,after\,risk} \right) * (1 - S_a) * Qclass_{ja} * Pclass_{cja} \right] \\ & + \left[Y_{a\,after\,risk} * \left(1 - HQ_{a\,after\,risk} \right) \right] * Pclass_{la} \\ & + \sum_{c=d}^{e} \sum_{j=k}^{i} \left(Y_{(a-1)\,after\,risk} * HQ_{(a-1)\,after\,risk} \right) \\ & * S_{(a-1)} * Qclass_{j(a-1)} * \left(Pclass_{cja} * f_{cj} \right) \end{aligned} \tag{10}$$

R indicates revenue, *S* the amount of apples stored and $Qclass_j$ the percentages of the classes extra and one (*k*) as well as class two (*i*) of higher quality apple. $Pclass_{cj}$ are the corresponding prices for qualities, referring to the two distribution channels *c*. Traditionally, apple growers can sell the fruits directly to consumers (market *d*) or via the wholesale market *e*. Furthermore, the variable $Pclass_l$ represents the price for processing quality (*l*). The price increase after storage is further considered by means of the factor *f*, which was calculated according to data provided by AMI (2014). Here, higher prices for stored apples are variety specific for the classes extra and one and are calculated as an increase of 4-12% of the price occurring in the actual year. In a last step direct, variable and fixed costs are subtracted from operating and non-operating (i.e. indemnities and subsidies) revenue. Costs associated with harvest and sorting of apples are considered as yield-dependent costs. Discounting with a rate of 4% and summation of the discounted cash flows leads to the NPV of the farming options. An overview of the cost calculation is provided in the supplementary material (Supplementary Table S1).

The farming scenarios include varieties, which are common in the considered production areas. In the north of Germany, mainly the varieties Braeburn, Elstar Jonagored, and Red Prince are produced, whereas in the south Braeburn, Elstar, Jonagold, and Gala are the predominant ones, usually grown on M.9 rootstocks. These varieties provide the basis for the analysis of one hectare of certain farming options over a period of 16 years of full bearing capacity. To evaluate the effect of already existing as well as non-established risk management tools, the following scenarios for common varieties of each region are compared.

The first step determines the optimal planting density for each variety under standard risk management strategies. In the North, frost irrigation is usually installed, whereas in the south hail nets serve as a standard risk management strategy. The best options determined in the first step, are further analyzed in a second step. For the north frost irrigation, combined with a hail insurance is considered and for the south hail insurance (HI) is analyzed as an alternative for hail nets. The preferred options are further considered in a third and last step of the analysis, where the focus lies on a hypothetical set of combined frost-hail insurance (FI & HI) for both regions.

As currently available subsidies cover up to 50% of installation costs and insurance premium costs, a two-step simulation, with and without subsidy payments is performed. For the subsidy schemes the following assumptions were made: in the south the material for hail nets, the installation costs of frost irrigation systems and insurance premiums are subsidized at a rate of 50%. In the north, the calculation is based on the sum insured multiplied by a distribution factor as laid down in the subsidy scheme of the producer organization. This distribution factor represents 1% of total apple sales and claim settlements, divided by the sum insured over all enterprises. Subsidies may not exceed the costs of the insurance premium and the sum insured may not be higher than 20,000 €/ha.

4. Results and discussion

It is of particular interest how apple growers can protect themselves against farm risk in open field production. For this purpose, a stochastic budgeting model was developed, which considers weather-extremes as well as price risks for miscellaneous varieties of apple and planting densities.

An example of the results of the simulation model is shown in Table 2, where fruit yields are measured in decitonnes (dt). The columns indicate the simulation results of the calculated mean, the standard deviation, the coefficient of variance, as well as the 5% and 95%-percentiles and the associated Minimum and Maximum. The total revenue is calculated based on the operating revenue, representing the revenue achieved through sales activities, plus insurance indemnity payments and subsidies. The sum insured is calculated by taking the expected yield achieved without extreme weather events multiplied by market prices. In the case of Red Prince, simulated with 3,300 trees per hectare, the sum insured exceeded the maximum of 20,000 €/ha. As a subsidized scenario is represented, the simulation is calculated under consideration of the maximum mentioned above. The monetary loss due to weather events is calculated by multiplying the sum insured with the total loss ratio (cf. Equation 7 for hail and Equation 9 for frost). For calculating the amount of hail related indemnity payments, deductibles which are determined by the total loss ratio have to be subtracted as described above. Costs of the insurance are set with a basic premium rate of 10%. After nine production years, the average total loss ratio determines an adapted premium rate, which represents a variable component in the model. Multiplying the sum insured with the distribution factor of 0.0424, which is a 4-year average stated by the producer organization (C. Greisiger, personal communication), average subsides of 848 € are calculated in the following scenario.

Four region-specific varieties under common practice are part of the first analytic step. Figure 3 displays the CDFs of NPVs for one hectare of the respective option for the north. In general, higher planting densities of a variety clearly dominate the lower densities in the sense of FSD, but also show higher variation.

Notably, the varieties of Elstar and Jonagored at a density of 1,800 trees per hectare can be considered as less efficient, since the probability to achieve a positive NPV is small. Comparing varieties planted at the same density, Braeburn and Red Prince dominate Elstar as well as Jonagored in the sense of FSD. In comparison to Red Prince, Braeburn indicates a steeper curve and is thus less risky. Furthermore, Red Prince at 2,500 trees per hectare dominates Elstar in terms of SSD, as their associated curves cross close to p=1.0. In contrast, the discrimination of the most efficient option among Braeburn and Red Prince at 3,300 trees per hectare is not possible with FSD and SSD. Later, SERF helps to achieve a clearer differentiation. On the basis of these results, Braeburn, Jonagored as well as Red Prince at 2,500 and 3,300 trees per hectare will be part of the further analysis. Results of the second analytic step for the north are given in Figures 4 to 6.

Table 2. Red Prince with 3,300 trees/ha, frost irrigation and a subsidized hail insurance (north).[1]

Red Prince 3,300 HI sub 10% IP	Mean	Stdev	CV	0.05 perc.	0.95 perc.	Min	Max
Net present value (€/ha)	109,688.96	20,416.93	0.19	77,193.81	145,020.98	38,497.16	187,930.53
Annuity (€/ha/a)	8,071.11	1,502.31	0.19	5,680.06	10,670.90	2,832.69	13,828.26
Direct costs (€/ha)	11,304.78	1,107.72	0.10	9,155.60	12,884.90	7,869.46	13,276.55
Variable costs (€/ha)	4,493.12	735.20	0.16	2,951.56	5,466.56	1,212.52	5,466.56
Fix costs (€/ha)	4,023.32	426.07	0.11	3,272.73	4,642.44	2,180.23	5,107.31
Total yield (dt/ha)	575.40	123.15	0.21	317.18	738.45	25.88	738.45
Classes extra and one (sold per year) (dt/ha)	433.03	134.40	0.31	168.82	633.29	20.18	711.93
Class two (sold per year) (dt/ha)	25.95	32.54	1.25	0.00	96.67	0.00	162.56
Processing fruit (sold per year) (dt/ha)	105.85	112.50	1.06	13.27	338.86	0.68	706.50
Percentage stored (%)	0.95	0.01	0.01	0.93	0.97	0.91	0.97
Percentage of market sales (%)	0.87	0.01	0.01	0.85	0.89	0.84	0.90
Market price classes extra and one (actual year) (€/dt)	42.88	7.55	0.18	30.17	54.64	30.17	54.64
Wholesale market price classes extra and one (actual year) (€/dt)	165.67	26.21	0.16	121.52	206.50	121.52	206.50
Operating revenue (€/ha)	30,679.52	10,615.82	0.35	12,178.06	48,064.85	2,161.86	60,522.03
Total revenue (€/ha)	33,505.10	11,205.97	0.33	14,456.56	52,252.22	3,197.35	74,242.38
Discounted profits (€/ha)	11,247.15	9,336.99	0.83	-4,542.63	27,184.53	-14,341.62	47,598.98
Sum insured (€/ha)	20,000.00	0.00	0.00	20,000.00	20,000.00	20,000.00	20,000.00
Indemnity payments hail (€/ha)	1,976.87	3,430.25	1.74	0.00	10,042.48	0.00	20,000.00
Insurance premium hail (€/ha)	2,000.00	0.00	0.00	2,000.00	2,000.00	2,000.00	2,000.00
Subsidies (€/ha)	848.71	0.00	0.00	848.71	848.71	848.71	848.71

[1] HI = hail insurance; IP = insurance premium; dt = decitonnes; CV = coefficient of variance; 0.05 perc = 5% percentile; 0.95 perc = 95% percentile.

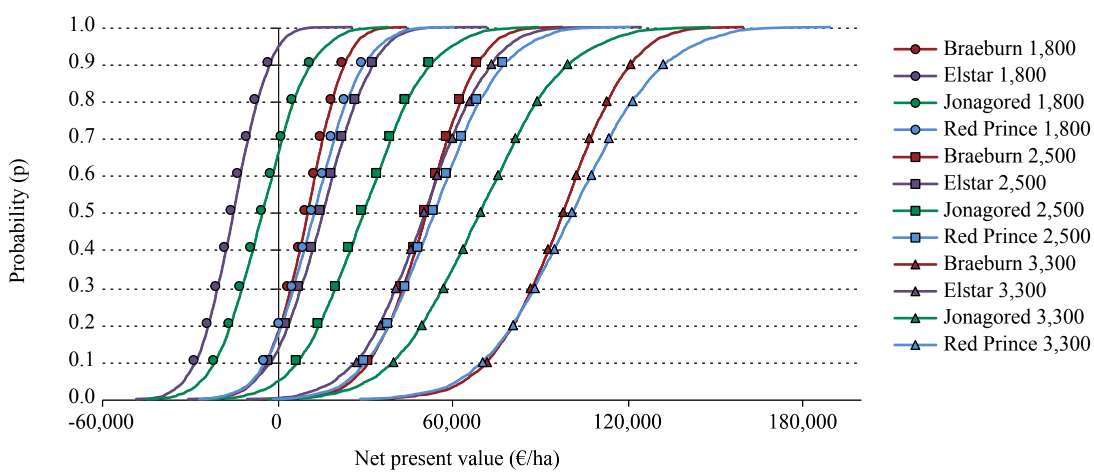

Figure 3. Basic scenario with frost irrigation (north).

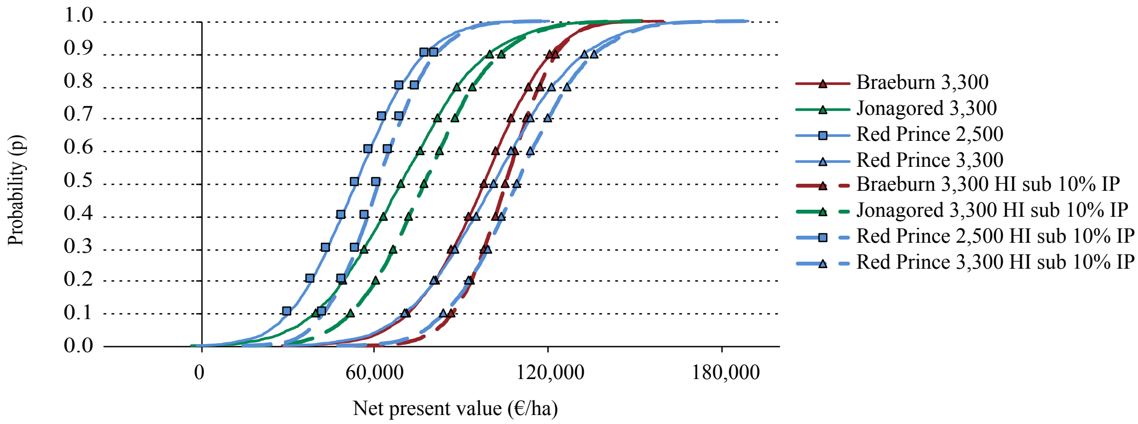

Figure 4. Subsidized hail insurance (HI sub) at a 10% insurance premium-level (IP) with frost irrigation (north).

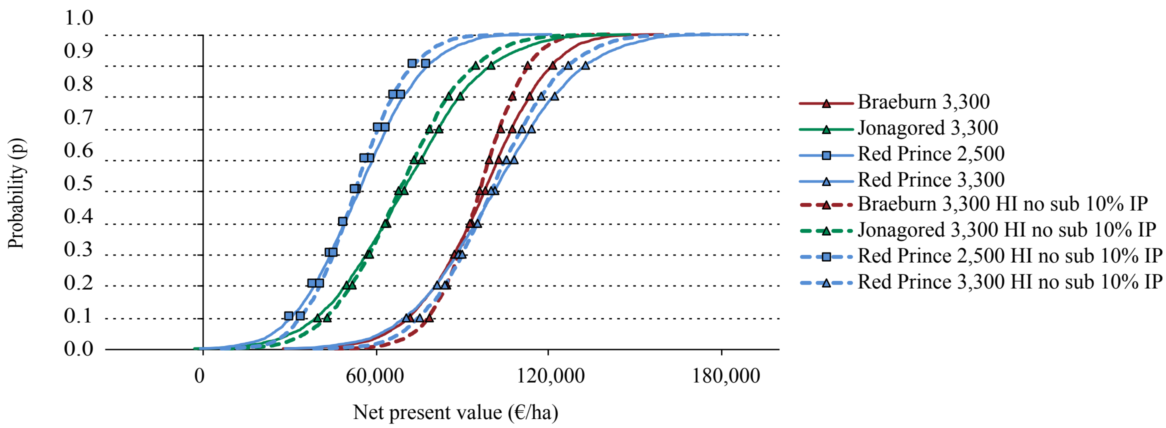

Figure 5. Unsubsidized hail insurance (HI no sub) at a 10% insurance premium-level (IP) with frost irrigation (north).

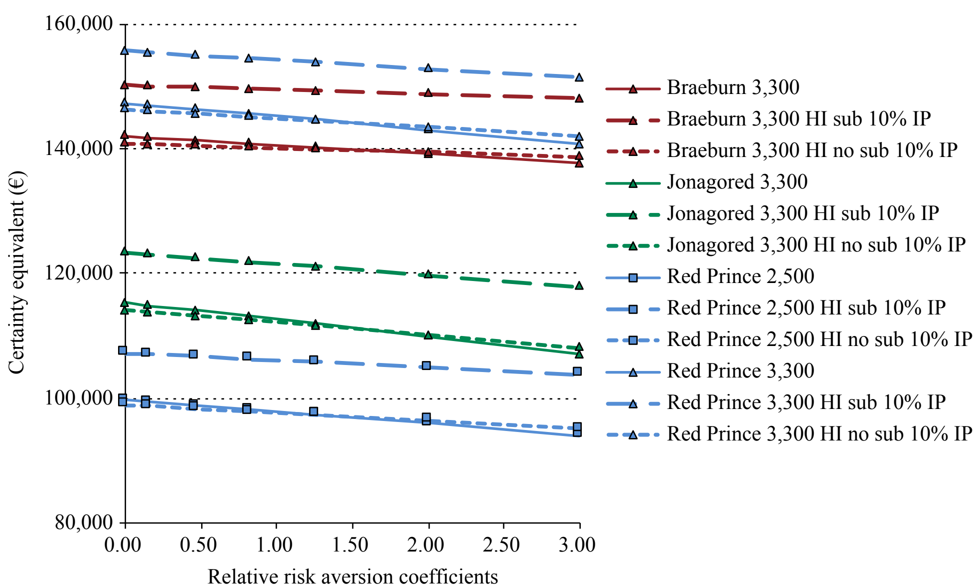

Figure 6. Stochastic Efficiency with Respect to a Function analysis with the basic scenario, subsidized hail insurance (HI sub) and unsubsidized hail insurance (HI no sub) at a 10% insurance premium-level (IP) (north).

As indicated in Figure 4, insured crops of all varieties dominate the associated common production practices in terms of SSD. This effect arises from both, insurance and subsidies, where the latter amount to about 850 € per hectare on average. However, with respect to Jonagored and Red Prince at a planting density of 3,300 trees per hectare the associated curves cross more than once in their upper range and thus, the application of stochastic dominance criteria does not lead to a final ranking.

Figure 5 presents the results of unsubsidized hail insurance. As can be seen, insurance policies without subsidies reduce risks as the associated curves become steeper in comparison to those of the basic scenario. Again, it is not possible to judge the performance of insurance according to FSD or SSD.

The SERF analysis (Figure 6) reveals that for slightly risk averse decision makers, the basic production practice, with frost irrigation as the only RMI, is more appropriate, whereas for risk averse persons an unsubsidized hail insurance provides slightly higher CEs. Nonetheless, a combination of frost irrigation and subsidized hail insurance provides the most efficient risk management strategy, irrespective of the variety. The SERF-analysis further shows that in the basic scenario with frost irrigation, Red Prince provides the most efficient option in the north over a wide range of relative risk aversion ($0 \leq r_r \leq 3$). These results are explained by the average yield-level of Red Prince exceeding those of Elstar and Braeburn. In addition, Red Prince attains higher net revenues than Jonagored due to slightly higher prices as well as lower variable costs. In contrast, an elevated price level causes higher revenues of Braeburn whereas yield is relatively low. As Braeburn is afflicted with smaller standard deviations in revenue as well as in direct and fixed costs, its CEs remain more stable across different risk aversion coefficients in comparison to Red Prince. The results further suggest that Jonagored is less efficient despite its high yield level, since it yields lower prices in the market. Furthermore, the standard deviation of the NPV for Jonagored is similar to the one obtained for Red Prince and likewise results in a considerable CE as well as utility reduction when risk aversion increases. The high yield-level of Jonagored as well as of Red Prince result in higher direct costs, as storage and harvesting costs are increased.

These results indicate that rational apple growers in the north should combine frost irrigation with subsidized hail insurance. However, data shows that 30% of the apple growers, who are already members in a producer organization, do not participate in hail insurance. This observation can possibly be explained with the effect of reference dependence. As described by Bocquého *et al.* (2013), prospect maximizers might be risk averse for gains, but show risk-seeking behavior in a context of losses. They accept the possibility to suffer a high loss instead of paying a certain amount of insurance premium regularly (Bocquého *et al.,* 2013). Furthermore, the results of SERF show that unsubsidized hail insurance only leads to a slight increase in efficiency. In consequence, it is not worthwhile for slightly risk averse growers to combine frost irrigation with unsubsidized hail insurance. Nevertheless, the reduction of standard deviation in NPV amounts to 4,520.75 €/ha on average for the highest planting densities. This leads to a slight increase in efficiency compared to the basic scenario, given a high risk aversion. Please note, that the unsubsidized hail insurance was simulated without a restriction of the sum insured (20,000 €/ha), which leads to higher indemnity payments as well as to a higher decrease in NPV standard deviations.

The results of NPV-CDFs calculated for the south are illustrated in Figures 7 to 8. Apparently, apple growers in the north achieve higher revenues than in the south. These differences stem from deviations of yield estimates, which are variety specific and amount to 59 and 89 dt per hectare for Braeburn and Elstar, respectively. An explaination might originate from an overestimation of yield risks. As the results of Menapace *et al.* (2014) indicate, persons who experienced specific risks in the past, show a significant increase in their associated risk perception for future events. An additional question in our survey captures the influence of the two main weather related risks in the past ten years. In the north, 28.8% stated that the operating income of the enterprise was severely or more than severely affected due to hail, whereas in the south even 48.5% indicated a strong impact of hail. In contrast to yield risks, differences in price levels for market prices are quite small and between 5 to 10 € per dt, whereas variations of wholesale market prices up to 40 € per dt have presumably a higher effect on revenue.

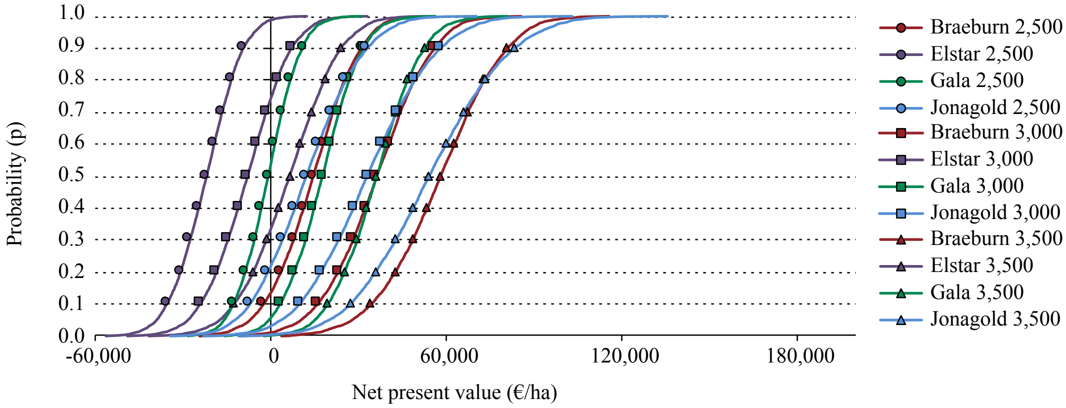

Figure 7. Basic scenario with hail nets (south).

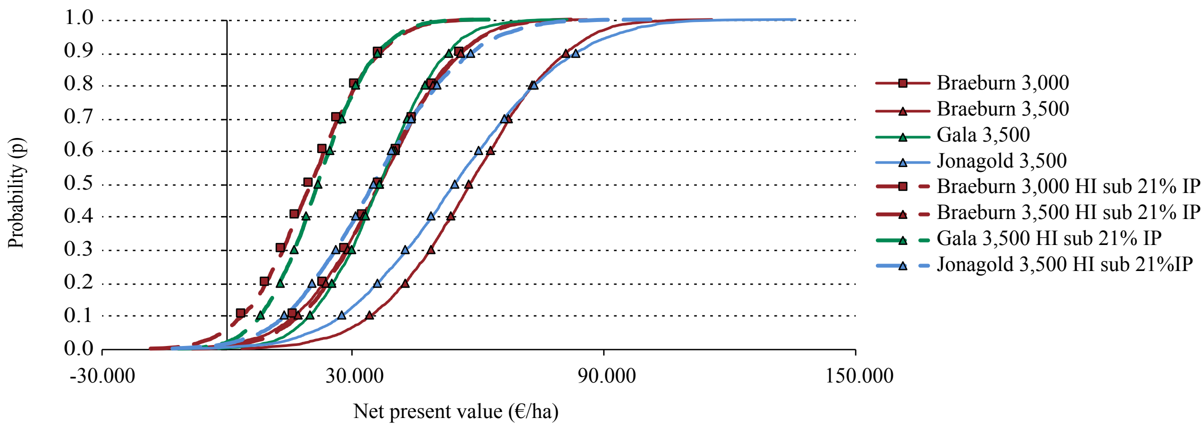

Figure 8. Subsidized hail insurance (HI sub) at a 21% insurance premium-level (IP) as an alternative for hail nets (south).

In the basic scenario for the south, Braeburn Gala and Jonagold are more profitable than Elstar at equivalent planting densities and dominate the latter in the sense of FSD. Thus, results suggest that Elstar does not provide an efficient option in either area, as it shows a lower level of yield and therefore lower revenue. The reason for the low yield of Elstar may in part be explained by its high tendency for alternate bearing (Atay *et al.,* 2013; Untiedt and Blanke, 2001). As a consequence, it is reasonable to suppose, that yield estimates of Elstar lie below of those of other varieties. Furthermore the basic scenario for the south shows that the CDFs for Jonagold indicate a higher risk, as their course is not as steep as the curves that represent the other varieties. Similar to the north, all varieties simulated at the highest planting density of 3,500 trees per hectare dominate the lower ones in sense of FSD. When focusing on the highest planting density, Jonagold is dominated by Braeburn in terms of SSD. However, no clear ranking according to FSD or SSD is observable when focusing on Braeburn at 3,000 trees per hectare as well as on Gala and Jonagold at 3,500 trees per hectare. Thus, Braeburn at 3,000 trees per hectare together with Braeburn, Gala and Jonagold at 3,500 trees per hectare are considered in the second part of the analysis.

Figure 8 shows the results for hail insurance as an alternative choice to hail nets in the south. Despite subsidies covering 50% of the premium, hail insurance seems to provide no appropriate solution, since the variety specific comparison of the RMI reveals a decrease in efficiency. However, hail insurance combined with high density and profitable varieties as Braeburn or Jonagold at 3,500 trees per hectare appear as efficient as Braeburn at 3,000 trees or Gala at 3,500 trees per hectare. One may recognize that distances between the basic scenario and subsidized hail insurance for Braeburn at a planting density of 3,500 trees per hectare are larger than for 3,000. This effect stems from an increase of expected yield, which is coupled with higher premium costs. Average values, obtained for a planting density of 3,500 trees per hectare, indicate that indemnity payments and subsidies do not meet revenue loss occurring without hail nets, which leads to a financial loss of about 632 €. Furthermore, direct costs increases up to 19.90%. With respect to unsubsidized hail insurance all basic scenarios dominate their analogs with unsubsidized hail insurance according to FSD.

Figure 9 summarizes the results for the south in terms of CEs. Generally, subsidized hail insurance in the south is less efficient than growing the same variety under hail nets. Subsidized hail insurance can only compete with the basic scenario, if the apple grower is risk neutral to slightly risk averse and chooses varieties characterized by a high yield or an elevated price level. For risk neutral apple growers, subsidized insurance solutions of Braeburn and Jonagold at 3,500 trees per hectare are as efficient as the production under hail nets of Braeburn at 3,000 trees and Gala at 3,500 trees per hectare. However, as the SERF analysis reveals for Gala, the underlying risk attitude may be important. As Gala at 3,500 trees under hail net is still afflicted with lower risks it shows higher CEs for risk averse individuals, who should give priority to this option. This result makes evident that regardless of the variety specific decrease of standard deviation achieved by the participation in insurance, the general risk of a variety has to be taken into account. Furthermore, the results indicate that without subsidies, hail insurance would be clearly dominated by common practice with hail nets and thus provides no reasonable alternative. Therefore, subsidies appear as a certain and non-negligible source of revenue.

The results further suggest that Braeburn is the most efficient variety due to its higher price level, even if the average yield of Braeburn is below that of Gala and Jonagold. Regarding the NPV's standard deviations, Jonagold shows the highest and Gala the lowest risk. Compared to Jonagold, standard deviations of Gala regarding the operating revenue, as well as the direct, fixed and variable costs are smaller. Similarly, Braeburn shows a lower standard deviation with respect to the operating revenue. Consequently, and as the SERF analysis reveals, Braeburn is afflicted with lower risk and risk averse individuals should opt for Braeburn instead of choosing Jonagold. With respect to costs, Jonagold shows higher fixed and variable costs, as its high yield leads to higher labor costs for harvesting.

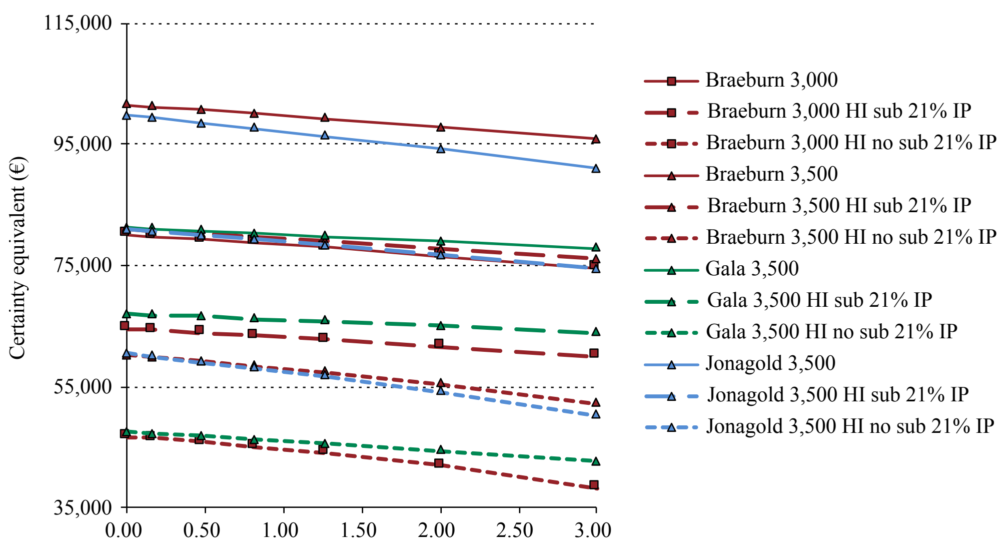

Figure 9. Stochastic Efficiency with Respect to a Function analysis with the basic scenario, subsidized hail insurance (HI sub) and unsubsidized hail insurance (HI no sub) at a 21% insurance premium-level (IP) (south).

As mentioned before, RMIs for apple growers against weather related risks are rare. Thus, subsidized hail-frost insurance as a (so far) hypothetical alternative was implemented. The associated CEs are plotted together with subsidized hail insurance and the basic scenario in figures 10 and 11. Figure 10 presents the results for the north at a 7% insurance premium level for frost insurance. The insurance premiums were obtained by a comparison of average premium costs and indemnity payments.

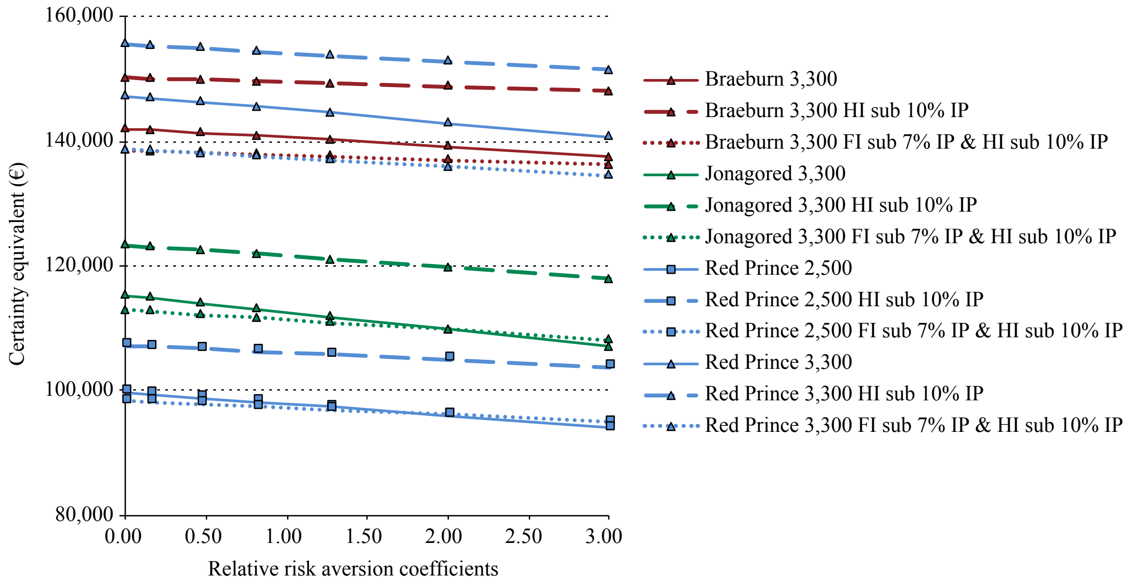

Figure 10. Stochastic Efficiency with Respect to a Function analysis with the basic scenario, subsidized hail insurance (HI sub) at a 10% insurance premium-level (IP) and combined frost-hail insurance (FI sub & HI sub) at a 7% IP for frost (north).

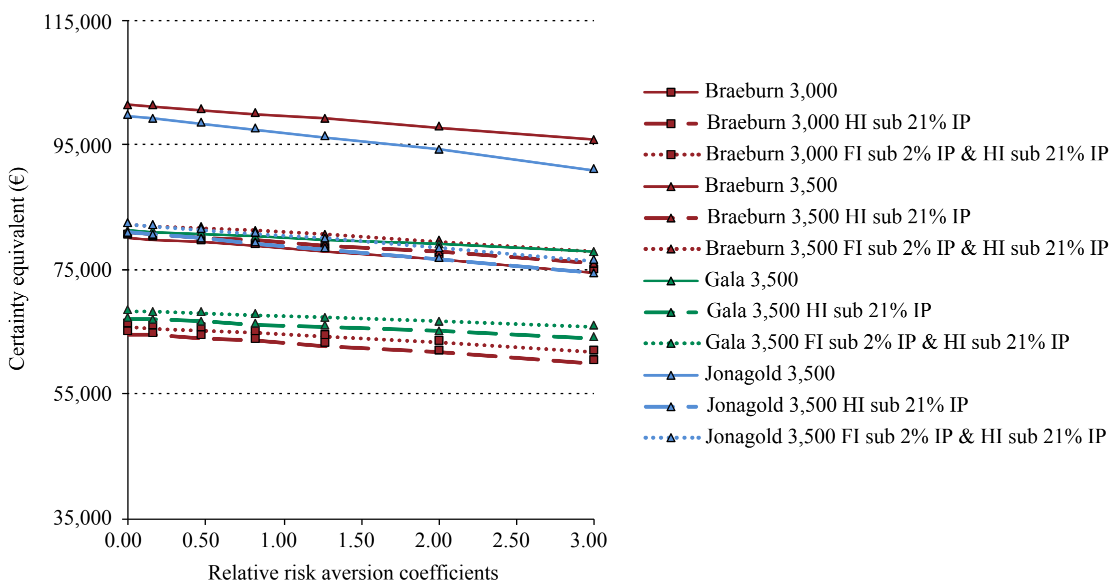

Figure 11. Stochastic Efficiency with Respect to a Function analysis with the basic scenario, subsidized hail insurance (HI sub) at a 21% insurance premium-level (IP) and combined frost-hail insurance (FI sub & HI sub) at a 2% IP for frost (south).

In the north, frost-hail insurance generally does not provide an efficient alternative to frost irrigation. The results suggest that subsidized, combined frost-hail insurance in the north is only attractive for very risk averse decision makers, even though the effect is variety-specific and depends on the planting density, as can be seen for Braeburn and Red Prince at 3,300 trees per hectare. Only extremely risk averse decision makers would obtain slightly higher CEs compared to the basic scenario of Red Prince at 2,500 trees per hectare and Jonagored at 3,300 trees per hectare. However, a disruption in the capability to supply regular customers with apples might jeopardize the business relationships in real life and apple growers are expected to prefer frost irrigation systems rather than insurance solutions.

In the south the basic (and most commonly found) farming options remain the most efficient ones, compared to subsidized insurance solutions (Figure 11). A combined frost-hail insurance with a 2% insurance premium would lead to slightly higher incomes due to subsidies, whereas damages due to late frosts are marginal and indemnity payments for high density plantations amount to 300 € in average. The CEs of the combined hail-frost insurance are close to those of single hail insurance, although the associated values always lie above due to the assumption of higher subsidy payments. Thus, the added value of a frost-hail insurance is low.

In 2017 frosts caused high damage in fruit and wine yards, located in the south of Germany. Coble and Barnett (2012) describe that ex post disaster assistance via direct payments in the United States reveal that these payments in contrast to insurance programs do not provide a support in sense of risk protection. In order to reduce the demand of ex post disaster payments, subsidies for insurance contracts clearly represent an incentive to increase the number of insurance contracts (Coble and Barnett 2012). Therefore, a subsidized multi-peril insurance could provide an appropriate solution to cope with damages due to frosts and hail. For example, a commercial multi-peril insurance is available for apple production in the Netherlands covering frost and hail damages in combination with other weather-related risks. This insurance receives a government subsidy up to 65% of the insurance premium (Berkhout *et al*., 2016). In contrast, our results indicate that the added value of a multiperil-insurance is low considering the estimated risk situation. Nevertheless, the effects of climate change may increase the occurrence of late frosts and multi-peril-insurances could become more relevant.

Finally, a potential criticism regarding the use of the NPV as the stochastic investment criterion should be addressed. Using the NPV implies an aggregate evaluation of the total simulation results over the economic life of the apple orchard, which tends to level the effect of a catastrophic year that could have caused bankruptcy. This could lead to an underestimation of the true risk. In line with Clancy *et al.* (2012), it is assumed that each variety on a 1 ha basis only represents a rather small percentage of farming activities and farmers' wealth, whose failure would not likely lead to insolvency of the enterprise. Also from a marketing perspective, apple growers are required to produce a certain mix of apple varieties to meet their customers' demands, which precludes the recommendation of a single variety.

5. Conclusions

Results of the present study reflect observed behavior in reality, where apple growers successfully apply available risk management strategies in their respective regions.

In the north, Red Prince appears as the most efficient variety. Furthermore, subsidized hail insurance would provide benefits for risk averse farmers in general, whereas an unsubsidized hail insurance is only more efficient if the apple grower is highly risk averse. In the south, none of the considered RMI provides a more appropriate alternative to common practices of using hail nets when the same variety and planting density are considered. Even if recent events of frost damages in the south arousing thoughts of developing multi-peril insurance programs, the results reveal that additional benefits under the present circumstances are low. As for the north, also in the South more efficient varieties could be identified. Braeburn is the most efficient variety and appropriate for slightly to highly risk averse individuals. Identifying efficient combinations of variety, planting density and RMI is only a first step, however, as diversification reduces farm income risk further and takes into account the customers' requirement of a certain product mix. As a consequence, future work should utilize whole-farm risk programming to capture the interaction between varieties as well as constraints to the implementation of risk management strategies by considering additional requirements, such as pollination management and farm-specific restrictions As the present paper aims to discuss RMIs universally applicable to apple producing orchards, restrictions as farm debts cannot be generalized and thus are not discussed. Future work may include these topics and considering farm debt repayment activities during catastrophic years which could lead to bankruptcy.

With respect to the hypothetical subsidized frost-hail insurance, variety specifications as well as the planting density have to be considered when interpreting the results. For high-yielding varieties in high density plantings, this insurance concept seems to be inappropriate. Otherwise, when considering very risk averse apple growers, using less intensive production systems, it may lead to a slight increase of efficiency compared to an ordinary frost irrigation. A subsidized, hypothetical multi-peril insurance covering frost and hail would lead to slightly higher net incomes than observed for the subsidized hail insurance alone in the south, due to its additional transfer payments. But nevertheless, the production of high yielding varieties catching good prices in high density plantations under hail nets still remains the most efficient option.

Apple growers of other European countries however have access to multi-peril insurance policies, which are often subsidized by the government. To analyze the effect of different risk management concepts, future work should compare European multi-peril insurance concepts, which cover a broad extent of weather-related risks.

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Supplementary material

Supplementary material can be found online at https://doi.org/10.22434/IFAMR2017.0022.

Table S1. Cost overview for Red Prince with 3,300 trees/ha, frost irrigation and subsidized hail insurance (north).

References

Ahmed, O. and T. Serra. 2015. Economic analysis of the introduction of agricultural revenue insurance contracts in Spain using statistical copulas. *Agricultural Economics* 46: 69-79.

AMI. 2013. AMI Marktbilanz Obst. 2013. AMI Agrarmarkt Informations-Gesellschaft mbH, Bonn, Germany.

AMI. 2014. AMI Marktbilanz Obst. 2014. AMI Agrarmarkt Informations-Gesellschaft mbH, Bonn, Germany.

Atay, A.N., F. Koyuncu and E. Atay. 2013. Relative susceptibility of selected apple cultivars to alternate bearing. *Journal of Biological and Environmental Sciences* 7(20): 81-86.

Berkhout, P., M. Van Asseldonk, R.W. van der Meer, H.A.B. van der Meulen and H.J. Silvis. 2016. Evaluatie regeling brede weersverzekering. Wageningen, Wageningen Economic Research, Rapport 2016-070. Available at: http://tinyurl.com/y8mds3aj.

Bielza Diaz-Caneja, M., C.G. Conte, F.J. Gallego Pinilla, J. Stroblmair, R. Catenaro and C. Dittmann. 2009. Risk management and agricultural insurance schemes in Europe. JRC Reference Reports, Institute for Protection and Security of Citizen, European Communities, Brussels, Belgium, pp. 1-32.

Bocquého, G., F. Jacquet and A. Reynaud. 2013. Expected utility or prospect theory maximisers? Assessing farmers' risk behaviour from field-experiment data. *European Review of Agricultural Economics* 41: 1-38.

Bravin, E., A. Kilchenmann and M. Leumann. 2009. Six hypotheses for profitable apple production based on the economic work-package within the ISAFRUIT project. *Journal of Horticultural Science and Biotechnology* 7: 164-167.

Catalá, L.P., G.A. Durand, A.M. Blanco and J.A. Bandoni. 2013. Mathematical model for strategic planning optimization in the pome fruit industry. *Agricultural Systems* 115: 63-71.

Chen, X., H.H. Wang and L.D. Makus. 2007. Production risk and crop insurance effectiveness: organic versus conventional apples. *Working Paper* No. SCC-76. Economics and Management Risk in Agriculture and Natural Resources Gulf Shores, Alabama, AL, USA.

Clancy, D., J.P. Breen, F. Thorne and M.Wallace. 2012. A stochastic analysis of the decision to produce biomass crops in Ireland. *Biomass and Bioenergy* 46: 353-365.

Coble, K.H. and B.J. Barnett. 2012. Why do we subsidize crop insurance? *American Journal of Agricultural Economics* 95(2): 498-504.

Dirksmeyer, W., H. Garming and K. Strohm. 2014. Horticulture report 2014. TI Braunschweig, Braunschweig, Braunschweig, Germany. Available at: http://tinyurl.com/y744hdrv.

Federal Statistical Office. 2014. Gesamtwirtschaft & Umwelt – Verbraucherpreisindizes – Verbraucherpreise – Statistisches Bundesamt (Destatis). Available at: http://tinyurl.com/yawlx7nz.

Hardaker, J.B. 2000. Some issues in dealing with risk in agriculture. Working paper No. 2000-3. *Working Paper Series* in Agricultural and Resource Economics, Graduate School of Agricultural and Resource Economics, University of New England, Armidale, Australia.

Hardaker, J.B., R.B.M. Huirne, J.R. Anderson and G. Lien. 2004. *Coping with risk in agriculture*, 2nd ed. CAB International, Wallingford, UK.

Hardaker, J.B. and G. Lien. 2010. Stochastic efficiency analysis with risk aversion bounds: a comment. *Australian Journal of Agricultural and Resource Economics* 54(3): 379-383.

Harper, J.K., A.J. Jimenez-Maldonado, R.M. Crassweller and D.E. Smith. 2013. Impact of producer risk preferences on selection of fresh-market apple training systems. *International Journal of Fruit Science* 13(3): 265-273.

Hoag, D.L. 2010. Applied risk management in agriculture. 1st ed. CRC Press-Taylor & Francis Group, Boca Raton, FL, USA.

Holt, C.A, and S.K. Laury. 2002. Risk aversion and incentive effects. *American Economic Review* 92(5): 1644-1655.

Kaufman, N. 2014.Why is risk aversion unaccounted for in environmental policy evaluations? *Climatic Change* 125: 127-135.

KTBL. 2010. Obstbau. *Betriebswirtschaftliche und produktionstechnische Kalkulationen*, 4th ed. Kuratorium für Technik und Bauwesen in der Landwirtschaft e.V. (KTBL), Darmstadt, Germany.

Landesbetrieb für Statistik und Kommunikationstechnologie Niedersachsen. 2008. Informationen für die Ernte- und Betriebsberichterstatter 8/2008 Available at: http://tinyurl.com/yafd8cba.

Landesbetrieb für Statistik und Kommunikationstechnologie Niedersachsen. 2012. Informationen für die Ernte- und Betriebsberichterstatter 6/2012. Available at: http://tinyurl.com/y9na7xge.

Lien, G. 2003. Assisting whole-farm decision-making through stochastic budgeting. *Agricultural Systems* 76 (2): 399-413.

Lien, G., and J.B. Hardaker. 2001. Whole-farm planning under uncertainty: impacts of subsidy scheme and utility function on portfolio choice in Norwegian agriculture. *European Review of Agricultural Economics* 28(1): 17-36.

Lien, G., J.B. Hardaker and O. Flaten. 2007a. Risk and economic sustainability of crop farming systems. *Agricultural Systems* 94: 541-552.

Lien, G., J.B. Hardaker, M.A.P.M. Van Asseldonk and J.W. Richardson. 2011. Risk programming analysis with imperfect information. *Annals of Operations Research* 190(1): 311-323.

Lien, G., S. Størdal, J.B. Hardaker and L.J. Asheim. 2007b. Risk aversion and optimal forest replanting: a stochastic efficiency study. *European Journal of Operational Research* 181(3): 1584-1592.

Menapace, L., G. Colson and R. Raffaelli. 2012. Cognitive heuristics and farmers' perceptions of risks related to climate change. Agricultural and Applied Economics Association's 2012 AAEA Annual Meeting, Seattle, Washington, DC, USA, pp. 1-23. Available at: http://tinyurl.com/y9l4od5r.

Menapace, L., G. Colson and R. Raffaelli. 2013. Risk aversion, subjective beliefs, and farmer risk management strategies. *American Journal of Agricultural Economics* 95(2): 384-389.

Menapace, L., G. Colson and R. Raffaelli. 2014. Farmers' climate change risk perceptions: an application of the exchangeability method. Available at: http://tinyurl.com/yar2f9cs.

Pennings, J.M.E., B. Wansink and M.T.G. Meulenberg. 2002. A note on modeling consumer reactions to a crisis: The case of the mad cow disease. *International Journal of Research in Marketing* 19(1): 91-100.

Schenk, J., P. Hellegers, M. van Asseldonk and B. Davidson. 2014. How do farmers react to varying water allocations? An assessment of how the attitude to risk affects farm incomes. *Agricultural Water Management* 136: 52-58.

Smidts, A. 1990. Decision making under risk: a study of models and measurement procedures with special reference to the farmer's marketing behaviour. PhD thesis, Wageningen University, Wageningen, the Nederlands.

Untiedt, R. and M. Blanke. 2001. Effects of fruit thinning agents on apple tree canopy photosynthesis and dark respiration. *Plant Growth Regulation* 35: 1-9.

Vereinigte Hagel. 2017. Vereinigte Hagel. Kölnische Hagel. Kundeninformation. Available at: http://tinyurl.com/yad9wbuu.

ZMP. 1998. ZMP-Marktstatistik. Obst 1998. Absatzmengen und Verkaufserlöse der deutschen Erzeugermärkte. Zentrale Markt- und Preisberichtstelle für Erzeugnisse der Land-, Forst- und Ernährungswirtschaft GmbH, Bonn, Germany.

ZMP. 2002. ZMP-Marktstatistik. Obst 2002. Absatzmengen und Verkaufserlöse der deutschen Erzeugermärkte. Zentrale Markt- und Preisberichtstelle für Erzeugnisse der Land-, Forst- und Ernährungswirtschaft GmbH, Bonn Germany.

ZMP. 2006. ZMP-Marktstatistik. Obst 2006. Absatzmengen und Verkaufserlöse der deutschen Erzeugermärkte. Zentrale Markt- und Preisberichtstelle für Erzeugnisse der Land-, Forst- und Ernährungswirtschaft GmbH, Bonn, Germany.