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Strategies to manage hail risk in apple production

Annkatrin Porsch
Chair of Economics of Horticulture and Landscaping, Technical University of Munich, Freising, Germany
Markus Gandorfer
Institute for Agricultural Engineering and Animal Husbandry, Bavarian State Research Center for Agriculture, Freising, Germany and Chair of Economics of Horticulture and Landscaping, Technical University of Munich, Freising, Germany, and
Vera Bitsch
Chair of Economics of Horticulture and Landscaping, Technical University of Munich, Freising, Germany

Abstract

Purpose – Hail risk management is essential for successful farm management in German fruit production, particularly because hail events and associated losses have increased in recent years. The purpose of this paper is to conduct a detailed risk analysis comparing different strategies to manage hail risk, taking into account farmers' risk aversion and farm-specific conditions.

Design/methodology/approach – Within an expected utility framework, two different strategies for managing hail risk are compared: one belonging to the group of financial instruments (hail insurance) and the other to the group of technical instruments (anti-hail net). A unique data set comprising a ten-year time series of orchard-specific hail damage and hail insurance data is used.

Findings – For orchards with low local hail risk and low yield potential, not using hail risk mitigation is most efficient. For orchards with high local hail risk and high yield potential, anti-hail nets provide the highest certainty equivalents. For orchards with high local risk, but low yield potential, hail insurance is most efficient. For orchards, with low local risk, but high yield potential, the certainty equivalents are higher for anti-hail net, when the farmer is risk neutral or slightly risk-averse. With increasing risk aversion, hail insurance is most efficient, which can be explained by the greater degree of the instrument's flexibility.

Originality/value – The novelty of the study lies in the direct comparison of the risk effects of anti-hail nets and hail insurance in fruit production.

Keywords Climate change, Risk management, Expected utility, Anti-hail net, Hail insurance, Historical simulation

Paper type Research paper

1. Introduction

Variability in crop yield due to extreme weather events influences the profitability and risk of fruit production. In the case of apple production, frost and hail are commonly considered the most important sources of risk for yield variability. Based on expert interviews, Gömann *et al.* (2015) found that hail is the first ranked risk in South Germany, followed by drought and late frost (see Table I).

Due to climate change, the frequency and extent of losses due to hail have increased in Central Europe over the past three decades (Kunz *et al.*, 2009; Mohr and Kunz, 2013). Therefore, this study focuses on hail. Hail events often cause high yield and quality losses because the quality of apples is highly sensitive to hail, and apples damaged by hail are only suitable for sale to the processing industry (e.g. apple-juice producers) after even a moderate hail event.

In Germany, fruit production is limited to a few growing areas: one-third of the entire fruit production area is located in Southern Germany (in the states of Bavaria and

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Baden-Wurttemberg). This region has been particularly affected by rising hail risk (Kunz and Puskeiler, 2010; Mohr and Kunz, 2013). An increase in the average number of hail days per year from 5 to 33 was recorded in South-western Germany between 1986 and 2004 (Kunz *et al.*, 2009). In regions where hail events are more frequent, they are often also more severe (Kunz and Puskeiler, 2010). In addition to production risk, specialty crop farms are highly exposed to risk due to the capital-intensive nature of production and the often high debt-to-asset ratios as a consequence of structural change (Hartwich *et al.*, 2015).

Therefore, an appropriate risk management strategy for hail risk is crucial. Various instruments are available for hail risk mitigation, including the spatial diversification of orchards, cloud-seeding planes, anti-hail nets and hail insurance. However, in practice, only anti-hail nets and hail insurance are generally used. Hail insurance has a long tradition in Germany, where approximately 70 percent of the agricultural area is insured. Although there are no official statistics concerning the percentage of apple production insured, it can be assumed that insurance is widespread to manage hail risk in fruit production. Porsch *et al.* (2018) found that 48 percent of surveyed fruit producers in Germany use hail insurance and 27 percent use anti-hail nets. Anti-hail nets have only become more important in recent years (Handschack, 2013).

Beside hail protection, anti-hail nets also reduce the risk of sunburn, which could lead to yield losses as well. However, there are also problems impeding the use of anti-hail nets including, e.g., delayed fruit coloring, more time needed until maturity, smaller fruit sizes and greater efforts for treatments against pest and diseases (Iglesias and Alegre, 2006). Technological improvements in net characteristics have reduced some of the problems associated with anti-hail net use (Iglesias and Alegre, 2006). In a previous study (Gandorfer *et al.*, 2016), notable differences have been identified between the two instruments in terms of their ability to mitigate hail risk. Anti-hail nets can help prevent yield and/or quality losses caused by hail and thus, the potential loss of the relationships to wholesale markets, food retailers or consumers due to the inability to fill orders are avoided. This is an important advantage over hail insurance, because direct marketing and marketing via wholesale play an important role for German fruit farms. German apple producers sell on average 22 percent of their production through wholesales markets and 12 percent through direct marketing (Gandorfer *et al.*, 2017). Both marketing channels require reliable delivery to sustain customer relationships. When selling through producer organizations, shortfalls in deliveries caused by hail only play a minor role. This can be explained by the position of the farmer in the value chain. When selling through producer organizations, farmers transfer the marketing task to the producer organization. Furthermore, they do not agree a defined amount of yield with the producer organization in advance.

Hail insurance is an indemnity insurance, meaning that the coverage includes the monetary yield and quality loss as a percentage of the agreed insured amount. The agreed insured amount should reflect the expected revenue, and it must be reported to the insurance company annually. The insurance period begins on the first day of January and ends on the last day of December. At the beginning of the growing season, neither yield nor price expectations are foreseeable. Therefore, fruit producers can report the expected revenue (insured amount) until the end of May (Keller, 2010). Farmers can decide what

Table I. Three most important risk sources in apple production for different production areas in Germany

Rank	North Germany (Niederelbe)	South Germany (Lake Constance)
1	Hail	Hail
2	Late frost	Drought
3	Flood	Late frost

Source: Gömann *et al.* (2015)

amount of the expected revenue to cover. According to Vercammen and Pannell (2000), the optimal insurance coverage is below 100 percent due to background risk, which occurs as a result of other sources of price and yield variability that are not covered by hail insurance.

The installation of an anti-hail net is a capital-intensive and long-term investment decision and can be considered as a technology adoption that cannot be adapted to yearly expected revenues. Therefore, hail insurance provides more flexibility to the farmer compared to anti-hail nets. The costs for hail insurance depend on two factors, the local hail risk and the agreed insured amount. This implies that with increasing yield potential the cost for hail insurance per ton of apples increases linearly. The cost of hail insurance ranges between 4 and 11 percent of the insured amount per hectare and year, depending on the local hail risk. The costs for anti-hail nets are constant and independent of the local hail risk and the expected revenue. However, the costs for anti-hail net per ton of apples decrease with increasing yield potential of the orchard (Iglesias and Alegre, 2006). The remaining risk in the case of hail insurance is the chosen deductible, whereas in the case of anti-hail nets the remaining risk comprises the potential occurrence of damages to the anti-hail net system or the anti-hail net itself. In contrast to most EU28 countries and the USA, hail insurance in Germany is not subsidized (Bielza Diaz-Caneja *et al.*, 2009; Gesamtverband der Deutschen Versicherungswirtschaft e.V, 2016). Although German fruit farmers are not very satisfied with hail insurance (Porsch *et al.*, 2018) the German Farmers' Association (DBV) requests a state subsidy, especially for multiple peril crop insurance (German Farmers' Association (DBV), 2017; Röhrig *et al.*, 2018).

For anti-hail nets, farmers can receive subsidies between 15 and 50 percent of the investment (Gömann *et al.*, 2015). The subsidy amount depends on the respective subsidy program. Within the government program ("Agrarinvestitionsförderung"), farmers can receive 15 percent of the investment. Further, recognized producer organizations provide a subsidy program for risk management and crisis management to their members, which include a subsidy of anti-hail nets up to 50 percent of the investment (Gömann *et al.*, 2015). The main purpose of recognized producer organizations consists in strengthening farmers' position in the value chain by pooling the produced products. The producer organizations themselves have contracts with the customers (e.g. wholesale markets or food retailers) with a concrete amount of yield explicitly stated. Therefore, they have an interest that farmers can deliver their products and offer a subsidy for anti-hail nets to their members.

Subsidy programs have led to an increase in the installation of anti-hail nets. However, only few studies provide an economic analysis of the use of anti-hail net or hail insurance to mitigate hail risk in fruit production. Furthermore, hail risk management decisions should not be based solely on the expected net returns, but should also consider uncertainties and farmers' attitudes toward risk, since anti-hail nets and hail insurance affect the variance and skewness of profits. Therefore, the expected utility approach is applied where the farmers' objective is to choose the hail risk management option that results in the highest expected utility. The advantage of this approach is that hail risk management options can be compared considering farmers' risk aversion, site conditions (e.g. local hail risk, yield potentials) and relevant farm characteristics.

The objective of this paper is to conduct a detailed risk analysis comparing different strategies to manage hail risk (insurance, anti-hail net) on the basis of a time series (2005–2014) of orchard-specific hail risk and hail damage data for 105 Bavarian apple orchards (Versicherungskammer Bayern, 2016). The analysis will consider differences in local hail risk and yield potential. Furthermore, the objective is to analyze the effect of risk aversion and different financial situations on the ranking of the analyzed risk management options. Finally, the study aims to offer recommendations for the optimal risk management strategy based on farm-specific conditions, e.g., the financial situation, local hail risk and yield potential.

2. Literature review

Studies which directly compare the risk effects of anti-hail nets and hail insurance in fruit production are rare. However, a comparable decision situation that is well studied in agricultural economics is the choice to use irrigation systems or instead to acquire drought insurance. The decision situation is comparable, as in both cases (hail insurance vs anti-hail nets and drought insurance vs irrigation) a technology (self-insurance strategy) is compared with a financial instrument (market-based strategy) in terms of its effectiveness in managing a specific weather risk.

A wide body of studies use regression analysis to analyze farmers' actual risk management behavior, e.g., factors influencing the actual choice of risk management instruments. However, studies using an expected utility approach to analyze factors influencing the optimal risk management decision are rare due to extensive data requirements, e.g., time series of site-specific yield losses. Three studies have been identified that compare irrigation and drought insurance with an expected utility approach. These studies were analyzed to identify relevant factors that may apply to the assessment of hail insurance (market-based strategy) vs anti-hail nets (self-insurance strategy). Furthermore, two recent studies analyzed different risk management strategies for specialty crops.

Barham *et al.* (2011) compared different combinations of irrigation and the use of crop insurance or put options for a representative cotton farm in the Texas Lower Rio Grande Valley (USA). In simulations where irrigation was required often, irrigation technology provided a higher expected utility than insurance. In the case of low need for irrigation (low local drought risk), insurance was preferred across all levels of risk aversion.

Lin *et al.* (2008) compared the use of a weather derivative (rain-based index insurance) and irrigation using an expected utility model. The authors found that across all levels of risk aversion the expected utility of irrigation was higher than the expected utility of the weather derivative.

Dalton *et al.* (2004) analyzed the use of different irrigation systems and crop insurance (multiple peril crop insurance with different coverage levels ranging from 50 to 75 percent of total yield) for a potato farm in Maine (USA). In all simulations, they found that irrigation stabilized yield variability. Nevertheless, the authors only partly confirmed the risk-reducing benefits of irrigation, because in years with no need for supplemental irrigation the investment cost of the irrigation technology had a negative impact on revenue. The alternative risk-reducing strategy analyzed in the study by Dalton *et al.* (2004) was the use of multiple peril crop insurance. Crop insurance was found to provide the lowest expected utility, which can be explained by the high deductible (highest available coverage level is only 75 percent of the expected yield). Therefore, the authors concluded that "current premium subsidies and production guarantee levels are inefficient at reducing producer exposure to rainfall risk" (Dalton *et al.*, 2004, p. 227). However, in the case of irrigation, the expected utility increased with higher levels of risk aversion.

Ho *et al.* (2018) examined different risk management strategies (high-tunnels, crop insurance and weather insurance) for small and medium sized sweet cherry producers in Michigan and New York State. The authors used several criteria, e.g., expected net returns, coefficient of variation, and distribution of net returns, to compare high tunnels, crop insurance and weather insurance (frost insurance, harvest rain insurance). They found that all risk management scenarios (insurances, high tunnels) are improvements compared to the status quo (no risk management). At higher levels of revenue, high tunnels are more effective than the insurance options analyzed.

For the two main apple production areas in Germany, Röhrig *et al.* (2018) compared different strategies of managing weather-related risks (hail and frost). For the southern production area, which is also the focus of this study, they compared the risk management instruments anti-hail net and hail insurance. The loss ratio due to hail is assessed with the fixed value method and a contribution rate of 21 percent is assumed. They found that for all scenarios (different apple varieties and plant densities) and across all levels of risk aversion, the certainty equivalents of the hail insurance were smaller than those of the anti-hail net.

Although initial wealth plays an important role in an expected utility framework, no detailed analyses on different wealth levels were conducted in these prior studies (Dalton *et al.*, 2004; Lin *et al.*, 2008; Barham *et al.*, 2011; Röhrig *et al.*, 2018). To summarize, studies using an expected utility approach have revealed various factors influencing the assessment of risk management instruments: risk aversion, local risk due to weather events, the functionality of the instrument and its costs. Because each of the studies about drought risk management described above modeled a single representative farm, different yield potentials were not considered. Nevertheless, yield potential plays an important role in determining costs. With increasing yield, the cost per ton of yield decreases in the case of a technical instrument and increases in the case of a financial instrument (Gandorfer *et al.*, 2016).

3. Data and methods

3.1 Risk model

An expected utility framework is used to model the decision situation of whether to opt for no hail risk management, acquire hail insurance or install an anti-hail net. Within this framework, local hail risk, farmers' risk aversion and initial wealth are considered. To describe farmers' utility, we employ the following functional form:

$$U = c + d\, W_t^{(1-R)} \tag{1}$$

where R is relative risk aversion, W_t is total wealth, c and d are constants that do not influence the ranking of hail risk management options (O'Connell *et al.*, 2003). The utility function implies constant relative risk aversion and decreasing absolute risk aversion. To capture a relevant range of farmers' risk attitudes, relative risk aversion coefficients ranging from $R=0$ (risk-neutral) to $R=4$ (very risk-averse) were analyzed (see also Anderson and Dillon, 1992, p. 55). To calculate the expected utility of a specific hail risk management option, the following equation is used:

$$E(U(W_t)) = \sum_{i=1}^{n} U(W_{in} + S + NR_i) \cdot prob(i) \tag{2}$$

where W_{in} indicates initial wealth, S are farm subsidies, NR_i are net returns of the hail risk management option in year i, $prob(i)$ is the probability of year i. Each of the years i of the ten-year time series was assigned an equal probability of 0.1. Farm subsidies S are decoupled direct payments on a per hectare basis, which are provided as a part of European Union's common agricultural policy. These subsidies are independent of initial wealth. NR_i of different hail risk management options under study are calculated by subtracting the sum of variable and fixed production costs and hail risk management costs from revenues and, if applicable, indemnity payments:

$$NR_i = (Y_i \cdot P_i + I_i - vCP_i - CHRM_i - fCP) \times A \tag{3}$$

where Y_i indicates the apple yield in year i, P_i is the producer price for apple in year i, I_i is the indemnity payment in year i, vCP_i are the variable production costs in year i, $CHRM_i$ are hail risk management cost in year i (i.e. annualized cost of anti-hail net; insurance premium), fCP are fixed production cost including land rents, and A is farm size. The data set made available by the insurance company provides no information on the individual farm sizes. Therefore, based on the statistics of the Bundesministerium für Ernährung, Landwirtschaft und Verbraucherschutz (BMELV) (2016), it is assumed that the average farm size is 22 hectares.

Hail insurance premiums depend on the site-specific hail risk and the agreed insured amount. Site-specific hail risk is reflected in the insurance premium rate. The premium rate of a single orchard can vary over time depending on the occurrence of hail events. The costs for hail insurance are calculated as a product of the insured amount in year i and the premium rate:

$$CHRM_{i,\,I} = (Y_i \cdot P_i) \times PR_i \tag{4}$$

where $CHRM_{i,I}$ indicates cost for hail insurance in year i, Y_i is the apple yield in year i, P_i is the producer price for apples in year i, and PR_i is the premium rate.

The indemnity payment in the case of a hail event is calculated as the product of insured amount and loss ratio adjusted for the selected deductible (shown in the following equation). It is assumed that the insured amount is equal to the expected revenues in year i and, therefore, can be calculated as the product of yield and price:

$$I_i = (Y_i \cdot P_i) \times (LR_i - D) \tag{5}$$

where I_i indicates indemnity payment in year I, Y_i is the apple yield in year i, P_i is the producer price for apples in year i, LR_i is the loss ratio in year i indicating the hail damage (%) assessed by the insurance company, and D is the selected deductible (10 percent). The amount of the deductible is common for specialty crops in Germany and was provided by the insurance company. However, farmers can increase the deductible to reduce the insurance premium (Keller, 2010). To receive an indemnity payment, the assessed loss ratio must be more than 10 percent.

Since expected utility is modeled based on a time series of net returns that are calculated with year-specific prices and yields, the applied model accounts for both price and yield risks. To facilitate the interpretation of the modeled expected utility values, the corresponding monetary certainty equivalent values *CE* are calculated (see Martin *et al.*, 2001):

$$CE_R = (1-R)E(U_R)^{\frac{1}{1-(R)}}; R \neq 1 \tag{6}$$

Finally, a utility-maximizing farmer will choose the hail risk management strategy that shows the highest certainty equivalent value. Thus, the advantage of hail risk management strategy A compared to an alternative strategy B, assuming a specific level of risk aversion, can be expressed as the difference between the CE values (Δ CE) of the two strategies.

3.2 Data and assumptions

The data used in this study are insurance data from 105 apple orchards located in the German state of Bavaria. For a ten-year period (2005–2014), the data set comprises the geographical position of the individual orchard, the premium rate for the orchard and year, and the assessed loss ratio per year, if a hail event had occurred. All other data needed as input variables for the model have been generated from official statistics. Because no farm-specific data were used, self-selection is considered negligible.

To compare the different strategies, all three scenarios (no instrument, hail insurance and anti-hail net) have been calculated for each orchard and year. The historical loss ratios of each orchard over ten years enabled the analysis of the efficiency of the three analyzed strategies to manage hail risk.

3.2.1 Yield data. Because orchard-specific yield data were not available, a time series of corresponding regional apple yield data from 2005 to 2014 were used (Destatis, 2005-2015). The aggregated yield data on county level may lead to underestimation of the yield risk, and thus to an underestimation of the potential advantages of the risk management instruments, especially in case of hail insurance. If the expected revenue decreases due to lower yields, the negative effect of the fixed costs of anti-hail net on farms' liquidity as well as the positive effect of the possibility to adapt expected revenue annually in the case of hail insurance will be underestimated.

For each orchard, detailed information on the geographical location is available. According to this information, corresponding regional yields were allocated. Therefore, in the case of no hail risk mitigation and hail insurance, Y_i corresponds to the regional apple yield in year i adjusted for farm-specific hail damage in year i. For the group where an anti-hail net was installed, Y_i corresponds to regional apple yield in year i. In the five different regions of Bavaria, mean regional apple yields ranged between 13 and 37 tha^{-1} (Table II). The use of aggregate yield data is a limitation of the present study, which may lead to an underestimation of yield variability.

3.2.2 Price data. For the study, marketing channel-specific nominal apple prices were obtained from the Agricultural Market Information Company for the period from 2005 to 2014. The marketing channel producer organizations are used, because the majority of farmers (54 percent) are selling their apples via producer organizations. The bias due to the aggregated price data is assumed to be small due to the high concentration of food retailing in Germany, indicating that there is high price pressure and low differences in prices among different producer organizations.

All nominal data were converted to real prices using the producer price index deflator "consumer price index" obtained from the German Federal Statistical Office (Destatis, 2016). The apple varieties Braeburn, Gala and Jonagold are the most common varieties cultivated on German fruit farms (Destatis, 2005-2015). Therefore, an average mixed price was calculated using the producer prices for these varieties and assuming equal shares of the three varieties (Table III). Furthermore, the assumption was made that 90 percent of the harvest will be of fresh apple quality and the remaining 10 percent will be of the quality used for processing (Peter *et al.*, 2013). Moreover, it is assumed that apple prices do not rise significantly after a hail event, because in contrast to frost, which often occurs as an accumulative risk, hail leads to small-scale damages, in most cases.

3.2.3 Wealth levels. To show the sensitivity of certainty equivalents to different levels of initial wealth, two different situations were considered in the analysis. The first situation uses an average German fruit farm of 22 ha size with a 50 percent share of owned land, where an initial wealth W_{in} of €35,746ha^{-1} is assumed. In the second situation, initial wealth

	Yield (t ha^{-1})				
Year	Upper Franconia	Lower Franconia	Upper Bavaria	Lower Bavaria	Swabia
2005	7	18	10	15	33
2006	13	40	12	20	26
2007	19	43	18	20	43
2008	18	44	18	37	30
2009	19	32	15	24	31
2010	13	23	10	22	26
2011	15	40	17	25	36
2012	28	31	13	29	35
2013	25	40	9	22	25
2014	30	54	9	36	38
Mean	19	37	13	25	32
STD	7	11	4	7	6
CV (%)	26	34	36	35	54

Notes: STD, standard deviation; CV, coefficient of variation
Source: Destatis (2005-2015)

Table II.
Annual regional apple yields

Year	Fresh apple prices (€ t^{-1}) Braeburn	Gala	Jonagold	Processing apples (€ t^{-1}) Braeburn	Gala	Jonagold	Weighted average price (€ t^{-1})
2005	490	574	768	426	481	730	593
2006	517	522	903	421	455	848	624
2007	521	556	892	443	477	842	634
2008	576	599	1,089	501	522	1,029	730
2009	472	530	1,068	460	459	994	663
2010	515	531	828	430	450	778	602
2011	534	657	1,054	432	526	992	720
2012	588	711	477	527	605	469	584
2013	633	815	626	597	681	622	684
2014	422	706	542	402	578	542	552
Mean	527	620	825	464	523	425	638
STD	61	99	220	60	76	90	59
CV (%)	12	16	27	13	15	21	9

Notes: STD, standard deviation; CV, coefficient of variation
Source: Agricultural Market Information Company (2015)

Table III. Annual real apple producer prices

(indicating a low equity cover) is set to €19,332ha^{-1}, representing a farm of 22 ha size with a share of rented land of 90 percent (BMELV, 2016). The second situation was analyzed to specifically show the effect of different hail management options for farms with a low risk-bearing capacity. Therefore, the difference in initial wealth comprises the lower level of land assets. Subsidies (mainly direct payments) for an average German fruit farm amount to €367 ha^{-1} (BMELV, 2016). The initial wealth does not influence the amount of the subsidy provided for installing an anti-hail net.

3.2.4 Production costs. Variable and fixed costs for year-specific yields Y_i are calculated using the Association for Technology and Structures in Agriculture (KTBL) net return calculator for apple production (Kuratorium für Technik und Bauwesen in der Landwirtschaft, 2016). The production costs are yield-dependent, and due to the aggregated yield-level, they will be underestimated. As the cost risk is of lesser importance in apple production, this underestimation is negligible (Hartwich *et al.*, 2015). Total production costs for the scenario "average wealth" are shown in Table IV.

Year	Total production cost (€ ha^{-1}) Upper Franconia	Lower Franconia	Upper Bavaria	Lower Bavaria	Swabia
2005	5,968	7,097	6,282	6,736	8,606
2006	6,521	9,291	6,415	7,227	7,887
2007	7,136	9,620	7,030	7,268	9,665
2008	7,064	9,732	7,123	9,030	8,329
2009	7,156	8,481	6,804	7,699	8,411
2010	6,531	7,598	6,291	7,464	7,845
2011	6,777	9,343	6,979	7,811	8,934
2012	8,110	8,369	6,538	8,200	8,853
2013	7,731	9,373	6,138	7,442	7,794
2014	8,336	1,0768	6,189	8,938	9,120
Mean	7,133	8,967	6,578	7,781	8,544
STD	744	1,087	374	742	613
CV (%)	10	12	6	10	7

Notes: STD, standard deviation; CV, coefficient of variation

Table IV. Annual regional total production costs (€ ha^{-1}) for the average wealth scenario

The production costs in the scenario "low wealth" are 6 percent higher due to the higher share of rented land.

3.2.5 Hail protection costs. Orchard-specific premium rates provided by an insurance company were used to calculate hail insurance premiums (Versicherungskammer Bayern, 2016). The premium rate is determined by the local hail risk, a crop-specific surcharge or discount indicating crop-specific sensitivity to hail, and the insurer's margin. In Germany, three insurance companies offer hail insurance for specialty crops. All of them have committed to using a general hail statistic provided annually by the German Insurance Association (GDV) for assessing local hail risk. Therefore, premium rates reflected in this data set are applicable all over Germany and not limited to customers of the specific insurance company providing the data set. Premium differences may exist only due to discounts. The baseline of the study's sample comprises orchards that are insured. There are no data for orchards that are not insured. However, any possible bias can be neglected, because hail risk cannot be influenced by the policyholder (Keller, 2010).

The costs for installing an anti-hail net are assumed to be 1,800 € ha^{-1} per year (Iglesias and Alegre, 2006; Dierend *et al.*, 2009) reduced by the generally available investment subsidy of 15 percent (see Gömann *et al.*, 2015, p. 138). The investment subsidy is assumed at 15 percent, because higher subsidies require membership in a recognized producer organization and, thus, are not relevant for the majority of apple producers. To maintain the anti-hail net, there are yearly operating costs, amounting up to Euro 91.30 per hectare per year (Dierend *et al.*, 2009). These costs have been added to the fixed costs less the investment subsidy.

4. Results and discussion

For all 105 orchards, net returns, expected utilities and corresponding certainty equivalents for the three risk management strategies (no hail risk mitigation, hail insurance and anti-hail net) and different risk aversion levels were calculated on a one-hectare level. In accordance with the yield potential, orchards were grouped into low or high yield potential groups. The mean yield of all orchards in the sample was 25.2 tha^{-1} (Table II). The criterion for assignment to the low yield category was a mean yield below 25 tha^{-1}, and for the high yield category a mean yield above 25 tha^{-1}. Second, yield potential groups are separated according to the insurance premium rate. The premium rate of hail insurance for apple production in Germany is based on local hail risk, and ranges between 0.08 and 0.40 (Versicherungskammer Bayern, 2016). Within the sample, the lowest premium rate was 0.12, the highest was 0.29 and the mean was 0.20, which corresponds to the average Bavarian hail risk (Versicherungskammer Bayern, 2016). In the low local hail risk group, the premium rate was less than or equal to 0.20, while in the high local hail risk group the premium rate was greater than 0.20.

4.1 The effect of hail risk management on the variability of expected net returns

For groups 1 (low yield, low risk) and 3 (high yield, low risk), the mean net returns of the strategy "no instrument" were highest, whereas for group 2 (low yield, high risk) the mean net returns of the strategy hail insurance and for group 4 (high yield, high risk) the mean net returns of the strategy "anti-hail net" were highest (Table V). With the exception of group 1, both hail insurance and anti-hail nets reduced the coefficient of variation. Comparing hail insurance and anti-hail net, the coefficient of variation is higher for all groups for the anti-hail net strategy. The reason for the lower reduction of the coefficient of variation in the case of anti-hail net lies in the costs of the instruments. These are constant for the anti-hail net, whereas the costs for hail insurance depend on the insured amount. Thus, in years where either the yield or price expectation is low, the insured amount is low and, therefore, the premium is also low. However, the costs for the anti-hail net do not adjust to annual yield

Table V. Statistics of the net returns of the different groups of orchards ($n = 105$) within this study

	G1: low yield, low local hail risk ($n = 3$)			G2: low yield, high local hail risk ($n = 10$)			G3: high yield, low local hail risk ($n = 37$)			G4: high yield, high local hail risk ($n = 55$)		
	No instrument	Hail insurance	Anti-hail net	No instrument	Hail insurance	Anti-hail net	No instrument	Hail insurance	Anti-hail net	No instrument	Hail insurance	Anti-hail net
Mean premium rate		0.16			0.28			0.12			0.24	
Mean loss ratio (%)	0	0	0	23	23	23	5	5	5	16	16	16
Years with hail events	0	0	0	4.2	4.2	4.2	1.4	1.4	1.4	2.8	2.8	2.8
Mean cost for the instrument (€ ha^{-1})	0	1,262	1,621	0	1,197	1,621	0	1,363	1,621	0	2,371	1,621
Low initial wealth, share of rented land 90%												
Net returns (mean in € ha^{-1})	8,355	7,093	6,734	−153	515	466	13,135	12,842	12,972	8,627	9,179	10,517
Standard deviation (€ ha^{-1})	4,409	4,069	4,409	3,578	2,113	2,605	6,384	5,596	6,186	6,615	2,851	3,391
Coefficient of variation (%)	53	57	65	2,335	410	559	49	44	48	77	31	32
Average initial wealth, share of rented land 50%												
Net returns (mean in € ha^{-1})	8,703	7,441	7,082	532	1,132	1,089	13,483	13,190	13,320	9,646	9,875	10,599
Standard deviation (€ ha^{-1})	4,409	4,069	4,409	3,632	2,189	2,698	6,384	5,596	6,186	6,159	3,758	4,303
Coefficient of variation (%)	51	55	62	683	193	248	47	42	46	64	38	41

and price expectations and – especially in years with low yields or prices – the constant costs for anti-hail net reduce net returns even further. This finding is in line with the results of Dalton *et al.* (2004), who concluded that constant costs may deter farmers from investing in risk-reducing technology, such as irrigation.

A higher initial wealth from a higher level of land assets = low share of rented land) has a stabilizing effect on the coefficient of variation of net returns. A lower net return variability indicates a lower need to implement risk management measures. These results confirm the findings of studies analyzing farmers' actual risk management behavior (e.g. Finger and Lehmann, 2012; Foudi and Erdlenbruch, 2012; Chakir and Hardelin, 2014). These studies show that increasing wealth has a negative effect on the willingness to implement risk management instruments.

4.2 The effect of hail risk management strategies on certainty equivalents

Based on the calculated expected utility of the risk management strategy, the certainty equivalent was derived for various individual levels of relative risk aversion. A positive (negative) difference (ΔCE in € ha^{-1}) between two risk management strategies indicates a higher (lower) expected utility for the first-named strategy (Table VI). In general, the differences between the certainty equivalents for the choice to implement no hail risk mitigation and both hail risk mitigation strategies were lower for farms with high initial wealth than for those with lower initial wealth, for all groups.

In case of low yield potential and low local hail risk (group 1), the certainty equivalents were highest when no hail risk management was adopted. For orchards with a high yield potential and a high local risk (group 4), anti-hail net is across all levels of risk aversion and independently of initial wealth, the risk management strategy with the highest certainty equivalents. These findings correspond with findings by Röhrig *et al.* (2018) that in the region around Lake Constance (region with high yield potential and high local risk), hail insurance is not an appropriate alternative to anti-hail net in terms of certainty equivalents.

For orchards with a low yield potential and a high local risk (group 2), the certainty equivalents were highest when hail insurance was used. This observation can be explained by the greater flexibility of the hail insurance in terms of costs, especially in years with low revenues. Until the end of May, farmers can inform the insurance company about the expected revenue (insured amount) of the orchard and, therefore, they can adopt the insurance premium to their yield and price expectations. For group 2 (low yield, high local hail risk), the positive impact of the flexibility of hail insurance is shown through the analysis of the costs per ton of apples. In the case of hail insurance, increasing site-specific yield leads to constant costs per ton of apples because the insurance premium also increases linearly. In the case of the installation of an anti-hail net, the cost per ton of apples decreases with increasing yields. For the orchards in group 2, the costs for anti-hail net installation per ton of apples were considerably higher than those for hail insurance due to the low yield potential. Especially in years with low revenues, this can lead to a risk-increasing effect, because the high costs for installing an anti-hail net would further reduce profits. However, the costs for hail insurance would be lower in years with low revenues due to the possibility of adapting hail insurance annually to reflect revenue expectations. These findings were not sensitive to the different levels of initial wealth.

For orchards with a high yield potential and a high local hail risk (group 4), both hail insurance and anti-hail net showed higher certainty equivalents compared to the strategy of not adopting any hail risk mitigation. Anti-hail net was preferable to hail insurance regarding the certainty equivalents in all constellations analyzed. The costs for the instruments have a greater impact on the ranking of the different management options than risk aversion. With increasing yield, the costs for the anti-hail net per ton of apples decrease, whereas the costs for hail insurance increase. The insurance costs also increase with increasing local hail

Table VI. Differences in certainty equivalents for the net returns (€ ha^{-1}) of the different risk management strategies (no instrument, hail insurance and anti-hail net) (subsidy level = 15 percent)

Relative risk aversion (RRA)	G1: low yield, low local hail risk ($n=3$) Insurance/no instrument	Anti-hail net/no instrument	Insurance/anti-hail net	G2: low yield, high local hail risk ($n=10$) Insurance/no instrument	Anti-hail net/no instrument	Insurance/anti-hail net	G3: high yield, low local hail risk ($n=37$) Insurance/no instrument	Anti-hail net/no instrument	Insurance/anti-hail net	G4: high yield, high local hail risk ($n=55$) Insurance/no instrument	Anti-hail net/no instrument	Insurance/anti-hail net
Low wealth												
RRA = 0	−1,262	−1,621	359	668	619	49	−293	−163	−130	552	1,889	−1,338
RRA = 2	−1,207	−1,655	448	1,075	923	151	−45	−151	106	2,283	3,533	−1,249
RRA = 3	−1,184	−1,669	485	1,282	1,082	199	57	−184	241	3,338	4,544	−1,206
RRA = 4	−1,166	−1,683	517	1,488	1,244	244	133	−243	376	4,378	5,541	−1,163
Average wealth												
RRA = 0	−1,262	−1,621	359	600	557	43	−293	−163	−130	220	948	−728
RRA = 2	−1,220	−1,634	415	808	704	104	−124	−137	13	781	1,421	−640
RRA = 3	−1,201	−1,640	439	911	777	135	−47	−139	92	1,095	1,689	−594
RRA = 4	−1,185	−1,645	461	1,013	849	164	22	−151	173	1,421	1,968	−547

risk, whereas the costs for the anti-hail net are independent of the hail risk. This observation corresponds with Barham *et al.*'s (2011) conclusion that, based on the calculated certainty equivalents regarding drought risk, at lower drought risk levels farmers preferred insurance and at higher levels of drought risk irrigation technologies were considered preferable. Further empirical studies analyzing the usage of drought insurance and irrigation technology show similar results. With increasing local drought risk, the probability that a farmer will choose to either use irrigation technology or crop insurance increases (e.g. Foudi and Erdlenbruch, 2012; Chakir and Hardelin, 2014). Finger and Lehmann (2012) ascertained that with increasing local hail risk, the use of hail insurance increases.

In contrast to groups 1 (low yield potential, low local hail risk), 2 (low yield potential, high local risk) and 4 (high yield potential, high local hail risk), risk aversion has an effect on the ranking of hail risk management options for group 3 (high yield potential, low local hail risk). For group 3, the certainty equivalent of no hail risk mitigation was always higher compared to that for the use of anti-hail net across all levels of risk aversion, and up to a relative risk aversion of 1 (for low initial wealth) or 2 (average wealth) when compared to hail insurance (see Figure 1).

The advantage of hail insurance for this group of orchards can be explained by the costs of the instruments. Due to the heterogeneity of site-specific hail risk, there is a range of premiums per hectare for hail insurance, whereas the costs for anti-hail net are independent of the local hail risk. These findings are in line with Dalton *et al.* (2004), who found that fixed costs can reduce the incentive to implement irrigation technology in the case of low local drought risk. Hence, the flexibility of hail insurance in terms of costs may be an advantage for farmers who are more risk-averse or are in a tense financial situation. This observation is supported by empirical studies analyzing the implementation of irrigation technology to manage drought risk. Ihli *et al.* (2012) found that risk-averse farmers tend to invest earlier in irrigation technology compared to less risk-averse farmers, but they also disinvest earlier than their less risk-averse counterparts. Viscusi *et al.* (2011) pointed out that an individual with higher risk aversion should make lower investment decisions.

Finally, the effect of the level of subsidy is analyzed. In the basic scenario of this study, a subsidy of 15 percent is assumed. To analyze the effect of the subsidy, different levels have been included in the calculation. First, no subsidy of anti-hail net is assumed. As the results indicate (see Table VII), the subsidy level of 0 percent has no effect on the general ranking of the risk management strategies with exception of group 3.

In this group, the results show that hail insurance dominates anti-hail nets even for risk neutral or risk averse decision makers. Second, the scenarios are calculated with a 50 percent subsidy of anti-hail net. Although there is no change in the most efficient strategy against hail risk for groups 1 and 4, for orchards in groups 2 and 3, anti-hail net becomes the

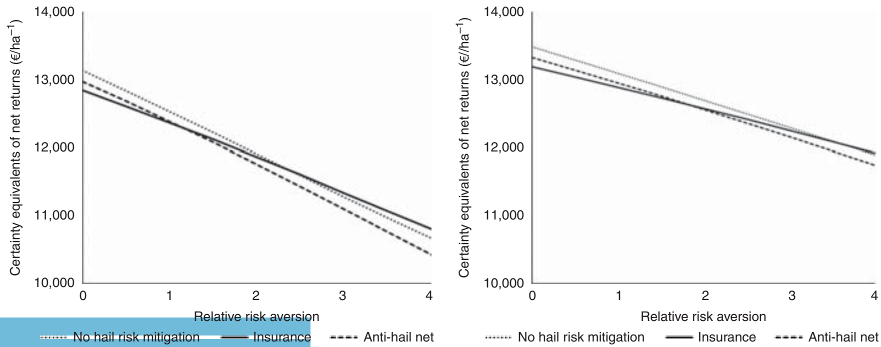

Figure 1.
Certainty equivalents for group 3 (high yield potential, low local hail risk) for different initial wealth levels

Table VII. Differences in certainty equivalents for the net returns (€ ha^{-1}) of the different risk management strategies (no instrument, hail insurance, anti-hail net) (level of subsidy = 0%)

Relative risk aversion (RRA)	G1: low yield, low local hail risk (*n* = 3) Insurance/ no instrument	G1 Anti-hail net/no instrument	G1 Insurance/ anti-hail net	G2: low yield, high local hail risk (*n* = 10) Insurance/ no instrument	G2 Anti-hail net/no instrument	G2 Insurance/ anti-hail net	G3: high yield, low local hail risk (*n* = 37) Insurance/ no instrument	G3 Anti-hail net/no instrument	G3 Insurance/ anti-hail net	G4: high yield, high local hail risk (*n* = 55) Insurance/ no instrument	G4 Anti-hail net/no instrument	G4 Insurance/ anti-hail net
Low wealth												
RRA = 0	−1,262	−1,891	629	668	349	319	−293	−433	140	552	1,619	−1,068
RRA = 2	−1,207	−1,931	724	1,075	650	425	−45	−433	388	2,283	3,260	−976
RRA = 3	−1,184	−1,948	763	1,282	807	475	57	−473	530	3,338	4,270	−931
RRA = 4	−1,166	−1,963	798	1,488	967	521	133	−538	671	4,378	5,266	−887
Average wealth												
RRA = 0	−1,262	−1,891	629	600	287	313	−293	−433	140	220	1,619	−1,068
RRA = 2	−1,220	−1,907	687	808	433	376	−124	−411	287	781	2,477	−1,008
RRA = 3	−1,201	−1,913	712	911	505	406	−47	−416	369	1,095	2,976	−978
RRA = 4	−1,185	−1,920	735	1,013	576	437	22	−431	453	1,421	3,507	−949

most efficient risk management strategy (see Table VIII). Therefore, it can be concluded, that the subsidy of anti-hail net leads to a decline in the competitiveness of hail insurance in some cases.

5. Conclusions

The ongoing climate change process presents major challenges for the agricultural sector. Whereas in cash crop production drought is seen as the most important risk source, hail is the most important source of risk in fruit production (Gömann *et al.*, 2015). Studies comparing alternative strategies for managing the same weather-related risk source are rare. Therefore, this study aimed to compare anti-hail nets (self-insurance strategy through technology) and hail insurance (market-based strategy through a financial instrument) using an expected utility approach and further compare these results with studies analyzing a similar decision situation, namely, irrigation technology vs drought insurance.

The reduction in the variability of net returns is an important reason for farmers to opt for a risk mitigating strategy. It can be concluded that the use of a technology (anti-hail net or irrigation) leads to yield stabilization, but not necessarily to stabilization of net returns. This was especially true in orchards where no hail damage occurred or in the case of drought risk, in cases where no supplemental irrigation was necessary (see Dalton *et al.*, 2004; Barham *et al.*, 2011). However, at higher levels of local risk, the use of a technology to reduce production risk results in lower variability of net returns than no risk mitigation.

For orchards with a low yield potential and a low local hail risk, the strategy of no hail risk management is the most risk efficient strategy. For orchards with a low yield potential and a high local hail risk, the strategy of hail insurance is the most risk efficient strategy, because the costs for hail insurance were considerably lower than those for anti-hail net due to the low yield potential. For orchards with a high local hail risk and a high yield potential, the use of technology is more appropriate because the technology entails constant costs per hectare, independent of the local risk. The dissatisfaction of the policyholders regarding the performance of the insurance strategy (Porsch *et al.*, 2018), which is similar to the studies analyzing management of drought risk (Dalton *et al.*, 2004; Barham *et al.*, 2011), was confirmed by the present study in general terms. Nevertheless, a key result of this study is the finding that hail insurance is preferable to anti-hail net installation at high levels of farmers' risk aversion for the group high yield potential but low local risk. This can be explained by the higher flexibility of hail insurance in terms of annual costs. Another factor in the annual costs of hail insurance is the deductible. Due to the database, the effect of different deductibles could not be considered, because the height of the deductible is an essential risk characteristic in the hail insurance tariff. Nevertheless, this is a question that could be pursued in future studies.

However, technologies offer an essential advantage compared to insurance in terms of mitigating production risk, which cannot be considered in a risk model. Their advantage lies in preventing the potential loss of customer relationships. Especially for farms with direct marketing or selling their apples via wholesale markets or food retailers, the relationship to their customers and therefore, their ability to deliver their products is important. The potential loss of business partners due to limited ability to deliver may also be the reason for the present subsidy policy for anti-hail nets, especially by recognized producer organizations. They pool the farmers' products and undertake the marketing task for them. For this function, they are subsidized by the EU's common agricultural policy. Nevertheless, especially for larger fruit farms the advantages of producer organizations (e.g. joint marketing) are lower. Therefore, it is important for producer organizations to be an attractive partner for producers as well as for customers. For producers, the main functions of producer organizations include ensuring sales as well as reducing income variability (see Bundesministerium für Ernährung, Landwirtschaft und Verbraucherschutz, 2017).

Table VIII.
Differences in certainty equivalents for the net returns (€ ha^{-1}) of the different risk management strategies (no instrument, hail insurance, anti-hail net) (level of subsidy = 50%)

Relative risk aversion (RRA)	G1: low yield, low local hail risk (*n* = 3) Insurance/no instrument	Anti-hail net/no instrument	Insurance/anti-hail net	G2: low yield, high local hail risk (*n* = 10) Insurance/no instrument	Anti-hail net/no instrument	Insurance/anti-hail net	G3: high yield, low local hail risk (*n* = 37) Insurance/no instrument	Anti-hail net/no instrument	Insurance/anti-hail net	G4: high yield, high local hail risk (*n* = 55) Insurance/no instrument	Anti-hail net/no instrument	Insurance/anti-hail net
Low wealth												
RRA = 0	−1,262	−991	−271	668	1,249	−581	−293	467	−760	552	2,519	−1,968
RRA = 2	−1,207	−1,011	−195	1,075	1,562	−487	−45	506	−551	2,283	4,169	−1,886
RRA = 3	−1,184	−1,020	−165	1,282	1,724	−443	57	488	−432	3,338	5,184	−1,846
RRA = 4	−1,166	−1,028	−138	1,488	1,889	−401	133	445	−312	4,378	6,184	−1,806
Average wealth												
RRA = 0	−1,262	−991	−271	668	1,249	−581	−293	467	−760	552	2,519	−1,968
RRA = 2	−1,220	−999	−221	878	1,405	−528	−124	504	−628	1,470	3,381	−1,912
RRA = 3	−1,201	−1,003	−199	982	1,483	−502	−47	508	−555	1,999	3,882	−1,884
RRA = 4	−1,185	−1,006	−179	1,085	1,562	−476	22	501	−479	2,558	4,414	−1,856

For customers, the main function provided by producer organizations is delivery reliability. This function is best served through the anti-hail nets for both producers and customers. However, subsidies of anti-hail nets lead to a decline in the competitiveness of the hail insurance, despite the advantages of insurances in some situations.

Furthermore, technologies to mitigate production risk often generate public controversy. Fruit production is frequently located in regions with high levels of tourism, where hail nets are criticized for having negative effects on the landscape. Comparable to some communities in South Tyrol (Italy), the prohibition of anti-hail nets is also discussed in some communities in Germany (Enderle, 2016). However, in most cases, the purchase of insurance is a viable alternative to anti-hail nets given that differences in the certainty equivalents between technological risk mitigation strategies and insurance are moderate in all cases, except those with high yield potential and high local risk. This public debate shows a trade-off between tourism and agriculture. Both are important employers, and both are subsidized by the government. However, apple production also forms the characteristic landscape in these tourism regions. Future research should, therefore, focus on alternatives for anti-hail nets in case of a prohibition of anti-hail nets and alternative types of anti-hail nets with less impact on landscapes.

If local communities decide to prohibit anti-hail nets, the government could consider an insurance subsidy for those farms belonging to the group with high yield potential and high local hail risk. If the subsidy were coupled with the local hail risk, it might still be conform to the WTO requirements.

The study does not consider the influence of apple varieties (different price and yield levels) on the ranking of risk management strategies. Nonetheless, the results offer an orientation regarding the most efficient risk management strategy depending on the yield and price level of the individual farm. Depending on the farm's marketing channels and the apple varieties planted, a combination of risk management strategies can also be the most suitable option for the farm. An example could be, using anti-hail net for apple varieties that are sold via wholesale or direct marketing and for high-price apples, and using hail insurance for apple varieties with a lower price level or apples that are sold via producer organizations. This may be an explanation for the combination of anti-hail nets and hail insurance, observed by Porsch *et al.* (2018) where 16 percent of the farmers surveyed used both hail insurance and anti-hail nets. For future research, the presented results should be retested with a broader data set, including orchards with different apple varieties, marketing channels as well as risk management strategies, to provide further insights.

References

Agricultural Market Information Company (2015), "Producer prices for different fruit and vegetable crops and different marketing channels", unpublished raw data.

Anderson, J.R. and Dillon, J.L. (1992), *Risk Analysis in Dryland Farming Systems*, Farm Systems Management Series 2, Food and Agriculture Organization of the United Nations, Rome.

Barham, E.H.B., Robinson, J.R., Richardson, J.W. and Rister, M.E. (2011), "Mitigating cotton revenue risk through irrigation, insurance, and hedging", *Journal of Agricultural and Applied Economics*, Vol. 43 No. 4, pp. 529-540.

Bielza Diaz-Caneja, M., Conte, C.G., Pinilla, F.G., Stroblmair, J., Catenaro, R. and Dittmann, C. (2009), "Risk management and agricultural insurance schemes in Europe", available at: http://publications.jrc.ec.europa.eu/repository/bitstream/JRC51982/lr_ipsc_reference_report_agriculture_insurance.pdf (accessed May 2, 2016).

Bundesministerium für Ernährung, Landwirtschaft und Verbraucherschutz (BMELV) (2016), "Buchführungsergebnisse der Testbetriebe 2014/15. haupterwerbsbetriebe. Detaillierte auswertungen nach betriebsformen", available at: www.bmel-statistik.de/landwirtschaft/testbetriebsnetz-landwirtschaft-buchfuehrungsergebnisse/buchfuehrungsergebnisse-landwirtschaft/ (accessed June 7, 2016).

Bundesministerium für Ernährung, Landwirtschaft und Verbraucherschutz (BMELV) (2017), "Nationale Strategie für nachhaltige operationelle programme der Erzeuger-organisationen für Obst und Gemüse in Deutschland", available at: www.bmel.de/SharedDocs/Downloads/Broschueren/NatStrategieObstGemuese.pdf;jsessionid=1C6C5E9E0F8ADA6ED527837CC1C7EC9E.1_cid358?__blob=publicationFile (accessed December 14, 2017).

Chakir, R. and Hardelin, J. (2014), "Crop insurance and pesticide use in French agriculture: an empirical analysis", *Review of Agricultural and Environmental Studies*, Vol. 95 No. 1, pp. 25-50.

Dalton, T.J., Porter, G.A. and Winslow, N.G. (2004), "Risk management strategies in humid production regions. A comparison of supplemental irrigation and crop insurance", *Agricultural and Resource Economics Review*, Vol. 33 No. 2, pp. 220-232.

Destatis (2005-2015), "Baumobsternte. Fachserie 3 (reihe 3.2.1)", available at: www.destatis.de/GPStatistik/receive/DESerie_serie_00000335?list=all (accessed May 03, 2016).

Destatis (2016), "Verbraucherpreise", available at: www.destatis.de/DE/ZahlenFakten/GesamtwirtschaftUmwelt/Preise/Verbraucherpreisindizes/Tabellen_/VerbraucherpreiseKategorien.html?cms_gtp=145120_list%253D1%2526145110_slot%253D2&https=1 (accessed May 5, 2016).

Dierend, W., Baab, G., Balmer, M., Bertram, A., Linnemannstöns, L. and Steinbauer, L. (2009), *Kulturschutzeinrichtungen im Obstbau*, Eugen Ulmer KG, Stuttgart.

Enderle, F. (2016), "Regionaler Obstbau steht vor Herausforderungen", available at: www.suedkurier.de/region/bodenseekreis-oberschwaben/ravensburg/Regionaler-Obstbau-steht-vor-Herausforderungen;art372490,8831777 (accessed December 5, 2017).

Finger, R. and Lehmann, N. (2012), "The influence of direct payments on farmers' hail insurance decisions", *Agricultural Economics*, Vol. 43 No. 3, pp. 343-354.

Foudi, S. and Erdlenbruch, K. (2012), "The role of irrigation in farmers' risk management strategies in France", *European Review of Agricultural Economics*, Vol. 39 No. 3, pp. 439-457.

Gandorfer, M., Hartwich, A. and Bitsch, V. (2016), "Hail risk management in fruit production: anti-hail net versus hail insurance in Germany", *Acta Horticulturae*, Vol. 1132, pp. 141-146.

Gandorfer, M., Porsch, A. and Bitsch, V. (2017), "Producer price volatility in the German fruit and vegetable industry", *European Journal of Horticultural Science*, Vol. 82 No. 3, pp. 149-154.

German Farmers' Association (DBV) (2017), "BOG: risikomanagement für landwirtschaft-liche betriebe verbessern", available at: www.bauernverband.de/bog-risikomanagement-fuer-landwirtschaftliche-betriebe-verbessern (accessed December 04, 2017).

Gesamtverband der Deutschen Versicherungswirtschaft e.V. (2016), "Landwirtschaftliche mehrgefahrenversicherung für deutschland", available at: www.gdv.de/wp-content/uploads/2016/12/09-12-2016_LW_Mehrgefahrenversicherung_Webversion.pdf (accessed May 05, 2017).

Gömann, H., Bender, A., Bolte, A., Dirksmeyer, W., Englert, H., Feil, J.-H., Frühauf, C., Hauschild, M., Krengel, S., Lilienthal, H., Löpmeier, F.-J., Müller, J., Mußhoff, O., Natkhin, M., Offermann, F., Seidel, P., Schmidt, M., Seintsch, B., Steidl, J., Strohm, K. and Zimmer, Y. (2015), "Agrarrelevante Extremwetterlagen und Möglichkeiten von Risikomanagementsystemen: Studie im Auftrag des Bundesministeriums für Ernährung und Landwirtschaft (BMEL)", available at: http://literatur.thuenen.de/digbib_extern/dn055248.pdf (accessed May 5, 2017).

Handschack, M. (2013), "Anbau von Tafeläpfeln unter Hagelnetz unter Sächsischen Bedingungen. Schriftenreihe des Landesamts für Umwelt, Landwirtschaft und Geologie Sachsen (LfULG) 11", available at: https://publikationen.sachsen.de/bdb/artikel/19011/documents/25424 (accessed March 14, 2015).

Hartwich, A., Gandorfer, M. and Bitsch, V. (2015), "Risk management in fruit and vegetable production in Germany", *Acta Horticulturae*, Vol. 1103, pp. 151-158.

Ho, S.-T., Ifft, J., Rickard, B. and Turvey, C. (2018), "Alternative strategies to manage weather risk in perennial fruit crop production", *Agricultural and Resource Economics Review*, pp. 1-25, doi: 10.1017/age.2017.29.

Iglesias, I. and Alegre, S. (2006), "The effect of anti-hail nets on fruit protection, radiation, temperature, quality and profitability of 'Mondial Gala' apples", *Journal of Applied Horticulture*, Vol. 8 No. 2, pp. 91-100.

Ihli, H., Maart, S.C. and Musshoff, O. (2012), "Investment and disinvestment in irrigation technology – an experimental analysis of farmers' decision behavior", paper presented at the Joint Annual Meeting of the American Agricultural Economics Association, Seattle, WA, August 12-14, available at: http://ageconsearch.umn.edu/record/124532/files/Investment%20and%20Disinvestment%20in%20Irrigation%20Technology.pdf (accessed March 14, 2015).

Keller, J. (2010), "Ernteversicherungen als Risikomanagementinstrument:Eine Analyse von Versicherungstypen und Tarifierungsmodellen", Insurance as a risk management tool: An analysis of insurance types and pricing models, available at: http://geb.uni-giessen.de/geb/volltexte/2010/7816/ (accessed December 14, 2016).

Kunz, M. and Puskeiler, M. (2010), "High-resolution assessment of the hail hazard over complex terrain from radar and insurance date", *Meteorologische Zeitschrift*, Vol. 19 No. 5, pp. 427-439.

Kunz, M., Sander, J. and Kottmeier, C. (2009), "Recent trends of thunderstorm and hailstorm frequency and their relation to atmospheric characteristics in southwest Germany", *International Journal of Climatology*, Vol. 29 No. 15, pp. 2283-2297.

Kuratorium für Technik und Bauwesen in der Landwirtschaft (2016), "Kalkulationsanwendung Obstbau", available at: www.ktbl.de/inhalte/it-anwendung/ (accessed March 3, 2016).

Lin, S., Mullen, J.D. and Hoogenboom, G. (2008), "Farm-level risk management using irrigation and weather derivatives", *Journal of Agricultural and Applied Economics*, Vol. 40 No. 2, pp. 485-492.

Martin, S.W., Barnett, B.J. and Coble, K.H. (2001), "Developing and pricing precipitation insurance", *Journal of Agricultural and Resource Economics*, Vol. 26 No. 1, pp. 261-274.

Mohr, S. and Kunz, M. (2013), "Recent trends and variabilities of convective parameters relevant for hail events in Germany and Europe", *Atmospheric Research*, Vol. 123 No. 1, pp. 211-228.

O'Connell, M., Pannell, D.J. and French, R.J. (2003), "Are high lupin seeding rates more risky in the western Australian wheatbelt?", *Australian Journal of Experimental Agriculture*, Vol. 43 No. 9, pp. 1137-1142.

Peter, G., Kuhnert, H., Hass, M., Banse, M., Roser, S., Trierweiler, B. and Adler, C. (2013), "Einschätzung der pflanzlichen Lebensmittelverluste im Bereich der landwirtschaftlichen Urproduktion. Bericht im Auftrag des Bundesministeriums für Ernährung, Landwirtschaft und Verbraucherschutz (BMELV)", available at: www.bmel.de/SharedDocs/Downloads/Ernaehrung/WvL/Studie_Lebensmittelveerluste_Landwirtschaft.pdf?__blob=publicationFile (accessed June 3, 2017).

Porsch, A., Gandorfer, M. and Bitsch, V. (2018), "Risk management of German fruit producers", *Review of Agricultural and Applied Economics*, Vol. 21 No. 1, pp. 10-22.

Röhrig, M., Hardeweg, B. and Lentz, W. (2018), "Efficient farming options for German apple growers under risk—a stochastic dominance approach", *International Food and Agribusiness Management Review*, Vol. 21 No. 1, pp. 101-120.

Vercammen, J. and Pannell, D.J. (2000), "The economics of crop hail insurance", *Canadian Journal of Agricultural Economics*, Vol. 48 No. 1, pp. 87-98.

Versicherungskammer Bayern (2016), "Orchard-specific hail risk and hail damage data for Bavarian apple orchards", unpublished raw data.

Viscusi, W.K., Phillips, O.R. and Kroll, S. (2011), "Risky investment decisions: how are individuals influenced by their groups?", *Journal of Risk and Uncertainty*, Vol. 43 No. 2, pp. 81-106.

Corresponding author
Annkatrin Porsch can be contacted at: annkatrin.porsch@tum.de