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ORIGINAL ARTICLE

Modelling the switch from hail insurance to antihail nets

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Abstract

We analyse the impact of the antihail net promotion on the actuarial soundness of the hail insurance market. Specifically, we present a simple model showing that, in the presence of an imperfect insurance market, incentives for antihail nets could cause low-risk farmers to exit the insurance market more likely than high-risk ones. This induces a typical adverse selection problem. The theoretical model predictions are corroborated by an empirical investigation. Based on a fixed-effect conditional logit regression, we show that a higher per-hectare output value and a location strongly affected by hail both increase the chance that a plot is hedged through antihail nets.

KEYWORDS

actuarial soundness, agricultural insurance, antihail nets, hail, panel data

JEL CLASSIFICATION

D22, Q12, Q18

1 | INTRODUCTION

In several regions of Europe, hail is a costly weather extreme for agriculture according to the European Environment Agency (Füssel et al., 2017). Punge and Kunz (2016) provide some figures of its economic significance: A hailstorm on the 27th – 28th of July 2013 in the German region of Baden–Württemberg generated 2.8 billion euros of insurance claims, while 2.3 billion were claimed after another hailstorm on the border between France and Belgium on the 8th – 10th of June 2014. Although these damages are not exclusive to agriculture, it is clearly the sector most affected by hail events. Some early studies have tried to assess the percentage losses of agricultural output due to hailstorms. Hübner (1856) estimates a 1% yearly loss in northern Germany and a 3% loss in the southern part of the country. Similarly, Dessens (1986a) estimates a mean yearly agricultural output loss in southern France equal to 3.8%, with a national average of 1% (Dessens, 1986b). For the Po valley in northern Italy, Roncali (1955) provides an estimate of 4% average loss. Similar results have been obtained more recently, with an estimated total output loss of 3% in the Australian region of Darling Downs in Queensland (Chandler et al., 2003).

The situation may become worse in future due to climate change. Thanks to better observation instruments, such as aerial and satellite imagery (Zhou et al., 2016), several studies analyse the role of climate change on hail. Raupach et al. (2021) provide a review of such studies, finding a positive relation between climate change and the frequency of hailstorms, although with strong spatial heterogeneity. For example, the frequency is likely to increase in Europe and Australia but to diminish in North America and in South-East Asia. The lack of a clear effect of climate change on the frequency of hailstorms has been confirmed by Eccel et al. (2012) and by Dessens et al. (2015), while the predictions of Raupach et al. (2021) for Australia and North America have been respectively corroborated by Niall and Walsh (2005) and by Brimelow et al. (2017). With regard to the intensity, there is a widespread belief that it will increase in most regions of the world (Dessens et al., 2015; Eccel et al., 2012; Raupach et al., 2021).

After having discussed the detrimental economic relevance of hail, particularly for the agricultural sector, it is opportune to stress some of the peculiarities characterising the instruments that farmers have at their disposal to hedge against this hazard. First, they can count on insurance, which is probably the most widespread hedging tool in agriculture, dating back to the beginning of the 20th century (see, e.g. the U.S. Agricultural Adjustment Act 1938). However, agricultural insurance is often problematic because the high correlation between the farmers' risk exposure and the relatively scarce adoption rate of insurance contracts poses a serious threat to the sustainability of agricultural insurance markets (Miranda & Glauber, 1997; Sherrick et al., 2004; Smith & Baquet, 1996). Hail hazards are far less problematic than other perils in this regard as it is a highly spatial stochastic phenomenon generally affecting relatively small areas. Thus, hail insurance markets alone could be more easily self-sustainable, whereas agricultural insurance markets in general are often supported through government subsidy programmes partially covering premia (Rogna et al., 2021). This claim may be rendered invalid in future if, under the mentioned enhancing effect of climate change, the hail risk will become more widespread and systemic.

Furthermore, farmers can prevent hail damages by adopting *ex ante* protective measures. In particular, antihail nets have recently become a widespread tool among fruit producers in several parts of the world (Middleton & McWaters, 2002; Porsch et al., 2018a). Through installing antihail nets, farmers have a third option besides the dichotomous choice of remaining unhedged or stipulating an insurance contract. Such a third option is not exclusive to hail risk and in fact a strong analogy exists with drought hazards, which can be mitigated through insurance or through the installation of irrigation systems (Dalton et al., 2004). The analogy goes further, since in both cases the technical device does not provide a complete protection from the weather hazard, making a possible combination of technical device and insurance theoretically viable. However, as testified by several studies, farmers generally perceive the adoption of technical devices and insurance as substitutes rather than complements (Dalton et al., 2004; Porsch et al., 2018b).

Subsidising agricultural insurance schemes has the primary objective of sustaining and stabilising the underlying insurance market with the concurrent aim of supporting farmers (European Commission, 2015). The presence of alternative hedging instruments has therefore not only increased the choice set of farmers, but also the one of governments. Countries such as the United States and Italy continue to subsidise insurance premia. In contrast, Germany has opted to sensibly reduce the support for insurance and, instead, to subsidise the adoption of technical devices. In the Federal State of Bavaria in Southern Germany, for example, farmers installing antihail nets receive a subsidy between 15% and 50% of the investment

(Gömann et al., 2015). Given this wide range of possibilities in policy intervention, including a mix of subsidisation to both instruments, the search of optimality becomes a challenging but stimulating task. Maisashvili et al. (2020), for example, study the possibility and the implications of reshaping the insurance subsidies for three major crops, namely corn, soybean and winter wheat in the United States.

The present paper does not pretend to solve such a complex task, but rather to provide some useful elements to shape an informed debate. Although several papers investigate which instrument, between ex ante technical devices and insurance, is more profitable for different classes of farmers, their analysis is conducted mostly through simulations rather than through econometric estimation (Barham et al., 2011; Dalton et al., 2004; Ho et al., 2018; Lin et al., 2008; Porsch et al., 2018b; Rogna et al., 2021). Furthermore, an aspect that is generally overlooked is that the switch of some farmers from insurance to technical devices may have an impact on the actuarial soundness of the insurance market whenever this market suffers from an imperfect risk assessment. Such an effect may be positive if farmers with a higher risk exposure are the ones more likely to switch to technical devices, or detrimental, in the opposite case. A clear understanding of this effect is crucial to implement optimal subsidy policies, while ignoring it may cause unexpected externalities in the insurance market. We first investigate this question theoretically, sketching a very simple model. Then, we test its validity through an econometric estimation by making use of a unique dataset of apples and wine-grape farmers located in the Italian Region of South Tyrol.

Our empirical analysis partially confirms a previous finding by Porsch et al. (2018b) and by Rogna et al. (2021), showing that antihail nets are generally more profitable than insurance for plots with a higher per-hectare yield. Furthermore, in line with both papers, we find that plots located in areas with a relatively strong hail risk are more profitably hedged through antihail nets rather than insurance. We show that for areas classified by insurance companies as having a homogeneous hail risk profile, the profitability of antihail nets versus insurance turns from being increasing for low levels of risk exposure to be decreasing for high levels, that is showing an inverse U-shaped relation. In simpler terms, if the homogeneity of risk exposure inside a municipality is not as homogeneous as assumed, the variance could cause a problem of adverse selection. For plots with a higher-than-average risk exposure, antihail nets become more profitable than insurance, but this greater profitability declines as the risk exposure increases further. Therefore, plots with mid- to mid–high risk exposure are more likely to be switched to antihail nets than the ones with high- and very high risk exposure. Thus, a typical adverse selection problem emerges, which is potentially problematic for the actuarial soundness of hail insurance markets. Given the mentioned importance of hail risk to agricultural activities and the likely increase in this detrimental phenomenon due to climate change, the paper identifies a potential conflict between the two available hedging instruments: hail insurance and antihail nets. This problem clearly deserves the attention of policymakers willing to implement a subsidisation programme to foster the farmers' adoption of protective measures against hail. To the best of our knowledge, this is the first attempt to point out the mentioned problem.

The paper is structured as follows: Section 2 presents a brief review of the relevant literature. Section 3 introduces the model of insurance versus antihail net profitability, and Section 4 is dedicated to the econometric analysis. Finally, Section 5 concludes.

2 | LITERATURE REVIEW

Two literature strands are particularly relevant to the present analysis. The first focusses on the determinants of agricultural insurance adoption. It is well-established and dating back to the creation of the first Multi-Peril Crop Insurance (MPCI) scheme and subsequent reforms in the United States. Nieuwoudt and Bullock (1985), Goodwin (1993), Goodwin and Kastens (1993), Coble et al. (1996), Smith and Baquet (1996) and Sherrick et al. (2004) are all examples of papers ascribable to this strand of literature. Besides noting a puzzling scarce adoption rate by US farmers of insurance contracts despite the high level of premia subsidisation offered by the MPCI (Babcock, 2015), these papers generally put in evidence a problem of adverse selection. In fact, a common finding is a greater premium elasticity of farmers with a lower insurance profitability, or else, with a lower exposure to risk. The problem of adverse selection and moral hazard has been subsequently confirmed in several other studies, both from a theoretical point of view (Ramaswami, 1993) and from an empirical one (Cohen & Siegelman, 2010; Walters et al., 2014; Wu et al., 2020). Although not explicitly related to insurance adoption, the paper of Ramsey (2020) offers an important contribution to the estimation of yield variance, a crucial aspect to understand the role of climate variability in expected output.

Similar studies have been conducted with a focus on the European market, which is characterised by a greater diversity since the common framework provided by the European Union for the support of agricultural insurance schemes leaves great flexibility to member states in the adoption of specific policies (Cordier & Santeramo, 2020; Meuwissen et al., 2018; Santeramo, 2018). Enjolras and Sentis (2011) examine the determinants of farmers' insurance demand in France, Enjolras et al. (2012) extend the analysis with a comparison between France and Italy, and Santeramo (2019), investigates the role of experience, both private and shared, in fostering the demand for insurance. Among the elements impacting the adoption of agricultural insurance, age and education do not seem to play a major role, with some of the studies finding them not significant and others providing contrasting evidence. Disaster relief programmes, instead, generally have a negative role being perceived as a substitute to insurance (Finger & Lehmann, 2012; Goodwin, 1993), while the greater elasticity to insurance price of farmers with plots less prone to hail risk confirms the problem of adverse selection (Goodwin & Kastens, 1993).

In the econometric literature focussed on agricultural insurance adoption, there are some papers that are particularly relevant to the present study. Since our investigation focusses on the switch from insurance to antihail nets, the papers of Cabas et al. (2008) and Santeramo et al. (2016), which examine the determinants of exit from the insurance market, share a similar point of view. There is, however, a significant difference since we restrict the attention to dropouts motivated by the passage to an alternative hedging instrument. The role of competing hedging strategies has also been investigated by several authors. Both Smith and Baquet (1996) and Finger and Lehmann (2012) consider the effect of disaster relief programmes and direct payments on the demand of agricultural insurance products with the former finding a complementary role and the latter, a substitution effect. Crop diversification is another competing hedging instrument whose impact on insurance demand has been considered. Santeramo et al. (2016) show that diversification decreases the probability of insurance adoption and that it increases the probability of dropping out. A similar result is obtained by Finger and Lehmann (2012), limited to the participation side.

The second relevant strand of literature compares the profitability of insurance contracts and other technical devices for different types of farmers. Such a methodology generally relies on simulations of a utility-maximising representative agent. Adopting this framework, Barham et al. (2011) compare insurance and irrigation systems for cotton farmers in the Texas Lower Rio Grande Valley (US), finding that the profitability of an irrigation system versus insurance is strongly correlated with the farmers' risk exposure to drought. Lin et al. (2008) and Dalton et al. (2004) focus on the comparison of financial hedging instruments and irrigation in the United States. In both papers, the technical device generally outperforms insurance.

Finally, Röhrig et al. (2018), Porsch et al. (2018b) and Rogna et al. (2021) compare the profitability of insurance contracts and antihail nets in apple production, with the former two studies focussing on Southern Germany, whereas the latter on South Tyrol, the same area that we focus on in the present paper. Röhrig et al. (2018) find a greater profitability of antihail nets than insurance for all levels of risk aversion taken into consideration. Porsch et al. (2018b) and Rogna et al. (2021) also include the option of no hedging in their analysis. They find that such an option guarantees the highest certainty equivalent (CE) expected utility for very low values of hail risk exposure and yield potential. Furthermore, they show that the differential profitability of antihail nets and insurance (the difference in CE expected utility obtained by adopting antihail nets or insurance) is an increasing function of both hail risk exposure and yield potential. This finding is confirmed by Rogna et al. (2021), whose results, however, depart from Porsch et al. (2018b) in two significant aspects. The first is the fact that no hedging is never a dominant strategy. The second is the effect of risk aversion that, in Porsch et al. (2018b), is positively correlated with the adoption of insurance rather than antihail nets, whereas this effect is reversed and almost trivial in magnitude in Rogna et al. (2021).

In summarising the two mentioned literature strands, we can say that several elements contribute to shape the demand for agricultural insurance products. Despite the chronic problem of underparticipation that has been solved in several countries, adverse selection and moral hazard are still important threats to the sustainability of agricultural insurance markets (Babcock, 2015). Competing risk-mitigating strategies, including technical devices, are often a significant determinant to enter or exit the insurance market, but do not necessarily imply a negative effect on its actuarial soundness. Assuming an imperfect insurance market, if farmers with a higher-than-average risk exposure adopt alternative risk-mitigating strategies and exit the insurance market, it will actually improve its actuarial soundness. Several studies comparing the profitability of technical devices, namely irrigation and antihail nets, with insurance contracts seem to suggest this possibility. The present paper, however, wants to deepen this aspect that has been, to date, partially overlooked.

3 | MODELLING FARMERS' UTILITY WITH ANTIHAIL NETS AND WITH HAIL INSURANCE

From the literature comparing the profitability of hedging instruments, it follows that technical devices are preferred over insurance contracts by farmers with a higher risk exposure and a higher (per-hectare) value of their yields. This is easily understandable by considering that the price of an insurance contract is determined as a proportion of the insured value, thus implying that it is a linear function of the per-hectare output value (Porsch et al., 2018b). Furthermore, the specific price is not fixed but it is an increasing function of the risk a farmer is subject to. Instead, the installation of an antihail net constitutes a fixed per-hectare cost, independent from the output value and from the level of risk.

Under insurance, therefore, farmers with higher yield potentials and risk exposure (i.e. those with higher expected indemnities from insurance companies) are also the ones paying higher premia. Figure 1 shows the positive correlation between received average per-hectare indemnities and the magnitude of premium rates.[1] The figure is based on a dataset of apples and wine-grape farmers in South Tyrol that will be better described in Section 4, when presenting the empirical analysis. When considering indemnities versus premium rates, it becomes evident that farmers with plots of high yield potential being exposed to higher risks prefer technical devices rather than insurance contracts. This is not necessarily beneficial to the actuarial soundness of the insurance market but could be neutral. These farmers, in fact, have higher expected indemnities, but they also pay higher premia.

[1]The premium rate, multiplied by the insured value, determines the premium a farmer has to pay to the insurance company.

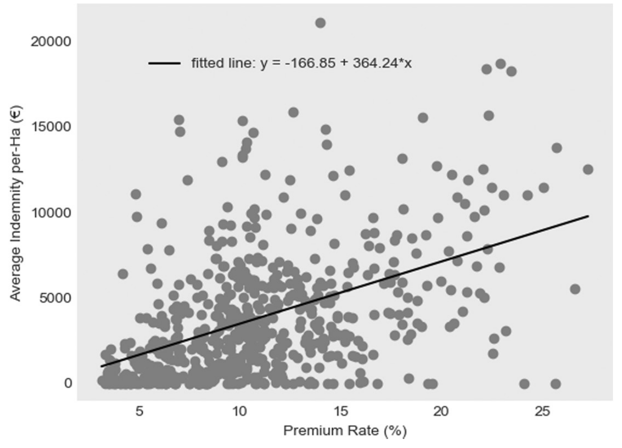

FIGURE 1 Relation between average indemnities and premium rates. *Source*: South Tyrol Hagelschutzkonsortium (HSK). Indemnities and premium rates of apple and wine-grape farmers for the period 2013–2017.

There is, however, another important element to consider. Ideally, the premium rate applied by an insurance company should perfectly reflect the idiosyncratic risk of the insured plot. This would entail a perfect risk classification capability on the side of the insurer, which, however, is more a textbook artifice rather than a real-world occurrence. Generally, the premium rate applied by insurance companies is set on a territorial basis, given a specific contract type. This implies that the premium rate reflects the average risk, for that particular contract type, in the specified area. In the case under analysis, a municipality constitutes the territorial basis. In other words, insurance companies assume a homogeneous risk exposure for all plots residing in the same municipality. Although this assumption may be quite safe since the extension of municipalities is generally rather small, especially if compared with the extension of certain weather hazards such as drought, there is still the possibility to have a nontrivial uneven distribution of plots' risk exposure inside such territorial units. This is particularly true for the case of hail, given the restricted extension of this atmospheric phenomenon emphasised by Changnon Jr (1977). The rest of this section presents a very simplified model to compare the profitability of antihail nets and insurance contracts inside a given territorial unit characterised by a single premium coefficient under the assumption of heterogeneity in farmers' risk exposure.

The model presented is a standard representative agent model rooted in expected utility theory. Our representative farmer is supposed to hold a single plot, which is a simplification to avoid a more cumbersome wording. For example, we will refer to a farmer-specific risk exposure or to the farmer's profitability of an insurance contract rather than referring to a specific plot owned by the same farmer. In the model, the choice of adopting a hedging or a risk-mitigating measure is considered as an investment option. The per-hectare output value is defined as the product of the selling price (P) and the per-hectare produced quantity (μ). There is only a predefined hail insurance contract available for subscription, and the choice between insurance and antihail net is dichotomous, implying that no mixing between the two is possible. According to Dalton et al. (2004) and Porsch et al. (2018b), both measures are substitutes. Hence, we exclude the choice to install antihail nets and to simultaneously purchase insurance. Moreover, from our data we know that less than 2% of plots covered by antihail nets are also insured.

Regarding insurance, the indemnity received by a farmer i is a function, $I(\delta_i, d)$, of the suffered damage (δ_i) and of the deductible structure of the insurance contract (d). Since the model is atemporal, the suffered damage is meant to be the yearly expected damage incurred by a farmer, defined as the proportion of lost production due to hail, that is $\delta_i \in [0,1]$. The cost of an insurance contract is determined by the premium to be paid. This is defined as a proportion (γ) of the insured value ($P\mu$) from which a subsidy (s) is subtracted, which is also defined in proportional terms: $\gamma \in (0,1)$ and $s \in [0,1)$. Regarding antihail nets, we assume they offer an almost total protection from hail damages, except for the presence of a residual risk (r) that is a constant proportion of the expected damage faced by a farmer. Furthermore, in order to compare insurance, whose premium is paid annually, and antihail nets, whose main cost component is represented by the expenditures for installation, we consider the equivalent annual cost (EAC) of antihail nets. This is defined as $C\rho\left(1-\frac{1}{(1+\rho)^T}\right)$, with C being the installation cost, T the lifetime in years of a net and ρ the discount rate. To this, we add the yearly cost for operating and maintaining the net (CY). The expected wealth (W) granted by the two hedging instruments is given by:

$$E\left[W_i^I\right] = P\mu\left(I_i\left(E\left[\delta_i\right],d\right) - \gamma(1-s)\right), \tag{1}$$

$$E\left[W_i^N\right] = P\mu E\left[\delta_i\right](1-r) - \text{EAC} - \text{CY}, \tag{2}$$

where the superscript I stands for insurance and N for hail net. For our purposes, it is crucial to examine γ in more detail. The premium coefficient is set by insurance companies. Assuming perfect competition in the insurance market, it must hold that the revenues of a representative insurance company are equal to its expenditures, represented by the indemnities paid to insured farmers, plus an operating margin to remunerate workers and capital, m. This last element is also defined in proportional terms. Without loss of generality, we assume all farmers having a parcel of exactly one hectare. Considering N as being the population of insured farmers in a given municipality, total indemnities are then given by $\sum_{j\in N} P\mu I_j\left(\delta_j,d\right)$. If we set $\mathcal{I}$ as the expected indemnity paid to, or received by, the average farmer in that location, we have $\mathcal{I} = P\mu\frac{\sum_{j\in N} I_j\left(\delta_j,d\right)}{|N|} = P\mu E\left[I(\Delta,d)\right]$, where $|N|$ indicates the cardinality of set N, and Δ is the distribution of the expected damage of each farmer in our reference population. Let us rewrite $E\left[I(\Delta,d)\right]$ as $\overline{I}$, for the sake of brevity. Therefore, we can rewrite equation (1) as:

$$E\left[W_i^I\right] = P\mu\left(I_i(E\left[\delta_i\right],d) - \overline{I}(1+m)(1-s)\right). \tag{3}$$

The expected wealth guaranteed by an insurance contract is therefore determined by the difference between a farmer's individual expected indemnity compared with the average expected indemnity in the population of insured farmers. The former individual expectation clearly depends on the idiosyncratic risk of hail damage faced by a single farmer, whereas the latter depends on the distribution of average risk in each area. In simpler words, farmers with a risk exposure below the average gain less from an insurance contract than farmers with a risk exposure above the average.

We assume, as standard in the literature, risk-averse farmers with a concave utility function who evaluate the CE of wealth: $U[CE] = E[U(W)]$. Willing to keep our equations as simple as possible, we adopt the following approximation: $U_i[CE] = E\left[U_i\left(W_i\right)\right] = W_i^0 + E\left[W_i\right] - \lambda_i\sigma_W^2$, where W_i^0 is the starting level of wealth, $E\left[W_i\right]$ the expected end-of-period wealth, σ_W^2 its variance and $\lambda_i = \frac{1}{2}\left(-\frac{U_{i''}(W_i)}{U_{i'}(W_i)}\right)$, equal to one-half the Arrow–Pratt measure of absolute risk aversion, is the parameter describing the intensity of risk aversion of the representative farmer. We then have:

$$E\left[U_i\left(W_i^I\right)\right] = W_i^0 + P\mu\left(I_i(E\left[\delta_i\right],d) - \overline{I}(1+m)(1-s)\right) - \lambda_i\sigma_{W^I}^2, \tag{4}$$

$$E\left[U_i\left(W_i^N\right)\right] = W_i^0 + P\mu E\left[\delta_i\right](1-r) - \text{EAC} - \text{CY} - \lambda_i\sigma_{W^N}^2. \tag{5}$$

A farmer decides which instrument to choose by comparing the expected utility. Our objective is to understand how the idiosyncratic risk exposure of a farmer influences her choice between the two instruments. Taking the derivative of equations (4) and (5) with respect to the expected idiosyncratic damage of farmer i helps in understanding this relation.

$$\frac{dE\left[U_i\left(W_i^I\right)\right]}{dE\left[\delta_i\right]} = P\mu \frac{dI_i\left(E\left[\delta_i\right], d\right)}{dE\left[\delta_i\right]} - \lambda_i \frac{d\sigma^2_{W^I}}{dE\left[\delta_i\right]}, \tag{6}$$

$$\frac{dE\left[U_i\left(W_i^N\right)\right]}{dE\left[\delta_i\right]} = P\mu(1-r) - \lambda_i \frac{d\sigma^2_{W^N}}{dE\left[\delta_i\right]}. \tag{7}$$

In both derivatives, there are two elements: the impact of the expected damage on the variance of wealth and on the direct return of the hedging/protective instrument. Focussing on the second element, we can see that the expected utility in the presence of antihail nets is a linearly increasing function of hail damages, given that the returns of a net is a constant of the damage itself: $P\mu(1-r)$. In case of insurance, instead, this depends on the shape of the indemnity function, which, in turn, depends on the deductible structure. Usually, the deductible structure has a threshold below which the farmer does not receive any compensation for the suffered damage, while, above this threshold, the compensation increases according to the level of the damage itself. Table 1 reports the most common deductible structure for both apple and wine-grape insurance contracts in South Tyrol.

The 31% of output loss is the threshold damage below which a farmer does not receive any compensation. For losses between 31% and 40% of the output, there is a linear increase in the indemnity of 3 percentage points for every percentage point of loss. After 40%, the indemnity is equal to the suffered damage minus 10 percentage points. Figure 2 shows the returns, in percentage of the output value, guaranteed by an antihail net (assuming the residual damage r being equal to 4%) and by insurance. Note that the difference in benefit between hail nets and insurance, the red line, has an inverse U-shape. For low levels of expected damage, the difference in the returns between antihail nets and insurance is an increasing function of the damage itself since, due to the deductible threshold, the returns of insurance are constantly equal to zero. Once the deductible threshold is reached, however, the difference becomes a declining function of the expected damage. Except for the variance of wealth, all other elements in the utility functions are constant; therefore, their value determines the position of the curves, but not their shape.

Therefore, the utility functions are likely to have the same shapes, and their difference is the same inverse U-shape, as in Figure 2, unless the variance components significantly change them. However, the shape of the difference in utility will not differ from the shape of the red line in Figure 2 if the variance components are scarcely affected by the level of the expected damage, if they have a trivial magnitude in both (3) and (4) or if the shape of the variance of

TABLE 1 Deductible structure

Apples and wine grapes											
δ	< 31	31	32	32	34	35	36	37	38	38	≥ 40
d	δ	28	26	24	22	20	18	16	14	12	10
I	0	3	6	9	12	15	18	21	24	27	$\delta - 10$

Note: All reported values are percentages. Source: Hagelschutzkonsortium webpage.

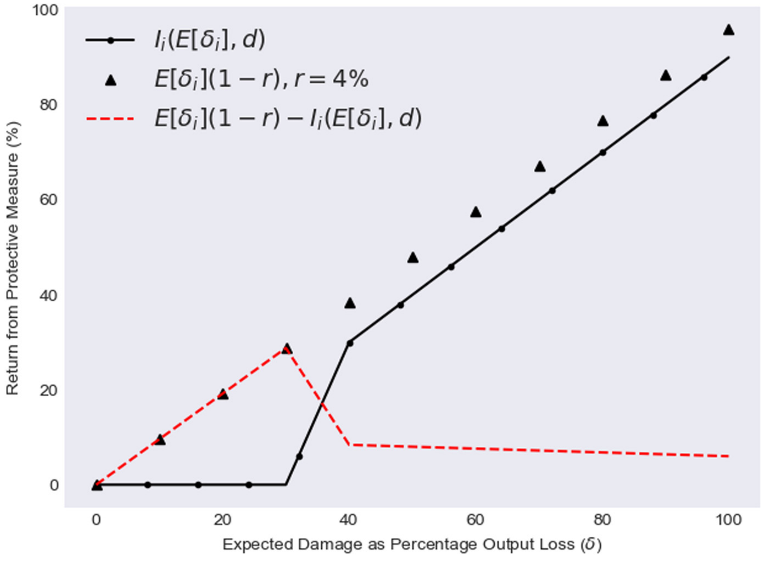

FIGURE 2 Returns of antihail nets and insurance, and their difference, as a function of farmer's idiosyncratic expected damage. [Colour figure can be viewed at wileyonlinelibrary.com]

wealth as a function of expected damage is similar both in the presence of insurance and in the presence of antihail nets.

Therefore, it is theoretically sound to expect that farmers with an idiosyncratic risk exposure below the average are more likely to prefer antihail nets than farmers with such a risk exposure above the average. This theoretical insight will be empirically tested in the next section.

4 | EMPIRICAL ANALYSIS

The main objective of the empirical analysis is to test the predictions presented in the model section together with the insights from the literature dedicated to the comparison of profitability of insurance contracts and technical devices. Röhrig et al. (2018), Porsch et al. (2018b) and Rogna et al. (2021) specifically focus on antihail nets and can be used to derive some easy-to-test hypotheses:

1. The profitability of antihail nets versus insurance is an increasing function of the per-hectare produced quantity.
2. The profitability of antihail nets versus insurance is an increasing function of the risk exposure for the plot location.
3. Regarding the present model, the hypothesis is that the relation between the differential profitability of the two hedging strategies and the profitability of insurance alone follows an inverse U-shaped relation.

The dataset used to perform the analysis provides detailed information for a five-year period (2013–2017) of insurance contracts signed by farmers in the province of Bolzano, South Tyrol. Information is available for each single plot insured, and it includes the type of insured crop, the insured quantity and price, the type of contract chosen, the paid premium, the eventual indemnity received, including the cause of the damage, and the plot size. The dataset has been provided by 'Hagelschutzkonsortium', the South Tyrolean association for the protection against weather shocks. Next, we provide a description of the variables used in our empirical model.

4.1 | The dependent variable

Due to a lack of data at the farm level, particularly regarding which plots are covered by antihail nets, we cannot model directly the choice between the two strategies. Therefore, we opt to investigate the switch from insurance to antihail nets. Since, by law, a farmer willing to insure a plot, in order to benefit from the EU and provincial subsidies, is required to insure all plots with the same crop belonging to the same municipality, it is possible to exploit this condition to individuate plots where a switch from hail insurance to antihail nets has taken place. A crop covered by antihail nets, in fact, is considered as a different typology of product and, therefore, it is not subject to the mentioned requirement of being insured. Consider a plot, identified by its type of cultivated crop, by its size and by its owner, that present in our dataset in a specific year. If that plot is not present any more in subsequent years, while the owner holds at least another insured plot with the same crop in the same municipality, it is categorised as having been switched to antihail nets. Although the possibility that a plot has been sold rather than switched to antihail nets cannot be excluded, the rigidity of the local land market should guarantee a minimal occurrence of this case. Furthermore, this error should be randomly distributed and uncorrelated with all the regressors. Our dependent variable (*switch_net*) is therefore a dummy taking the value of one for plots whose status switches from being insured to being covered by an antihail net. The value of one is assigned to the last year the plot has been insured. Note that this operation necessarily requires to drop the last year's observation, that is, the year 2017.

4.2 | Regressors of main interest

For testing our first hypothesis, our main regressor is the per-hectare insured quantity (*output*, μ in the model). It has to be noted that the selling price of the output (P) may also positively affect the switch to antihail nets, since it also contributes to determine the insurance premium, with higher prices implying higher premia. Therefore, our first hypothesis could have been that the product of P and μ favours antihail nets over insurance. However, if the positive effect of per-hectare output is theoretically straightforward, the one of price is far less so. Therefore, we prefer to keep the two variables separated for several reasons. First, there exists a well-known trade-off between quantity and quality, as documented in Ramsey et al. (2019). Second, our database provides the price the farmer has paid for output insurance, which can be selected inside a range provided by the insurance companies. Therefore, it could be different from the actual selling price of the crop. Farmers with high expected hail damages could find it profitable to inflate such a price. But then, according to the inverse U-shape hypothesis of this paper, these should also be the farmers less likely to switch to antihail nets, that is, this is an opposite effect compared with the one previously hypothesised. In conclusion, we prefer to limit our first hypothesis to the per-hectare output, considering price as a control.

For testing the second hypothesis, the premium rate (*premium*, corresponding to γ in the model) is the regressor of interest. Note that the premium rate varies according to the municipality where the insured plot is located and according to the contract type. From our hypothesis, we expect its coefficient to be positive. However, there is a potential contrasting effect. Whereas all contracts include hail damages, they vary in the number of alternative risks covered, such as sunburn, excess of rain or snow. The higher this number, the more expensive the contract will be. Clearly, since antihail nets provide protection only from hail, farmers choosing more expensive contracts to hedge other risk typologies are less likely to switch towards nets. The variable *premium*, therefore, conveys contrasting information since, from one side, it is a direct measure of a location's risk of hail damage, but, on the other, it includes the plot-specific probability to face risks other than hail. These effects are supposed to have opposite directions on the dependent variable.

Figure 3 shows the paid indemnities for each year in our dataset divided by the event causing them. Except for frost in 2016, it is possible to observe how the other sources of damages are just a very tiny portion of the total, implying that the potentially confounding factor imbued in *premium* is very mild. Furthermore, a dummy (*no_hail*) indicating when a plot has been subject to damages other than hail is added to further take into consideration this aspect.

For testing the third hypothesis, we adopt two indexes of insurance profitability. In the theoretical section, we have compared the profitability of the two instruments as a function of the expected damage of a farmer, evidencing an inverse U-shaped relation. Given that insurance profitability is a monotonically increasing function of expected damage, we can use the mentioned profitability as a proxy for the expected damage. The first index (*index_simple*) is rather naive, and it simply consists in the ratio of the received indemnity over the paid premia for a specific plot averaged over time:

$$index\_simple_i = \sum_{t \in T} \frac{I_{i,t}}{Pr_{i,t}},$$

with $I_{i,t}$ indicating the received indemnity for plot i at time t, $Pr_{i,t}$ being the paid premium and T being the set of time periods. To test the U-shaped relation, we add such index both as level and in its squared form, expecting a positive coefficient for the linear and a negative one for the squared term. The second index (*index_soph*) is a more complex measure of the profitability of an insurance contract that better takes into consideration the relation between the plot-specific and the average profitability as described in the theoretical section. It is defined as the per-hectare difference of a plot's received indemnity with its associated premium minus the same difference averaged over all plots in the same municipality insured with the same type of contract. With this being the numerator, the denominator is simply its standard deviation:

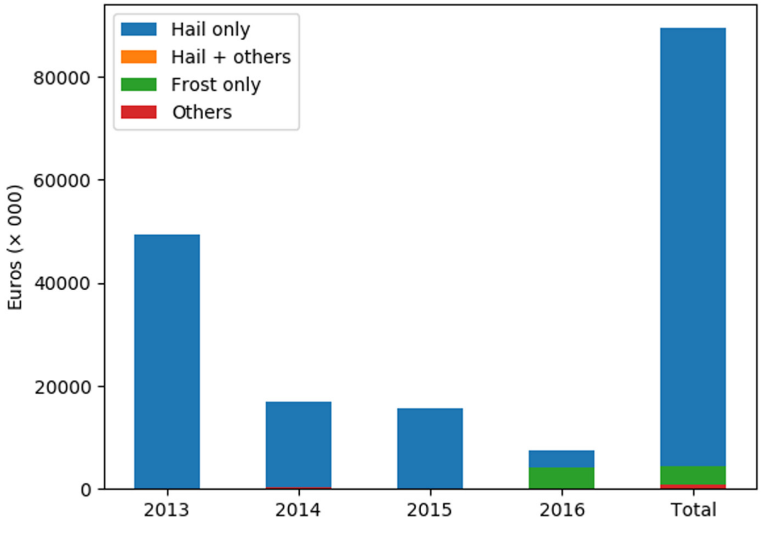

FIGURE 3 Indemnities by damage typology. [Colour figure can be viewed at wileyonlinelibrary.com]

$$index\_soph_i = \frac{\frac{1}{|T|}\sum_{t\in T}\left(I_{i,t} - Pr_{i,t}\right) - \frac{1}{|T|\times|MV_i|}\sum_{j\in MV_i}\sum_{t\in T}\left(I_{j,t} - Pr_{j,t}\right)}{\sqrt{\frac{1}{|MV_i|}\sum_{j\in MV_i}\left(\frac{1}{|T|}\sum_{t\in T}\left(I_{j,t} - Pr_{j,t}\right) - \frac{1}{|T|\times|MV_i|}\sum_{j\in MV_i}\sum_{t\in T}\left(I_{j,t} - Pr_{j,t}\right)\right)^2}},$$

where $I_{i,t}$, $Pr_{i,t}$, i and T are defined as previously, whereas MV_i is the set of plots in the same municipality of, and insured with the same type of contract as plot i. To verify the hypothesised inverse U-shaped relation between risk exposure and the difference in the profitability of the two instruments, we need to include both the level and the square of the indexes. The hypothesised relation would then be confirmed if the level of the indexes is positive, entailing an initial positive effect of insurance profitability, or else, risk exposure, in fostering the switch to antihail nets, and a negative coefficient of the squared index. This implies a diminishing probability of switch for higher levels of risk exposure. With regard to the second index, since this variable measures the number of standard deviations that the insurance profitability of a plot is below or above the average profitability, it poses difficulties when added in its squared form due to the negative values. Therefore, we applied an affine transformation so that its lower bound is equal to 1.

Finally, although not explicitly mentioned in our hypothesis, there is a further element that is interesting to investigate. Figure 2 shows that the difference between antihail nets and insurance profitability is, for modest values of a farmer's risk exposure, an increasing function of it. This result is mainly driven by the deductible structure of the local insurance contracts that do not provide any compensation for damages below 31% of the insured value. It seems therefore reasonable to hypothesise that farmers expecting to often suffer damages below such threshold are more incentivised to switch to antihail nets. Two variables are added to check for such a hypothesis. Farmers have the option to stipulate an additional contract with insurance companies to hedge damages below the 31% threshold, a contract that, however, is not subsidised. The first variable (*contract_31*) is a dummy taking the value of 1 when a farmer has signed an additional private contract to insure her plot for the portion of damages below the 31% level. We expect its coefficient to be positive. Since a private insurance contract could be a substitute for the purchase of an antihail net, the second variable (*contract_prop*) tries to solve this potential source of confusion. It is defined as the sum of the premia paid for private contracts in a municipality over the municipal sum of total paid premia. A higher value of *contract_prop* should identify a municipality where damages below the deductible are more likely, but eliminating the substitution effect that *contract_31* may have.

4.3 | Control variables

A set of controls is added to avoid potential biases due to omitted variables. The per-hectare received indemnity (*indemnity*) is added in order to control for a potential psychological effect according to which farmers are less prone to switch to another hedging method after having received an indemnity. Similarly, the per-hectare subsidy (*subsidy*) received for an insurance contract is added with the idea that higher subsidies discourage the switch to antihail nets.

Furthermore, we consider the normalised Herfindhal–Hirschman index of concentration (*HHI*), the inverse of diversification, since it has been treated as an alternative protective strategy in Finger and Lehmann (2012) and in Santeramo et al. (2016). Two dummies are further included: the first (*no_hail*) individuates plots having been damaged by events other than hail, whereas the other (*grape*) indicates plots cultivated with wine grapes rather than apples.

TABLE 2 Variables and basic statistics

Variable	Mean	SD	Min.	Max.	Expected sign of Est. Coef.
switch_net	0.32	0.46	0	1	/
price	87.18	69.82	16	315	+
output	497.13	374.11	0.37	16438.36	+
premium	2.84	1.41	0.36	21.29	+
index_simple	2.62	6.79	0	165.43	+/−
index_soph	16.10	0.95	1	42.98	+/−
contract_31	0.36	0.48	0	1	+
contract_prop	0.05	0.08	0	1	+
indemnity	1832.46	5990.45	0	337,960	−
subsidy	1782.21	1424.60	0	100289.3	−
HHI	0.20	0.23	0	1	?
grape	0.23	0.42	0	1	−
no_hail	0.02	0.12	0	1	−

Both dummies should have negative signs: the first for obvious reasons and the second because the profitability of antihail nets is lower in the vine-growing region since hail damages are generally lower than for apple trees. Finally, a dummy for each year in our dataset is added. Table 2 lists basic statistics and the expected sign of their estimated coefficient for all variables. Note that, for the profitability indexes, '+/−' indicates an expected positive coefficient for their linear and a negative coefficient for their squared term.

4.4 | Results

The estimated econometric model is a conditional fixed-effect logistic regression, with the stratification variable being the farmers' identification number (Chamberlain, 1980). Given the lack of controls in our dataset for farmers' characteristics, for example, education, social origin and wealth, potentially important for influencing the choice of the hedging instrument and likely to be correlated with some of the selected regressors, it is mandatory to control for such unobserved characteristics. For example, education has been found to significantly affect the choice of insurance adoption by Finger and Lehmann (2012). Moreover, it has been found to be a strong predictor of farm efficiency in several studies, thus correlated with per-hectare output in our model (Lockheed et al., 1980). Although the choice of insurance adoption is different from the choice of switching to antihail nets, the risk of running into the omitted variable bias is very strong. The fixed-effect component has to take two other elements of the utility functions described in equations (4) and (5) into account, starting wealth (W^0) and risk aversion (λ), due to the lack of information about them. A dummy regression is precluded by the excessive number of farmers in our dataset, and, consequently, of dummy coefficients to be computed. These reasons lead us to opt for the mentioned model. The conditional fixed-effect logit model can be written as:

$$Pr\left(y_{j,i,t} = 1 \mid \boldsymbol{x}_{j,i,t}\right) = F\left(a_i + \boldsymbol{x}_{j,i,t}\beta\right), \tag{8}$$

where F is the cumulative logistic distribution: $F(z) = \frac{exp(z)}{1+exp(z)}$. Note that i is the identifier of each farmer whereas j represents a specific plot and t, time. The dependent variable, $y_{j,i,t}$, is the switch at time t of plot j, owned by farmer i, from insurance to antihail nets: *switch_net*. The unobserved farmers' characteristics, a_i, are taken into account by the fixed-effect component of the model, whereas $\mathbf{x}_{j,i,t}$ is the set of regressors described in Table 2. More explicitly, we have:

$$Pr\left(switch\_net_{j,i,t}=1 \mid \boldsymbol{x}_{j,i,t}\right)=F(a_i+\beta_1 price_{j,i,t}+\beta_2 output_{j,i,t}+\beta_3 premium_{j,i,t} \\ +\beta_4 index\_simple_{j,i,t}+\beta_5 index\_simple^2_{j,i,t}+\beta \boldsymbol{x}_{j,i,t}+\varepsilon_{j,i,t}). \quad (9)$$

$$Pr\left(switch\_net_{j,i,t}=1 \mid \boldsymbol{x}_{j,i,t}\right)=F(a_i+\beta_1 price_{j,i,t}+\beta_2 output_{j,i,t}+\beta_3 premium_{j,i,t} \\ +\beta_4 index\_sofh_{j,i,t}+\beta_5 index\_soph^2_{j,i,t}+\beta \boldsymbol{x}_{j,i,t}+\varepsilon_{j,i,t}). \quad (10)$$

From Table 1, we have that β_1, β_2, β_3 and β_4 are expected to be positive and β_5, negative.

Table 3 reports the estimated coefficients as odds ratios with values above one indicating an increase in probability and below one the reverse. Odds ratios are reported instead of marginal effects given the unreliability of these lasts when FE models are adopted (Beck, 2018; Verbeek, 2021). In fact, marginal effects will be computed under the assumption that fixed effects are equal to zero, but this assumption would be unrealistic, since an FE model is chosen specifically for dealing with nonzero fixed effects (Allison, 2009). Regression (1) uses *index_simple* as index of insurance profitability, whereas in regression (2) the index is provided by *index_soph*. Starting with the first hypothesis that a greater per-hectare output renders antihail nets more profitable and, consequently, it increases the probability of switching to antihail nets, this finds a good confirmation. In regressions (1) and (2), the odds ratio of *output* is above one and statistically significant. Note that, due to the inability of distinguishing plots

TABLE 3 Parameter estimation of the conditional FE logit regression in equation (8). Model 1 reports the estimate of equation (9), whereas Model 2, the ones of equation (10). Reported coefficients are odds ratios.

	(1)	(2)		(1)	(2)
	switch_net	**switch_net**		**switch_net**	**switch_net**
price	0.99864***	0.99952	*indemnity*	0.99998***	0.99999
	(−3.69)	(−1.27)		(−6.10)	(−1.68)
output	1.00020**	1.00022***	*subsidy*	0.99996	0.99998
	(2.36)	(3.36)		(−1.78)	(−1.09)
premium	1.12178***	1.10679***	*HHI*	1.67698**	1.60177**
	(6.61)	(5.77)		(3.17)	(2.95)
index_simple	1.04515***		*grape*	0.93779	0.51683***
	(9.17)			(−0.71)	(−6.82)
index_simple2	0.99991		*no_hail*	0.93219	0.93845
	(−0.87)			(−0.55)	(−0.48)
index_soph		3.08525***	*Year_14*	0.49698***	0.49839***
		(18.41)		(−12.24)	(−12.09)
index_soph2		0.96455***	*Year_15*	0.50009***	0.50235***
		(−17.02)		(−14.27)	(−14.16)
contract_31	0.97680	0.95236	*Year_16*	1.51661***	1.66014***
	(−0.42)	(−0.90)		(8.55)	(10.49)
contract_prop	0.95993	0.74576	Pseudo-R^2	0.0527	0.0715
	(−0.12)	(−0.82)	N. obs.	110,996	110,594

t statistics in parentheses. $^{*}p<0.05$, $^{**}p<0.01$, $^{***}p<0.001$.

that are sold or left unproductive from the ones switched to antihail nets, since the former are likely to be less productive, it may be possible that the odds ratio of *output* is downward biased. However, we think this bias to be very mild. The odds ratio of *price*, which we supposed could have a role similar to per-hectare output, is actually lower than one in both regressions (even though it is statistically significant only in the first). We have already provided a possible reason for the negative effect of *price* when discussing the inclusion of variables in our model.

The second hypothesis, according to which the profitability of antihail nets versus insurance is an increasing function of the hail risk exposure of the plot's location, is fully confirmed.

The odds ratio of *premium* is above one and significant (0.1% level) in both regressions. As a further confirmation, refer to the coefficient for *grape*, the dummy for the sector less affected by the hail risk, which is significant and below zero in regression (2).

The main hypothesis of the present paper regarding the inverse U-shaped relation described in our theoretical model is supported. In regression (2), we have an odds ratio above zero for *index_soph* as level and a coefficient below zero for its squared term, as hypothesised. Both are strongly significant. The same can be observed in regression (1) for *index_simple*, despite here only the odds ratio of the level is significant. A reasonable explanation for the lack of significance of the squared form of *index_simple* could be the rather simplified nature of this index, unable to fully capture the hypothesised relation. We can notice that regression (1) has a lower pseudo-R^2 and – not reported – a lower pseudo-log-likelihood than regression (2). However, if we interpret the result of regression (1) with its simpler index as a robustness check, we can fairly say that the model is not oversensitive to modifications.

We do not find any confirmation that farmers with a higher probability of suffering damages below the deductible threshold switch more easily to antihail nets. In both regressions, in fact, the odds ratio of *contract_31* and the ones of *contract_prop* are not significant. For *contract_31*, a possible explanation is the fact that signing a private contract to hedge damages below the deductible threshold is a substitute to switching towards antihail nets as mentioned earlier. For *contract_prop*, used as a proxy of the likelihood to have damages below the deductible threshold in a given municipality, it could be that this index does not capture very well the plot-specific probability to suffer such a type of damage.

Regarding the controls, we note that the odds ratios for *indemnity*, *subsidy*, *grape* and *no_hail* are in line with our expectations in both regressions. However, only *indemnity* in regression (1) and *grape* in regression (2) are significant. Furthermore, note that the low value of the pseudo-R-squared values (0.05 and 0.07 in, respectively, models (1) and (2)) is due to lack of controls for important determinants at the farm level. Although the omitted variable problem is addressed by the fixed-effect nature of the regressions, individual farmer's characteristics are not directly introduced as it would be in a dummy regression, possibly leading to a low value of the pseudo-R-squared.

5 | CONCLUSIONS

Considering that hail damages represent a significant source of agricultural output loss, the present paper investigates the relation between two commonly adopted instruments to address this weather phenomenon: agricultural insurance and antihail nets. In particular, the paper follows two strands of literature, the first investigating empirically the determinants of insurance adoption and the second benchmarking the farmers' profitability by choosing different hedging/protective options through expected utility theory. From the first strand, we know that agricultural insurance markets are often characterised by moral hazard and adverse selection problems, whereas, from the second, we learn that technical devices, and antihail nets in particular, are often preferred by farmers with higher yield potentials and for plots located in areas with strong risk exposure. These last two findings, exposed in Porsch et al. (2018b) and in Rogna et al. (2021), suggest that the diffusion of antihail nets could be beneficial for the actuarial soundness of the hail insurance market. The present paper, however, challenges this view.

By presenting a simple model, we show that in the presence of an insurance market with imperfect risk classification, the difference between the profitability of antihail nets and insurance is an increasing function for low individual risk exposure and decreasing for higher risk exposure. Such an inverse U-shaped relation between the difference in profitability between the two protective instruments and the gap between individual and average risk exposure suggests another potential source of adverse selection in the insurance market. Farmers with a low- or medium-risk exposure tend to switch more easily to antihail nets than farmers with a strong idiosyncratic risk exposure. Therefore, while adverse selection in insurance markets has been largely identified by previous studies such as Goodwin (1993), Cohen and Siegelman (2010) and Ali et al. (2020), in the present study we identify an additional source of adverse selection caused by the competing role of antihail nets. This implies that, in countries where hail insurance contracts are still highly subsidised, a switch to some form of subsidisation of antihail nets could cause problems to the actuarial soundness of the insurance market if such a policy is not carefully designed.

Due to the lack of data availability, such as farmers' elasticity to subsidy for insurance and for antihail nets, we are not able to provide clear and straightforward indications of optimal subsidy strategies, but identifying the presence of this problem is a first step towards finding possible solutions. A better modelling of the interplay between these instruments with the aim of providing more precise indications at the policy level is a promising field of research. We also note that alternative insurance schemes, such as weather index insurance (Clement et al., 2018; Pu et al., 2018) or the newly proposed EU Income Stabilization Tool (Cordier & Santeramo, 2020; Meuwissen et al., 2018), which insures both losses from reduced production and from price variations, may further complicate the picture increasing the choice set of farmers and policymakers. As shown in this paper, potential interactions and externalities among these instruments may create detrimental conflicts.

An econometric estimation, based on a dataset of South Tyrolean apple and wine–grape farmers, has been performed. We find that plots located in areas with higher risk exposure are more likely to switch to antihail nets. Furthermore, we find a partial confirmation for the hypothesis that higher yield potentials favour the adoption of antihail nets. By dividing yield potentials into its two subcomponents, price and output per hectare, only the role of the latter is confirmed. The econometric analysis also shows a good support for the main hypothesis of this paper, namely the inverse U-shaped relation mentioned earlier.

This last finding has a clear relevance from a policy point of view. Policy aimed at fostering the adoption of antihail nets should take into consideration the actuarial soundness of the hail insurance market. The presence of a scarcely subsidised hail insurance market in Germany coupled with the subsidisation of antihail nets implies that the potential negative consequences suggested by our findings should not be overemphasised. However, our analyses show that such effects should be considered when implementing a subsidisation policy.

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DATA AVAILABILITY STATEMENT

The data used in this paper, provided by the Hagelschutzkonsortium, are confidential and cannot be shared without the prior authorization of the data provider.

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