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Abstract

In several areas of the world, hail is one of the most detrimental atmospheric phenomenon for agriculture, causing a significant loss of output and, consequently, of farms' revenues. Despite being a highly stochastic and localized phenomenon, thus allowing for a sustainable insurance market to hedge against its detrimental effects, this last is often subsidised. The present paper tries to figure out if the promotion of an alternative hedging instrument, anti-hail nets, could help to increase the actuarial soundness of the hail insurance market. In the first part of the paper a simple model is presented showing that the relation between the differential profitability of anti-hail nets versus insurance and the plot specific versus the average expected damage has an inverse U-shape. This implies that incentives to anti-hail nets could cause low risk farmers to exit the insurance market more likely than high risk ones. Such finding is confirmed by the empirical investigation, further showing that higher per-hectare output values and being located in an area strongly affected by hail increase the chance of a plot to be hedged through anti-hail nets.

Keywords: Actuarial soundness; Agricultural insurance markets; Anti-hail nets; Hail; Panel data.

J.E.L. D22; Q12; Q18.

1 Introduction

In several regions of Europe, hail is one of the costlier weather extremes for agriculture according to the European Environment Agency (EEA) [Füssel et al., 2017]. Although not systematically, several studies have tried to provide a rough estimation of the total damages caused by this atmospheric phenomenon. Some figures may serve to provide a clear idea of its economic significance: a hailstorm on the 12^{th} of July 1984 in Southern Bavaria, Germany, caused damages for approximately 3 billion euros, among which roughly half resulted in insurance claims [Kaspar et al., 2009]. In 2013, a hailstorm on the $27^{th} - 28^{th}$ of July in the German region of Baden-Württemberg generated 2.8 billion euros of insurance claims, while 2.3 billions were claimed after another hailstorm on the border between France and Belgium on the $8^{th} - 10^{th}$ of June 2014 [Punge and Kunz, 2016].

Although the just mentioned damages are not exclusive to agriculture, this is clearly the sector most affected by hail events. Some studies have tried to assess the percentage losses of agricultural output due to hailstorms. Hübner [1856] estimates a 1% yearly loss in Northern Germany increasing to 3% 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, one of the most agriculturally productive area of the country, Roncali [1955] provides an estimate of 4% average loss. Either the lack of precise instruments at the time these studies have been conducted and the widespread opinion that hail events are increasing in intensity, if not in frequency (e.g. Kunz et al. [2009], Eccel et al. [2012] and Dessens et al. [2015]), make these estimations potentially downward biased.

If average figures well testify the detrimental effects of hailstorms in the long run, it must be remembered that, at local level, they may be the result of several years of absence of hail and exceptional years with very large output losses. In order to avoid the income shocks entailed by this situation, agricultural insurance contracts have been envisaged since, at least, the beginning of the previous century (see, for example, the U.S. Agricultural Adjustment Act 1938). Despite having been judged as an effective tool for income smoothing by several scholars [Wright and Hewitt, 1994; Goodwin and Smith, 1995], the scarce participation rate and the high correlation of risk exposure of farmers residing in relatively large territories, pose serious problems to the actuarial soundness of agricultural insurance markets [Miranda and Glauber, 1997]. One of the few working remedies that has been adopted to keep agricultural insurance contracts in place has been a strong State interventionism in the form of subsidies to premia. This happened either in the U.S., with the Multiple Peril Crop Insurance (MPCI) program that reached a peak subsidy of 70% of the insurance premium [Coble et al., 1996] and in Europe, with the E.U. offering subsidies of analogous magnitude [Falco et al., 2014; Santeramo et al., 2016; Santeramo and Ford Ramsey, 2017].

Although hailstorms are highly stochastic and they affect areas with an amplitude generally inferior to other weather extremes such as droughts, frost or hurricanes,[1] being, therefore, less problematic in terms of actuarial soundness, hail insurance contracts still benefit from subsidization. The main reason is probably the diffused practice of bundling in single insurance contracts different hazardous events, practice that is often promoted by the subsidizing agencies, as in the European case [Santeramo, 2018a].[2] Despite the literature focusing on the actuarial soundness of agricultural contracts is vast and it is augmented by the papers focusing on public policies (see Wright and Hewitt [1994] and Coble et al. [1997] for a review), relatively few studies have specifically covered hail alone, probably because of the just mentioned grouping of hazards in single contracts. Hail damages, however, represent an interesting case since, at least for certain types of crop, they can be hedged through alternative methods other than insurance. Although the efficacy of hail cannons or rockets is scientifically strongly questioned [Wieringa and Holleman, 2006], anti-hail nets provide an effective remedy.

The existence of an alternative hedging instrument for hail risk becomes then interesting at the academic and policy-making level insofar understanding its effect on actuarial soundness may open the possibility of better directing the large amount of subsidies currently spent on lowering insurance premia for farmers. It is important to understand which type of farmers prefers which instrument and if there is a systematic difference in the class of risk between the choosers of one rather than the other instrument. Given that the vast literature focusing on the determinants of insurance adoption has clearly shown how theoretical predictions may be at odd with real practice [Goodwin, 1993; Just and Calvin, 1994; Smith and Baquet, 1996; Sherrick et al., 2004], any theoretical model on this topic should be tested on real data. This is the purpose of the present paper where we will first sketch a very simple model to compare the profitability of hail insurance versus anti-hail nets in the Northern Italian province of Bolzano and, subsequently, we will test if the results of the model have some explanatory power in predicting the shift from insurance to anti-hail nets using a panel dataset of farmers located in the mentioned area.

Section 2 presents a brief review of the relevant literature, Section 3 introduces the model and a brief numerical simulation, Section 4 is devoted to the econometric estimation and Section 5 draws the conclusions.

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[1] For the U.S., Changnon Jr [1970] and Changnon Jr [1977] have found that the 80% of hailstorms interest an area smaller than 40 km^2.

[2] For the area object of the present analysis, for example, the public subsidy is offered only for insurance contracts including at least three hazardous events.

2 Literature Review

One of the first aspects related to agricultural insurance markets that has been deeply investigated is the farmers' elasticity to premia and, more specifically, the differences in elasticity according to the farmers' idiosyncratic risk exposure. 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, focusing on the U.S. agricultural market, dealing with this topic. For the European market, similar analyses have been conducted by Enjolras et al. [2012], focusing on Italy and France, by Santeramo et al. [2016] and Santeramo [2018b], limited to Italy, and by Garrido and Zilberman [2008], for Spain. Finger and Lehmann [2012] consider the Swiss case, although their primary focus is on the competing effect of direct payments to farmers with insurance contracts. A main finding of this literature strand, although not unanimous, is that the elasticity to premia is higher for farmers with a lower idiosyncratic exposure to risk. In other words, agricultural insurance contracts generally suffer from an adverse selection or moral hazard problem [Cohen and Siegelman, 2010; Walters et al., 2014]. This finding, together with a general scarce adoption rate observed in several markets [Babcock, 2015; Santeramo, 2018a], has important policy implications since lowering the subsidies to premia may cause a higher exit rate among low-risk farmers, thus negatively affecting actuarial soundness.

Besides the relation between elasticity to premia and risk exposure or, more broadly, the existence of adverse selection and moral hazard, other policy relevant aspects have been investigated. As mentioned, Finger and Lehmann [2012] focus on the potential competing effects of direct payments, finding a significant substitution effect, whereas a previous study of Smith and Baquet [1996] found a complementary role of disaster relieve programs. In addition to insurance adoption, market exit has also been investigated by Cabas et al. [2008] and Santeramo et al. [2016]. This last paper finds a positive and significant relation between the probability to drop out and a loss-ratio index that measures the profitability of holding an insurance contract. This fact contradicts theoretical predictions and it seems to play in favour of actuarial soundness. With regard to competing hedging strategies, the same paper tests crop diversification, showing that it either decreases the probability of insurance adoption and it increases the one of dropping out. A similar result has been obtained by Finger and Lehmann [2012], limited to the participation side.

Rogna et al. [2019] examine theoretically the difference in certainty equivalent expected utility between anti-hail nets, hail insurance and no hedging. The paper shows that anti-hail nets are preferable to insurance the higher the risk of hail damages and the higher the per-hectare output value, whereas the role of farmer's risk aversion is uncertain. Although the paper presents a simulation to check the robustness of such findings, it lacks a proper empirical validation. The present work tries to fill this gap and to expand the previous insights by analysing the correlation between the profitability of anti-hail nets with the one of insurance.

3 Modeling the Differential Profitability of Anti-hail Nets and Hail Insurance

The model we are going to present focuses on an aspect that has been neglected in Rogna et al. [2019]. It shares therefore several elements with the model proposed in the mentioned paper, but it only retains that components functional to the present scope. In particular, one of the main results in Rogna et al. [2019] is that the profitability of anti-hail nets compared to hail insurance is an increasing function of the overall hail damage risk faced by farmers in a given location. The association between anti-hail nets profitability and hail risk seems to imply that anti-hail nets may be an efficient tool to reduce the overall risk of insured farmers, thus fostering actuarial soundness. In fact, such association suggests that farmers facing a higher hail risk are more prone to switch to anti-hail nets. However, this interpretation may be misleading. The fact that anti-hail nets are more profitable in locations with a higher risk of hail damages, and, consequently, higher insurance premia, does not necessarily imply that farmers are more prone to adopt anti-hail nets on plots facing a higher idiosyncratic risk compared to the average risk. The absence of this implication puts in doubt the positive effect of anti-hail nets on actuarial soundness. The present model precisely focuses on this aspect, benchmarking the profitability of the two hedging strategies as a function of the individual risk probability of a farmer compared to the average risk faced by all farmers residing in a given location. A clarification is necessary with regard to the use of the term individual. We should actually use the expression plot specific since a farmer may have more than one plot in an area sharing the same risk profile (and the related insurance premium coefficient), but in our model, for mere simplifying purposes, we assume a farmer owns a single plot thus making the use of the two expressions interchangeable.

In the model, the choice of adopting a hedging measure is considered as an investment a farmer has the option to undertake. Our representative farmer is assumed to be risk-neutral[3] since risk-aversion, although more realistic, would not affect the qualitative results of the present analysis. The per hectare output value, defined as the product of the selling price (P) and the per hectare produced quantity (μ) is constant and identical for all farmers. There is only a predefined hail insurance contract available for subscription and the choice between insurance or anti-hail net is dichotomous, implying that no mixing between the two is possible. With regard to insurance, the indemnity received by a farmer is a function $[I_i(\cdot)]$ 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,

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[3] In Rogna et al. [2019], instead, farmers were assumed to be risk-averse.

defined as the proportion of lost production due to hail: $\delta_i \in [0, 1]$. We therefore have: $I_i(\delta_i, d)$. 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 ($P\mu$) to which it is subtracted a subsidy (s), also defined in proportional terms: $\gamma \in (0, 1)$ and $s \in [0, 1)$. With regard to anti-hail nets, we assume they offer an almost total protection from hail damages, except for the presence of a residual damage risk (r) that is a constant proportion of the expected risk faced by a farmer. Furthermore, in order to compare insurance, whose premium is paid annually, and anti-hail nets, whose main cost component is represented by the expenditures for installation, we are going to consider the equivalent annual cost (EAC) of these lasts, defined as $C\left(\rho\left(1 - \frac{1}{(1+\rho)^T}\right)\right)$; 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, in terms of labour, for operating the net (CY). The profit (π) given by the two hedging instruments is therefore given by:

$$\pi_i^I = P\mu\left(I_i(\delta_i, d) - \gamma(1 - s)\right). \tag{1}$$

$$\pi_i^{HN} = P\mu\delta_i(1 - r) - \text{EAC} - \text{CY}. \tag{2}$$

where the superscript I stays for insurance and HN for hail-net. For our purposes, it is crucial to better examine γ. The premium coefficient is decided by insurance companies. Assuming perfect competition into 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, defined in proportional terms. Note that, the per-farmer revenues of an insurance company are given by $P\mu\gamma\theta$, with θ being the extension, in hectares, of the farmer plot. Without loss of generality, we assume $\theta = 1$ for all farmers. Consider N as being the population of insured farmers, total indemnities are then given by $\sum_{i \in N} P\mu I_i(\delta_i, d)$. If we set $\mathcal{I}$ as the expected indemnity paid to, or received by, the representative farmer, we have $\mathcal{I} = (P\mu)\frac{\sum_{i \in N} I_i(\delta_i, d)}{|N|} = P\mu E[I(\Delta, d)]$, where $|N|$ indicates the cardinality of set N and Δ is the distribution of the expected individual proportional damage in our reference population of farmers. Therefore, we can rewrite equation (1) as:

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

The profitability of an insurance contract for a farmer is therefore determined by the difference between her individual expected indemnity compared to the population of insured farmers' expected indemnity and by the magnitude of the subsidy. The former expectation clearly depends on the idiosyncratic risk of hail damage faced by a single farmer, whereas the latter on the overall distribution of risk on a given area. The idea is quite intuitive. Since the premium coefficient is calibrated by insurance companies in order to cover the average repaid indemnity, determined by the average risk, if a farmer faces a risk below such average, the profitability of the insurance contract will be lower for her compared to a farmer with an individual risk above the average. Note that, in presence of risk aversion, even for negative values of π_i^I, a farmer could still find profitable in terms of expected utility to sign an insurance contract. The choice of which hedging instrument to adopt is simply determined by which, between π_i^I and π_i^{HN}, has a higher value. It is meaningless, however, to analytically compare equations (1B) and (2) without providing some realistic values to the various parameters involved. Furthermore, it is necessary to know the deductible structure of the insurance contract to perform a comparison. In order to do this, we will use data of apples and wine-grapes farmers in South Tyrol, that will be subsequently used for estimating our econometric model.

The dataset at our disposal provides detailed information for a five-years period (2013-2017) of insurance contracts signed by farmers in the province of Bolzano, South Tyrol. Information is related to each single plot insured and it includes the type of insured crop, its 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" (HSK), the South Tyrolean association for the protection against weather shocks. Furthermore, we have access to a long period of yearly aggregate data (1975-2013) of premia received by insurance companies and indemnities paid, from which it is possible to estimate a reliable operating margin. In this case too, data have been obtained from HSK. The data are similar to the ones used in the simulation of Rogna et al. [2019], although some differences are present given the diverse choice of reference insurance contract type and since we are now considering wine-grapes farmers in addition to apples growers. The costs for anti-hail nets are kept identical as in Rogna et al. [2019]. Table 1 shows the estimated relevant parameters, divided according to the two crops under scrutiny. A 95% confidence interval, where appropriate, is reported in rounded brackets under the estimated parameter, whereas the right column indicates the number of observations used to obtain the estimation. The parameters r, EAC and CY are not empirically estimated. The latter two have been taken from Rogna et al. [2019], where the method of estimation is described, whereas r is set equal to the premium coefficient for plots covered with an anti-hail net as specified in the HSK web-site. This is invariant for crop type. It must be noted that the parameters γ are actually specific for each municipality in the Bolzano province. The ones shown are therefore provincial averages.

Table 1: Parameter's Values

Param.	**Apples**	**N. obs.**	**Wine-grapes**	**N. obs.**
$P\mu$	28617.2€\ha	44772	21884.5€\ha	24467
	(28459.5, 28775.0)		(21770.3, 21998.7)	
γ	0.100	44772	0.045	24467
	(0.100, 0.101)		(0.0449, 0.0452)	
s	0.685	44772	0.667	24467
	(0.684, 0.686)		(0.666, 0.668)	
m	0.16	39	0.16	39
	(-0.04, 0.36)		(-0.04, 0.36)	
r	0.02	/	0.02	/
	/		/	
EAC	1720.1€\ha	/	1720.1€\ha	/
	/		/	
CY	600€\ha	/	600€\ha	/
	/		/	

With regard to the deductible structure, it is reproduced below as a function of damage. Note that it is identical for apples and wine-grapes and it is also retrieved from the HSK web-site.

Table 2: Deductible Structure

	Apples and wine-grapes									
δ	0.31	0.32	0.33	0.34	0.35	0.36	0.37	0.38	0.39	≥ 0.4
d	0.28	0.26	0.24	0.22	0.20	0.18	0.16	0.14	0.12	0.10

For damages below the 31% of the insured value, the indemnity is equal to zero, unless it is signed a specific insurance contract that, however, does not benefit from any subsidy. Once defined the deductible structure and considering the equality $\gamma = E[I(\Delta, d)](1+m) \rightarrow E[I(\Delta, d)] = \frac{\gamma}{1+m}$, we have the possibility to estimate Δ. In Rogna et al. [2019], a similar exercise has been performed in order to estimate the overall distribution of hail-damage risk whereas in the present case, although the procedure is basically the same, we want to estimate the distribution of the individual expected damage probability in our hypothetical reference population of farmers. A truncated normal distribution, in the $[0, 1]$ outcome space, seems to be a reasonable choice. Therefore, we are considering the distribution of individual expected damages from hail in our farmers' reference population as a continuous random variable.[4] Given the

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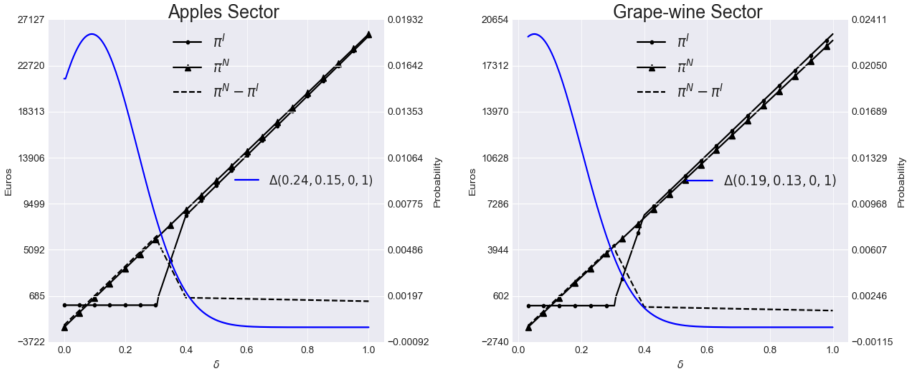
[4] This implies that we are considering the reference population of insured farmers as a

deductible structure d in Table 2, we can represent the indemnity function as follows:

$$I(\delta, d) = \begin{cases} 0, & \text{for} \quad \delta < 0.31 \\ 3(\delta - 0.3), & \text{for} \quad 0.31 \leq \delta < 0.4 \\ \delta - 0.1, & \text{for} \quad \delta \geq 0.4. \end{cases}$$

From Table 1, we have that $\frac{\gamma}{1+m} \equiv 0.087$ for apples farmers and $\frac{\gamma}{1+m} \equiv 0.039$ in the wine-grapes sector. By assuming a given standard deviation, we only need to find the appropriate mean $(\bar{\delta})$ to characterize the distribution $\Delta(\bar{\delta}, \sigma, 0, 1)$ that solves $E[I(\Delta, d)] = 0.087$ for the apples and $E[I(\Delta, d)] = 0.039$ for the wine-grapes sectors. Furthermore, by plugging in the parameters' values of Table 1 into equations (1B) and (2) and letting δ vary in the [0,1] range, we can compute the profit of the two hedging strategies and their differential as a function of a farmers' individual risk probability given a specific distribution of the risk in the population. Figure 1 shows the results for the two sectors given the selected values of σ.

Figure 1: Profitability of hedging strategies as a function of δ



The first thing we can notice from Figure 1 is that the differential in the profitability of anti-hail nets and hail insurance (dashed line) follows an inverted U-shaped curve rather than being an increasing function of δ. For very low levels of δ, when both hedging strategies have a negative return, hail insurance performs better due to the relatively high fixed costs of anti-hail nets. However, for such low levels of the expected damage, it is likely farmers would rather avoid adopting any hedging strategy, even if strongly risk averse. For moderate levels of expected damages, hail-nets perform better and the differential of the profitability of the two strategies is effectively an increasing function of δ. This is clearly due to the deductible structure according to which no indemnity is given for damages below 31%. This last, in fact, is the level of δ for which the differential is maximum. After this threshold, it firstly decreases fast and then

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continuum rather than as a discrete variable.

keeps declining mildly. Note that, in both cases, a value of δ greater than 0.6 for both sectors is unlikely. Finally, by the comparison of the two sectors, it is possible to have a confirmation of the findings in Rogna et al. [2019]. In fact, the higher overall damage risk in the apples sector is associated to a higher profitability of anti-hail nets compared to hail insurance.

4 Empirical Analysis

From Rogna et al. [2019], we know that the differential profitability of anti-hail nets versus hail insurance is an increasing function of the overall risk of hail damages. This may lead to think that favouring anti-hail nets has a positive effect on the actuarial soundness of the insurance market. However, as Figure 2 shows, there is a clear positive relation between the expected costs (average indemnity due to farmers) of insurance companies and the premium coefficient, determining the cost for farmers, applied by them.

Figure 2: Average Indemnities and Premium coefficients

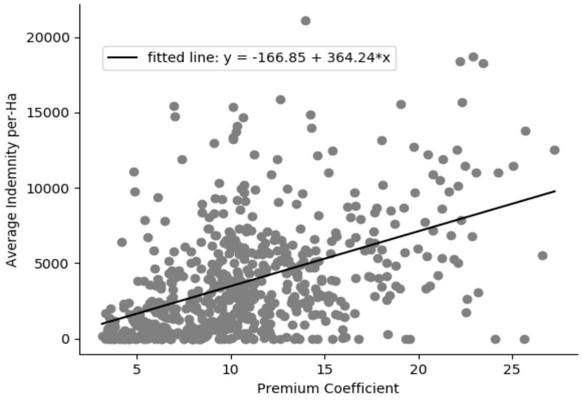

Figure 2, in fact, shows, on the abscissa, the time average of the premium coefficients for each contract type in each municipality in the dataset, whereas, on the ordinate, it shows the average per-hectare indemnity paid for each contract in each municipality.

Areas more subject to hail damages are also the ones charged with higher premia, so that the switch of farmers to anti-hail nets in such locations may not bring any benefit to actuarial soundness. This last, instead, would improve if farmers with individual expected damages above the average switch towards anti-hail nets. From the previous section, however, this does not seem to be a likely result, given the inverted U-shape relation put in evidence. This fact has important implications from a policy perspective since incentivising the purchase of anti-hail nets by, for example, diverting part of the current subsidy benefiting insurance contracts to this alternative hedging instrument, could actually worsen the sustainability of the insurance market. This negative effect would be stronger in sectors where the overall risk is lower, such as the wine-grapes sector in our example. Before drawing these conclusions, however, it is necessary to perform an empirical investigation in order to validate the correctness of the findings derived by the present model and by the one in Rogna et al. [2019].

4.1 The dependent variable

The possibility to model directly the choice between the two hedging strategies – and no hedging – is actually precluded to us for lack of data at farm level. However, thanks to the mentioned dataset obtained from HSK, we get access to extensive information about insured farmers for a five-years period. The database lists all insured plots in the Bolzano province providing several ancillary information. Since, by law, a farmer willing to insure a plot, in order to benefit from the E.U. and provincial subsidy, is required to insure all plots with the same crop belonging to the same municipality,[5] it is possible to exploit this condition to individuate plots where a switch from hail insurance to anti-hail nets has taken place. A crop covered by anti-hail nets, in fact, is considered as a different typology of product and, therefore, it is not subject to the mentioned requirement of being insured. Given a plot, identified by its type of cultivated crop, by its size and by its owner, present in our dataset in a specific year, if such plot is not present any more in subsequent years, while the owner holds at least another insured plot of the same crop in the same municipality,[6] it is categorized as having been covered by an anti-hail net. Our dependent variable (*hail_s*) is therefore a dummy taking the value of one for plots whose status switch from being insured to being covered by a 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 of our observations (2017).

4.2 Regressors of main interest

The main objective of our empirical analysis is to test the predictions of the model presented in Section 3 together with the insights gained from Rogna et al. [2019]. In particular, this last paper offers some easy to test hypotheses:

1) The profitability of anti-hail nets versus insurance is an increasing function of the per-hectare output value, defined as the product of the selling price and the per-hectare produced quantity.

2) The profitability of anti-hail nets versus insurance is an increasing function of the overall average risk faced by farmers.

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[5] This is explicitly mentioned in the insurance conditions as reported in the HSK web-site.

[6] Note that it is not necessary that the other insured plot is cultivated with the same variety of crop, but simply with the same crop.

With regard to the present model, we want to test the inverse U-shaped relation between the differential profitability of the two hedging strategies and the difference between the insurance profitability of a specific plot[7] compared to the average insurance profitability. Note that, on the long run, the average insurance profitability should tend to zero or, better, to a small negative number that covers the operating costs of insurance companies. Since the insurance profitability of a specific plot is determined by the difference of the intrinsic risk of such plot versus the average risk of all plots in the same municipality with the same type of hedging contract, we could rephrase our previous sentence saying that we want to test the inverse U-shaped relation between the differential profitability of the two hedging strategies and the difference between a plot specific versus average hail risk. Furthermore, as observable in Figure 1, the differential profitability of the two hedging strategies is strongly influenced by the deductible structure of insurance contracts that penalizes plots with low expected risk. This is another element of clear interest.

Our main regressors will therefore be the chosen price (*price*, equivalent to P in the model) at which the output quantity is insured, the per-hectare insured quantity (*aut_pha*, μ in the model) and the coefficient determining the premium to be paid to insurance companies (*pr_coef*, γ in the model). As mentioned, our hypothesis is that the product of P and μ favours anti-hail nets over insurance, therefore we should adopt the multiplication of the two last mentioned variables as regressor. However, we prefer to keep them separated given the potential trade off existing between quantity and quality of production. Furthermore, although, theoretically, they should both affect positively the propensity to switch towards anti-hail nets, the price variable presents a complication. What we have in our dataset is the price at which the farmer has chosen to insure her output, that, according to HSK information, can be selected inside a range provided by insurance companies. Therefore, it could be different from the actual price of output sale. Farmers with individual high expected hail damages could then find profitable to inflate such price. But then, according to the inverted U-shape hypothesis of this paper, these should also be the farmers less likely to switch to anti-hail nets. If this second effect of the price variable prevails, its multiplication with the per-hectare output quantity would possibly confound the resulting coefficient.

For the second hypothesis derived from Rogna et al. [2019] we can simply observe *pr_coef*. The premium coefficient 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, also in this case, there is a potential contrasting effect. Whereas all contracts include hail damages, they vary in the number of alternative risks covered. The higher this number, the more expensive will be the contract. Clearly, since anti-hail nets provide

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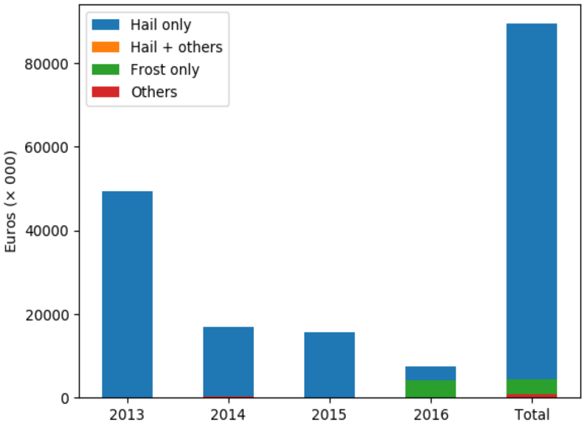
[7] Whereas in the model we have identified individual with plot-specific risk due to the assumption of each farmer owning just a single plot, now we need to drop this simplifying assumption and revert to the use of plot-specific risk.

Figure 3: Indemnities by damage typology



protection only from hail, farmers choosing more expensive contracts to hedge other risk typologies are less likely to switch towards this measure. The variable *pr_coef*, therefore, conveys contrasting information since, from one side, it is a direct measure of the municipality 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 signs. 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 trivial portion of the total, implying that the potentially confounding factor imbued in *pr_coef* 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 the measure of plot-specific versus average insurance profitability, two indexes are adopted. The first one (*ind_pr*) 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:

$$\mathit{ind\_pr}_i = \sum_{t \in T} \frac{I_{i,t}}{Pr_{i,t}};$$

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. The second index (*ins_prof*) 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. 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 with the same contract type. With this being the numerator, the denominator is simply its standard deviation:

$$\mathit{ins\_prof}_i = \frac{\frac{1}{|T|}\sum\limits_{t\in T}(I_{i,t}-Pr_{i,t}) - \frac{1}{|T|\times|MV_i|}\sum\limits_{j\in MV_i}\sum\limits_{t\in T}(I_{j,t}-Pr_{j,t})}{\sqrt{\frac{1}{|MV_i|}\sum\limits_{j\in MV_i}\left(\frac{1}{|T|}\sum\limits_{t\in T}(I_{j,t}-Pr_{j,t}) - \frac{1}{|T|\times|MV_i|}\sum\limits_{j\in MV_i}\sum\limits_{t\in T}(I_{j,t}-Pr_{j,t})\right)^2}};$$

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 contract type as, plot i. Note that, since in our model we consider the expected risk of a plot, we have taken the time average rather than the year profitability of the insurance contract on a specific plot. Although the time periods in our dataset are rather scarce, this should nonetheless approximate better the expectation of such value. 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, operation necessary to evaluate the inverse U-shaped hypothesis. Therefore, we applied an affine transformation so that its lower bound is 1:

$$\mathit{ins\_prof}_i = \mathit{ins\_prof}_i + \min(\mathit{ins\_prof}) + 1.$$

Finally, we add other two variables in order to test the greater propensity of farmers with an expected damage below the deductible threshold to switch to anti-hail nets. The first (*pi_d*) is a dummy taking the value of 1 when a farmer has signed an additional private contract to insure herself for the portion of damages below the 31% level. This additional contract, not subsidized, has a constant 10% deductible threshold. Since a private insurance contract could be a substitute of the purchase of an anti-hail net, the second variable (*pr_tot*) tries to solve this potential source of confusion. It is defined as the sum of the premia paid for private contracts in a given municipality over the municipal sum of total paid premia. A higher value of *pi_tot*, therefore, should identify a municipality where damages below the deductible are more likely.

4.3 Control variables

Finally, a set of controls are added to avoid bias due to omitted variables. The per-hectare received indemnity (*ind_pha*) 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 (*sub_pha*) received for an insurance contract is added with the idea that higher subsidies discourage the switch to anti-hail nets.

Furthermore, it is considered the normalized Herfindhal-Hirschman index of concentration (*HHI*), the inverse of diversification, this last having been treated as an alternative hedging strategy in Finger and Lehmann [2012] and in Santeramo et al. [2016]. The normalized HHI is defined as:

$$HHI_{i,t} = \frac{\sum_{j\in V_{i,t}} s_j^2 - \frac{1}{|V_{i,t}|}}{1-\frac{1}{|V_{i,t}|}};$$

with $V_{i,t}$ being the set of varieties cultivated by farmer i during year t and s_j being the share, in terms of dedicated hectares over total cultivated hectares, of variety j. The term $\frac{1}{|V_{i,t}|}$, one over the number of varieties cultivated by a farmer in a given year, is used as the normalization factor. Two dummies are further included, the first (*no_hail*) individuates plots being damaged by events other than hail, whereas the other (*grape*) indicates plots cultivated with wine-grapes rather than apples.

Table 3: Variables and Basic Statistics

Variable	**Mean**	**St. Dev.**	**Min.**	**Max.**	**Expected Sign of Est. Coef.**
hail_s	0.3156	0.4648	0	1	/
price	87.1802	69.8174	16	315	+
out_pha	497.1314	374.1144	0.3731	16438.36	+
pr_coef	2.8359	1.4127	0.36	21.292	+
ind_pr	2.6174	6.7936	0	165.4321	+/-
ins_prof	16.0962	0.9460	1	42.9829	+/-
pi_d	0.3606	0.4802	0	1	+
pi_tot	0.0515	0.0758	0	1	+
ind_pha	1832.459	5990.451	0	337960	-
sub_pha	1782.211	1424.602	0	100289.3	-
HHI	0.1969	0.2332	0	1	?
grape	0.2296	0.4206	0	1	-
no_hail	0.0158	0.1248	0	1	-

Both dummies should have a negative sign, the first for obvious reasons whereas the latter because the profitability of anti-hail nets is lower in the wine-grape sector, as shown in Figure 1. Finally, a categorical for the different years in our dataset is taken into consideration. In Table 3, all variables are reported with basic statistics and with the expected sign of their estimated coefficient. Note that for the indexes of profitability the "+/-" indicates a plus for the level and a minus related to their squares.

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 – e.g. education, social origin, wealth, etc. – potentially important in influencing the choice of the hedging instrument and likely to be correlated with some of the selected regressors, the chosen model appears appropriate to tackle this issue. The conditional fixed effect logit model can be written as:

$$Pr(y_{i,j,t} = 1|\boldsymbol{x}_{i,j,t}) = F(a_i + \boldsymbol{x}_{i,j,t}\boldsymbol{\beta}),$$

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, clearly, time. The unobserved farmers characteristics, a_i, are taken into account by the fixed effect component of the model, whereas $\boldsymbol{x}_{i,j,t}$ is the set of regressors described in Table 3.

Table 4 reports the estimated coefficients. Regression (1) uses *ind_pr* as index of insurance profitability, whereas in regressions (2) the index is provided by *ins_prof*. Starting with the first hypothesis, as to say that a greater value of the produced output renders anti-hail nets more profitable and, consequently, it increases the probability of switching to this hedging instrument, this hypothesis finds a partial confirmation. Either in regressions (1) and (2), in fact, the coefficient of *out_pha* is positive and statistically significant. However, the one of *price* is negative for both regressions even if it is statistically significant only in the former. We have already provided a possible reason for the negative sign of *price* when discussing the inclusion of the output value separating its two subcomponents rather than as a single variable.

The second hypothesis derived from Rogna et al. [2019], according to which the profitability of anti-hail nets versus insurance is an increasing function of the overall risk of damages, is, instead, fully confirmed. The coefficient of *pr_coef*, in fact, is positive and significant (0.1% level) in all regressions. As a further confirmation it can be mentioned the negative, and significant, coefficient of *grape*, the dummy indicating the less risky sector in regression (2).

The main hypothesis of the present paper regarding the inverse U-shaped relation described in Section 3 finds a good support. In regression (2) we have a positive coefficient for *ins_prof* as level and a negative coefficient for its squared term, as hypothesised. Both of them are strongly significant. The same sign can be observed in regression (1) for *ind_pr*, although here only the coefficient for the level is significant. A reasonable explanation for the lack of significance of the squared form of *ind_pr* could be the rather simplified nature of this index, unable to fully capture the hypothesised relation. We can notice, in fact, 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 over-sensitive to modifications.

We do not find any confirmation, instead, that farmers with a higher probability of suffering damages below the deductible threshold switch more easily to anti-hail nets. In both regressions, in fact, either the coefficients of *pi_d* and the ones of *pi_tot* are not significant. Moreover, they are all negative. For *pi_d*, a possible explanation is the fact that signing a private contract to hedge damages below the deductible threshold is a substitute of switching to anti-hail nets, thus explaining the negative coefficient. For *pi_tot*, that we used as a proxy of the

Table 4: Estimates

	(1)	**(2)**
	hail_s	***hail_s***
price	-0.00136***	-0.000480
	(-3.69)	(-1.27)
out_pha	0.000193**	0.000220***
	(2.36)	(3.36)
pr_coef	0.115***	0.101***
	(6.61)	(5.77)
ind_pr	0.0442***	
	(9.17)	
ind_pr^2	-0.0000896	
	(-0.87)	
ins_prof		1.127***
		(18.41)
ins_prof^2		-0.0361***
		(-17.02)
pi_d	-0.0235	-0.0488
	(-0.42)	(-0.90)
pi_tot	-0.0409	-0.293
	(-0.12)	(-0.82)
ind_pha	-0.0000204***	-0.00000552
	(-6.10)	(-1.68)
sub_pha	-0.0000384	-0.0000218
	(-1.78)	(-1.09)
HHI	0.517**	0.471**
	(3.17)	(2.95)
grape	-0.0642	-0.660***
	(-0.71)	(-6.82)
not_hail	-0.0702	-0.0635
	(-0.55)	(-0.48)
year_14	-0.699***	-0.696***
	(-12.24)	(-12.09)
year_15	-0.693***	-0.688***
	(-14.27)	(-14.16)
year_16	0.416***	0.507***
	(8.55)	(10.49)
Pseudo R^2	0.0527	0.0715
N. obs.	110996	110594

t statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

likelihood to have damages below the deductible threshold in a given municipality, it could be that this index is not very good in capturing the plot-specific probability to suffer such type of damages.

With regard to the controls, it worth to notice how the signs of the coefficients for *ind_pha*, *sup_pha*, *grape* and *no_hail* are in line with our expectations in both regressions. However, only *ind_pha* in regression (1) and *grape* in regression (2) are significant. Finally, the positive and significant, in both regressions, coefficient of *HHI* is difficult to interpret from an economic point of view. However, its significance suggests that its inclusion is opportune.

5 Conclusions

Starting from the consideration that in several areas of the world hail is a significant source of agricultural output loss, the present paper investigates the relation between two of the most commonly adopted hedging instruments to face this atmospheric phenomenon: agricultural insurance and anti-hail nets. In particular, given the findings of a companion paper, Rogna et al. [2019], according to which the profitability of anti-hail nets versus insurance is an increasing function of the overall risk of damages from hail in a given area, we are interested in understanding if the diffusion of anti-hail nets could be beneficial for the actuarial soundness of insurance markets. This topic is investigated firstly through a simple model coupled with a numerical simulation and, subsequently, through an econometric estimation to validate it.

The model presented here benchmarks the profitability of anti-hail nets versus insurance as a function of the plot-specific expected damage compared to the average expected damage of plots in the same area. In other words, as a function of plot-specific versus average insurance profitability. By using data from apples and wine-grapes producers in the South Tyrolean region, it is shown that such function has an inverse U-shape. This implies that an attempt to promote anti-hail nets by subsidizing them, as currently done for agricultural insurance, may promote the exit of low risk rather than high risk farmers, thus lowering the financial sustainability of such market.

The econometric estimation, that models the switch from insurance to anti-hail nets by using the same dataset of South Tyrolean farmers just mentioned, finds a good confirmation of the theoretical insights. The inverse U-shaped relation is tested using, separately, two indexes, with the second being more complex. In both regressions the level of the indexes has a positive and significant coefficient whereas its squared term a negative one, confirming the prediction. However, the negative coefficient for the squared term is significant only for the less naive index. Furthermore, the econometric estimation finds confirmation for the hypothesis in Rogna et al. [2019] of anti-hail nets being more profitable than insurance for higher values of the overall risk of hail damages. The hypothesis, still derived from Rogna et al. [2019], that anti-hail nets are more profitable the higher is the value of per-hectare output is partially confirmed. The sign of output price, opposite to our predictions, could be due to a shortcoming in the data at our disposal, since we only have the insured price and not the actual selling price.

In conclusion, if it is true that plots with higher values of output and located in areas relatively more subject to hail risk tend to be hedged more easily through anti-hail nets rather than insurance, it is nonetheless true that plots with higher expected damages compared to the location average are less likely to switch to anti-hail nets. The first effect suggests a potential positive contribution of anti-hail nets to insurance markets actuarial soundness, but the second element plays in the opposite way. A policy aimed at fostering the adoption of anti-hail nets, maybe by rethinking the actual level of subsidy in favour of insurance contracts, should then take into serious consideration the last mentioned element in order to avoid to negatively affect the actuarial soundness of the hail insurance market.

References

Babcock, B. A. (2015). Using cumulative prospect theory to explain anomalous crop insurance coverage choice. *American Journal of Agricultural Economics*, 97(5):1371–1384.

Cabas, J. H., Leiva, A. J., and Weersink, A. (2008). Modeling exit and entry of farmers in a crop insurance program. *Agricultural and Resource Economics Review*, 37(1):92–105.

Chamberlain, G. (1980). Analysis of covariance with qualitative data. *The Review of Economic Studies*, 47(1):225–238.

Changnon Jr, S. A. (1970). Hailstreaks. *Journal of the Atmospheric Sciences*, 27(1):109–125.

Changnon Jr, S. A. (1977). The scales of hail. *Journal of Applied Meteorology*, 16(6):626–648.

Coble, K. H., Knight, T. O., Pope, R. D., and Williams, J. R. (1996). Modeling farm-level crop insurance demand with panel data. *American Journal of Agricultural Economics*, 78(2):439–447.

Coble, K. H., Knight, T. O., Pope, R. D., and Williams, J. R. (1997). An expected-indemnity approach to the measurement of moral hazard in crop insurance. *American Journal of Agricultural Economics*, 79(1):216–226.

Cohen, A. and Siegelman, P. (2010). Testing for adverse selection in insurance markets. *Journal of Risk and Insurance*, 77(1):39–84.

Dessens, J. (1986a). Hail in Southwestern France. I: Hailfall Characteristics and Hailstrom Environment. *Journal of Climate and Applied Meteorology*, 25(1):35–47.

Dessens, J. (1986b). Hail in southwestern France. II: Results of a 30-year hail prevention project with silver iodide seeding from the ground. *Journal of Climate and Applied Meteorology*, 25(1):48–58.

Dessens, J., Berthet, C., and Sanchez, L. J. (2015). Change in hailstone size distributions with an increase in the melting level height. *Atmospheric Research*, 158:245–253.

Eccel, E., Cau, P., Riemann-Campe, K., and Biasioli, F. (2012). Quantitative hail monitoring in an alpine area: 35-year climatology and links with atmospheric variables. *International Journal of Climatology*, 32(4):503–517.

Enjolras, G., Capitanio, F., and Adinolfi, F. (2012). The demand for crop insurance: Combined approaches for France and Italy. *Agricultural Economics Review*, 13(1):5.

Falco, S. D., Adinolfi, F., Bozzola, M., and Capitanio, F. (2014). Crop insurance as a strategy for adapting to climate change. *Journal of Agricultural Economics*, 65(2):485–504.

Finger, R. and Lehmann, N. (2012). The influence of direct payments on farmers' hail insurance decisions. *Agricultural Economics*, 43(3):343–354.

Füssel, H.-M., Jol, A., Marx, A., Hildén, M., Aparicio, A., Bastrup-Birk, A., Bigano, A., Castellari, S., Erhard, M., Georgi, B., et al. (2017). *Climate Change, Impacts and Vulnerability in Europe 2016-An Indicator-based Report*. Publications Office of the European Union.

Garrido, A. and Zilberman, D. (2008). Revisiting the demand for agricultural insurance: the case of Spain. *Agricultural Finance Review*, 68(1):43–66.

Goodwin, B. K. (1993). An empirical analysis of the demand for multiple peril crop insurance. *American Journal of Agricultural Economics*, 75(2):425–434.

Goodwin, B. K. and Kastens, T. L. (1993). Adverse selection, disaster relief, and the demand for multiple peril crop insurance. *Contract Report for the Federal Crop Insurance Corporation*.

Goodwin, B. K. and Smith, V. H. (1995). *The economics of crop insurance and disaster aid*. American Enterprise Institute.

Hübner, O. (1856). *Das Hagelversicherungswesen im preussischen Staate*. Verlag der Expedition, Berlin (1856).

Just, R. E. and Calvin, L. (1994). An empirical analysis of US participation in crop insurance. In *Economics of Agricultural Crop Insurance: Theory and Evidence*, pages 205–252. Springer.

Kaspar, M., Müller, M., Kakos, V., Rezacova, D., and Sokol, Z. (2009). Severe storm in Bavaria, the Czech Republic and Poland on 12–13 July 1984: A statistic-and model-based analysis. *Atmospheric Research*, 93(1-3):99–110.

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: A Journal of the Royal Meteorological Society*, 29(15):2283–2297.

Miranda, M. J. and Glauber, J. W. (1997). Systemic risk, reinsurance, and the failure of crop insurance markets. *American Journal of Agricultural Economics*, 79(1):206–215.

Nieuwoudt, W. L. and Bullock, J. B. (1985). The demand for crop insurance. *Agricultural Economics Report*, No. 991-2016-77564, pp. 655-667.

Punge, H. J. and Kunz, M. (2016). Hail observations and hailstorm characteristics in Europe: A review. *Atmospheric Research*, 176:159–184.

Rogna, M., Günter, S., and Weissensteiner, A. (2019). Choosing between Hail Insurance and Anti-Hail Nets: A Simple Model and a Simulation among Apples Producers in South Tyrol. Technical report, BEMPS - Bozen Economics & Management Paper Series, No BEMPS62.

Roncali, G. (1955). Sui danni della grandine in italia. *Mem. UCM Ii. A., Ser. IV*, 1.

Santeramo, F. G. (2018a). I Learn, You Learn, We Gain Experience in Crop Insurance Markets. *Applied Economic Perspectives and Policy*, 41(2):284–304.

Santeramo, F. G. (2018b). Imperfect information and participation in insurance markets: evidence from Italy. *Agricultural Finance Review*, 78(2):183–194.

Santeramo, F. G. and Ford Ramsey, A. (2017). Crop Insurance in the EU: Lessons and Caution from the US. *EuroChoices*, 16(3):34–39.

Santeramo, F. G., Goodwin, B., Adinolfi, F., and Capitanio, F. (2016). Farmer participation, entry and exit decisions in the Italian crop insurance programme. *Journal of Agricultural Economics*, 67(3):639–657.

Sherrick, B. J., Barry, P. J., Ellinger, P. N., and Schnitkey, G. D. (2004). Factors influencing farmers' crop insurance decisions. *American Journal of Agricultural Economics*, 86(1):103–114.

Smith, V. H. and Baquet, A. E. (1996). The demand for multiple peril crop insurance: evidence from Montana wheat farms. *American Journal of Agricultural Economics*, 78(1):189–201.

Walters, C. G., Shumway, C. R., Chouinard, H. H., and Wandschneider, P. R. (2014). Asymmetric information and profit taking in crop insurance. *Applied Economic Perspectives and Policy*, 37(1):107–129.

Wieringa, J. and Holleman, I. (2006). If cannons cannot fight hail, what else? *Meteorologische Zeitschrift*, 15(6):659–669.

Wright, B. D. and Hewitt, J. A. (1994). All-risk crop insurance: lessons from theory and experience. In *Economics of Agricultural Crop Insurance: Theory and Evidence*, pages 73–112. Springer.