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# **Choosing Between Hail Insurance and Anti-Hail Nets: A Simple Model and a Simulation among Apples Producers in South Tyrol**

**Marco Rogna, Günter Schamel, and Alex Weissensteiner**

*Selected paper prepared for presentation at the 2019 Summer Symposium: Trading for Good – Agricultural Trade in the Context of Climate Change Adaptation and Mitigation: Synergies, Obstacles and Possible Solutions, co-organized by the International Agricultural Trade Research Consortium (IATRC) and the European Commission Joint Research Center (EU-JRC), June 23-25, 2019 in Seville, Spain.*

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# Choosing between Hail Insurance and Anti-Hail Nets: A Simple Model and a Simulation among Apples Producers in South Tyrol

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May 5, 2019

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## Abstract

There is a growing interest in analysing the diffusion of agricultural insurance, seen as an effective tool for managing farm risks. Much attention has been dedicated to understanding the scarce adoption rate despite high levels of subsidization and policy support. In this paper, we analyse an aspect that seems to have been partially overlooked: the potential competing nature between insurance and other risk management tools.

We consider hail as a single source weather shock and analyse the potential competing effect of anti-hail nets over insurance as instruments to cope with this shock by presenting a simple theoretical model that is rooted into expected utility theory. After describing the basic model, we perform some comparative static analysis to identify the role of individual elements that are shaping farmers' decisions. From this exercise it results that the worth of anti-hail nets compared to insurance is an increasing function of the overall risk of hail damages, of the farmers' level of risk aversion and of the worth of the agricultural output.

Finally, we develop a simulation model using data related to apple production in South Tyrol, a Northern-Italian province with a relatively high risk of hail. The model generally confirms the results of the comparative static analysis and it shows that, in this region, anti-hail nets are often superior than insurance in expected utility terms.

**Keywords:** Actuarial soundness; Agricultural insurance markets, Anti-hail nets; Hail; Expected utility.

**J.E.L.:** Q12; Q18.

# 1 Introduction and literature review

The dependence of agricultural output from weather conditions is one of the main sources of revenues volatility in farming [Moss and Shonkwiler, 1993; Ray et al., 2015], in addition to variations in input [Apergis and Reztis, 2003] and output prices [Gilbert and Morgan, 2010]. Whereas the latter two are shared with other economic sectors, whether risks are an important peculiarity for agriculture. Moreover, agriculture suffers from a structural weakness since, on average, agricultural incomes are typically lower than entrepreneurial incomes in other productive sectors [European Commission, 2015]. Together with the strategic importance of the sector, these reasons have encouraged efforts to stabilize or, at least, sensibly smooth, agricultural incomes using a number of different policy measures.

Insurance is seen as an effective tool and, in fact, it has been one of the first remedies. However, since systemic weather effects induce a high-correlation among individual farms' risk exposure, private insurance markets are often unsustainable [Miranda and Glauber, 1997]. This has led to steady government interventions in crop insurance markets, usually through a variable subsidization of insurance premia. A first example is the Agricultural Adjustment Act 1938, introducing a subsidized multi-peril federal insurance program in the United State (U.S.). This has been subsequently reformed during the mid-eighties and, in 1994, the Federal Crop Insurance Reform Act of 1994 introduced major changes. Starting with the first reform during the mid-eighties, there has been a growing research interest in this topic leading to at least three review articles being published on the topic: Wright and Hewitt [1994], Goodwin and Smith [1995] and Knight and Coble [1997].

First, the main research interest centered on understanding the scarce participation of farmers in insurance markets. Despite high level of subsidization, peaking at 70% of the premium, not more than 25% of the eligible acreage in the U.S. was enrolled in the Multiple Peril Crop Insurance (MPCI) program until 1989 [Coble et al., 1996]. This puzzling phenomenon boosted empirical investigations of the elasticity to premia and of the other determinants of farmers' demand for insurance using county level data: Nieuwoudt et al. [1985]; Gardner and Kramer [1986]; Hojjati and Bockstaal [1988]; Barnett et al. [1990] and Goodwin [1993] or farm level data: Goodwin and Kastens [1993]; Just and Calvin [1994]; Coble et al. [1996]; Smith and Baquet [1996] and Sherrick et al. [2004].

MPCI program adoption increased after 2000 and in 2015 more than 80% of crop acreage in U.S. was insured [Babcock, 2015]. In the European Union the subsidization of insurance premia started later, but the same problem of under-adoption of agricultural insurance has prompted research to investigate its causes: e.g. Finger and Lehmann [2012]; Falco et al. [2014] and Santeramo et al. [2016].

Besides the central adoption theme, several other aspects related to agricultural insurance have been investigated. The moral hazard problem related to insurance contracts has been studied theoretically by Ramaswami [1993] and empirically tested by Horowitz and Lichtenberg [1993]; Quiggin et al. [1993]; Smith and Goodwin [1996] and Coble et al. [1997]. In developing countries, fragmented credit markets and the relatively low mean size of cultivated plots together with asymmetric information and high transaction costs pose further problems to the adoption and sustainability of crop insurance instruments [Barnett and Mahul, 2007]. Weather Index-based Insurance (WII) has been adopted in low- and middle-income countries to mitigate the previously mentioned problems, and a large strand of the literature focuses on assessing its effectiveness in alleviating poverty and in contributing to rural development: e.g. Breustedt et al. [2008]; McIntosh et al. [2013] and Leblois et al. [2014].

The papers related to agricultural insurance and the broad spectrum of topics covered by them call for a clear definition of what this paper aims for. Its first objective is to present a simple theoretical framework to describe the problem of farmers deciding to protect their crop or not. The novelty of our paper is to present a model that includes the possibility of choosing an alternative and competing protective measure besides adopting an insurance. We restrict our attention to hail weather shocks and consider, as the competitive protective measure, the possible adoption of anti-hail nets. This choice further narrows the scope of our analysis to crops, such as fruit trees, that allow for the use of this hedging instrument. In particular, we will focus on apples tree. In the literature regarding the determinants of insurance adoption and particularly in related empirical analyses, the potential competitive role of other instruments has clearly emerged. Crop diversification, for example, is generally regarded as an alternative risk management practice and several papers found that it significantly decreases the demand for insurance (e.g. Nieuwoudt et al. [1985]; Barnett et al. [1990] and Finger and Lehmann [2012]). The effect of disaster relieve programs, also supposed to have a competing effect with insurance, has been tested by Smith and Baquet [1996] and Finger and Lehmann [2012], with the former finding a complementary role whereas the latter a substitution effect.

Since a wide adoption of insurance, particularly among farmers with lower risk exposure, is a key factor for actuarial soundness and for lowering insurance premia, investigating the role of competing alternative measures in potentially lowering risk becomes important. To the best of our knowledge, this paper is a first attempt to theoretically model competing alternatives, even though for a very specific case. The model allows to perform a comparative static analysis to understand the role of each single element in shifting the preference between the two alternatives. Particularly important is to understand the role of risk exposure. If anti-hail nets are preferred by low risk farmers, this might pose a further problem to actuarial soundness.

The second objective of the paper is to perform a simulation to assess the

predictive capability of the model and to derive potentially useful information for policy makers. The data to calibrate the simulation model relate to specialized apple farmers in South Tyrol, North-Eastern Italy, exposed to a relatively high level of hail risk.<sup>1</sup> We will quantify the differential certainty equivalent (CE) expected utility of a representative apple farmer in South Tyrol deciding either to adopt or not an hedging instrument and, in the former case, choosing between insurance or anti-hail nets. Should anti-hail nets be a relatively better instrument than insurance to address the negative effects of hail, the current insurance subsidies could be considered as a distortionary and inefficient measure. However, the environmental impact of nets could be considered as a negative externality, particularly in a region with a high volume of tourism such as South Tyrol. The simulation will provide useful data to shape the policy debate on the subject.

The rest of the paper is organized as follows: Section 2 presents the theoretical model, Section 3 performs the comparative statics exercise, whereas Section 4 is dedicated to the simulation. Conclusions are covered in Section 5.

## 2 A simple model of insurance versus anti-hail nets

### 2.1 Preliminaries

The present model is based on standard expected utility theory and closely resembles the models of Coble et al. [1996] and Sherrick et al. [2004] in several aspects. As we have stressed before, our focus is to compare different options to hedge against a weather shock (hail). Our representative farmer has three options: no hedging measures; signing a (hail specific) insurance contract; buying and installing anti-hail nets. Our model is static and it disregards the possibility to mix the three options. Whenever applicable, quantities for all modelling parameters will be on a per hectare basis (e.g. average yield, inputs cost, insurance premia, anti-hail net costs) and, consequently, the choice of the preferred option will be applied to each hectare of cultivated land. Some simplifying assumptions are made relative to the protection being provided by insurance and anti-hail nets. Specifically, we assume that anti-hail nets provide full protection from hail damages, whereas hail insurance does not, given the presence of a deductible. This last element, typical of insurance contracts, is a threshold damage below which the farmer, even if insured, is not entitled to receive any indemnity for the incurred damages.

Farmers maximize expected utility with wealth ( $W$ ) as the only argument assuming a standard von Neumann-Morgenstern utility function which is monotonically increasing and concave in wealth –  $U'(W) > 0, U''(W) < 0$  – with

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<sup>1</sup>According to the WineRisk web-site, the Italian Alps area is the second wine region worldwide to be most affected by hail damages.

concavity necessarily implying risk aversion.

Wealth is simply defined as the profit generated by the farming activity of a single crop:

$$W = Py - \mathbf{w}^T \mathbf{x}. \quad (1)$$

In equation (1),  $P$  is the given price of the agricultural good, assuming that farmers are price takers,  $y$  is per-hectare production function,  $\mathbf{x}$  is a vector of (per-hectare) inputs – excluding the eventual hail insurance premium and the cost of anti-hail nets – and  $\mathbf{w}$  is a vector of associated input prices. The production function takes three arguments –  $y = f(\mathbf{x}, \omega, \eta)$  – with  $\omega$  being a random realization of climatic and environmental conditions affecting agricultural production, and  $\eta$  representing the random realization of hail events. Actually, we should subdivide  $\eta$  into two components. The first, let us say  $h$ , being the number of hailstorms during cropping season and the latter, say  $i$ , representing the intensity of each hailstorm (e.g. kinetic intensity). However, this would require to work with the joint distribution of a discrete ( $h$ ) and a continuous ( $i$ ) variable, and therefore, for mere tractability, we suppose the information related to the number and intensity of hail-storms can be condensed into a single continuous variable ( $\eta$ ), which can be considered a measure of the overall severity of hailstorms during the whole cropping season.

The yield,  $y$ , is a continuous, monotonically increasing function of  $\omega$  in its outcome space and monotonically decreasing in  $\eta$ . More specifically, we define  $\delta(\eta) \in [0, 1]$  as the damage function determining the proportion of yield lost due to the cumulative effect of hail damages. Furthermore, we assume that  $\omega$  and  $\eta$  are independent. Having defined  $\omega$  as the realization of climatic and environmental conditions, it may appear odd to consider its distribution independent from hailstorms. However,  $\omega$  represents the whole climatic conditions along the cropping season whereas hailstorms, due to their short time span and relatively rare occurrence, are considered as independent events.

The expected wealth of a farmer neither adopting hail insurance nor anti-hail-nets is given by:

$$E[W] = \int_{\omega_L}^{\omega_U} \int_0^{\eta_U} (Pf(\mathbf{x}, \omega, \eta) - \mathbf{w}^T \mathbf{x})g(\omega)u(\eta)d\omega d\eta;$$

where  $g(\omega)$  is the distribution function of  $\omega$  and  $u(\eta)$  the one of  $\eta^2$ . Divide then the production function  $f(\mathbf{x}, \omega, \eta)$  into its two components. First, we have the output produced in absence of any hailstorm,  $o = r(\mathbf{x}, \omega) \rightarrow E[o] = \int_{\omega_L}^{\omega_U} r(\mathbf{x}, \omega)g(\omega)d\omega = \mu_o$ ; and second, we have the potential loss caused by the cumulative effect of hailstorms during cropping season:  $\rightarrow E[\delta] =$

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<sup>2</sup>The subscripts  $L$  and  $U$  are used to indicate, respectively, the lower and upper bound of the outcome space of a variable: e.g.  $\omega \in [\omega_L, \omega_U]$ .



$\int_0^{\eta_U} \delta(\eta)u(\eta)d\eta = \mu$ . In this way, it is possible to concisely write the utility of the expected wealth as follows:

$$U(E[W]) = U(P\mu_o(1 - \mu) - \mathbf{w}^T \mathbf{x}). \quad (2)$$

Due to the assumed concavity of the farmer's utility function, or, equivalently, due to her risk aversion, we know a farmer evaluates the certainty equivalent of wealth, i.e.  $U[CE] \approx E[U(W)]$ . Following Sherrick et al. [2004], we then adopt the convenient approximation  $U[CE] \approx E[U(W)] = \bar{W} - \lambda\sigma_W^2$ , where  $\bar{W}$  is the expected end of period wealth,  $\sigma_W^2$  its variance and  $\lambda = \frac{1}{2} \left( -\frac{U''(W)}{U'(W)} \right)$  is equal to one half the Arrow-Pratt measure of absolute risk aversion. In this way, we can write (2) as:

$$E[U(W)] = P\mu_o(1 - \mu) - \mathbf{w}^T \mathbf{x} - \lambda P^2(\sigma_o^2\sigma^2 + \sigma_o^2\mu^2 + \sigma^2\mu_o^2); \quad (3)$$

where  $\sigma_o^2$  and  $\sigma^2$  are, respectively, the variance of the output  $o$  and of the hail damage, with  $\text{VAR}(\delta) = \text{VAR}(1 - \delta)$  and where the expression in the rounded brackets following  $\lambda$  is motivated by the independence of  $o$  and  $\delta$ .

## 2.2 Hedging through hail insurance

Let us now derive the expected utility of a farmer that decides to adopt an hail insurance contract which has a deductible. It follows that farmers will not receive any compensation for hail damages below a certain threshold, indicated by  $\underline{\delta}$ . For damages superior to this given threshold, we assume that full compensation is paid. Then, by indicating with  $I$  the insurance payment, we have:

$$I = \begin{cases} 0 & \text{if } \delta \leq \underline{\delta} \\ P\mu_o\delta, & \text{if } \delta > \underline{\delta}. \end{cases}$$

With an insurance policy, the equation for the expected wealth becomes:

$$\begin{aligned} E[W_I] &= P\mu_o(1 - \mu) - \mathbf{w}^T \mathbf{x} + E[I] - \Gamma \\ &= P\mu_o(1 - \mu) - \mathbf{w}^T \mathbf{x} + \theta P\mu_o\mu_\theta - \Gamma \\ &= P\mu_o(1 - \mu + \theta\mu_\theta) - \mathbf{w}^T \mathbf{x} - \Gamma \\ &= P\mu_o(1 - \mu_I) - \mathbf{w}^T \mathbf{x} - \Gamma; \end{aligned} \quad (4)$$

where  $\theta$  is the probability that  $\delta > \underline{\delta}$  ( $\theta = Pr(\delta > \underline{\delta})$ ) and  $\mu_\theta$  is the expected value of  $\delta$  conditional on  $\delta > \underline{\delta}$  ( $\mu_\theta = E[\delta|\delta > \underline{\delta}]$ ) and  $\Gamma$  is the per-hectare insurance premium effectively paid by the farmer. Finally  $\mu_I = \mu - \theta\mu_\theta$  is simply the expected damage – or loss of agricultural revenues – in presence of insurance. From (4), it is possible to easily derive the expected utility (certainty equivalent) in presence of insurance:

$$\begin{aligned} E[U(W_I)] &= P\mu_o(1 - \mu_I) - \mathbf{w}^T \mathbf{x} - \Gamma \\ &\quad - \lambda P^2(\sigma_o^2\sigma_I^2 + \sigma_o^2\mu_I^2 + \sigma_I^2\mu_o^2). \end{aligned} \quad (5)$$

The only difference between (4) and (5) is the replacement of the mean and variance of damages,  $\mu$  and  $\sigma^2$ , with their counterpart given an insurance contract,  $\mu_I$  and  $\sigma_I^2$ , and the insurance premium. It is then crucial to understand how the two moments of the damage function are affected.

Next, let us better define  $\theta$ . It is the probability of the damage being higher than a given threshold (the deductible). Since  $\delta$  is monotonically increasing in  $\eta$ , there exists then a value  $\eta^*$  such that:

$$E[\delta] = \int_0^{\eta^*} \delta(\eta)u(\eta)d\eta = \underline{\delta}.$$

Then, for  $\eta \in [0, \eta_U]$ , we have  $(1 - \theta) = Pr(\eta < \eta^*)$  and  $\theta = Pr(\eta > \eta^*) = 1 - Pr(\eta < \eta^*)$ . From this, it follows that, for  $\eta \in [0, \eta^*]$ ,  $I(\eta)$  is always equal to zero, whereas for  $\eta \in (\eta^*, \eta_U]$  it is exactly the same as  $\delta(\eta)$ . Since  $\delta_I(\eta) = \delta(\eta) - I(\eta)$  and given what just said, we have:

$$\begin{aligned} \mu_\delta &= \int_0^{\eta^*} \delta(\eta)u(\eta)d\eta + \int_{\eta^*}^{\eta_U} \delta(\eta)u(\eta)d\eta \\ &= (1 - \theta)\mu_{(1-\theta)} + \theta\mu_\theta. \\ E[I] &= \int_0^{\eta^*} I(\eta)u(\eta)d\eta + \int_{\eta^*}^{\eta_U} I(\eta)u(\eta)d\eta \\ &= 0 + \int_{\eta^*}^{\eta_U} \delta(\eta)u(\eta)d\eta \\ &= \theta\mu_\theta. \\ \mu_I &= \int_0^{\eta^*} (\delta(\eta) - I(\eta))u(\eta)d\eta + \int_{\eta^*}^{\eta_U} (\delta(\eta) - I(\eta))u(\eta)d\eta \\ &= \int_0^{\eta^*} \delta(\eta)u(\eta)d\eta + 0 \\ &= (1 - \theta)\mu_{(1-\theta)}. \end{aligned}$$

This clearly demonstrates that the insurance has a positive effect on expected gross agricultural revenues because  $\mu_I < \mu$ . Another benefit for farmers being insured is the reduced variance of gross agricultural revenues that, in our simple model, translates into a lower variance of  $\delta_I$  compared to  $\delta$ . In Sherrick et al. [2004], the lower variance of revenues under insurance was described as a ‘‘mild assumption’’. In our model, it is possible to have a more direct measure of the mildness of such assumption. First, let us rewrite the variance of the hail damage  $\delta$  in terms of its two sub components: the damage provided  $\delta \leq \underline{\delta} = \eta \leq \eta^*$  and  $\delta > \underline{\delta} = \eta > \eta^*$ :

$$\begin{aligned} \sigma^2 &= \theta\sigma_\theta^2 + (1 - \theta)\sigma_{(1-\theta)}^2 + \theta(\mu_\theta - \mu)^2 + (1 - \theta)(\mu_{(1-\theta)} - \mu)^2, \\ &= \theta\sigma_\theta^2 + (1 - \theta)\sigma_{(1-\theta)}^2 + \theta\mu_\theta^2 + (1 - \theta)\mu_{(1-\theta)}^2 - \mu^2, \\ &= \theta\sigma_\theta^2 + (1 - \theta)\sigma_{(1-\theta)}^2 + \theta(1 - \theta)(\mu_\theta^2 + \mu_{(1-\theta)}^2 - 2\mu_\theta\mu_{(1-\theta)}). \end{aligned} \tag{6}$$

Since, in presence of insurance, either  $\mu_\theta$  and  $\sigma_\theta^2$  are equal to zero, the variance of the damage in presence of insurance,  $\sigma_I$ , is equal to:

$$\sigma_I^2 = (1 - \theta)(\sigma_{(1-\theta)}^2 + \theta\mu_{(1-\theta)}^2).$$

Finally, by writing  $\sigma_I^2$  in terms of  $\sigma^2$ , we have:

$$\sigma_I^2 = \sigma^2 - \theta\sigma_\theta^2 - \theta(1 - \theta)(\mu_\theta^2 - 2\mu_\theta\mu_{(1-\theta)}). \quad (7)$$

From this, it is easy to see the condition for  $\sigma_I^2$  being lower than  $\sigma^2$ :  $\sigma_\theta^2 > (1 - \theta)\mu_\theta(2\mu_{(1-\theta)} - \mu_\theta) = \frac{1}{(1-\theta)}D_\theta > 2\mu_{(1-\theta)} - \mu_\theta$ , with  $D_\theta = \frac{\sigma_\theta^2}{\mu_\theta}$  being the index of dispersion of  $\delta_\theta$ . Since  $\mu_\theta$  is necessarily greater than  $\mu_{(1-\theta)}$ , and  $D_\theta > \sigma_\theta^2$  since  $\mu_\theta \in (0, 1)$ , the condition appears to be effectively mild.

A hail insurance contract will be purchased if the expected value of utility of wealth (certainty equivalent) under insurance is greater than without it:  $E[U(W_I)] - E[U(W)] > 0$ . By inserting (7) into (5) and subtracting to the result (3), we have:

$$\begin{aligned} E[U(W_I)] - E[U(W)] = & P\mu_o\theta\mu_\theta \left[ 1 + \lambda P (D_o\theta\mu_\theta - 2\mu_o(1 - \theta)\mu_{(1-\theta)}) \right] \\ & + \lambda P^2\theta(\sigma_o^2 + \mu_o^2)(\sigma_\theta^2 + (1 - \theta)\mu_\theta^2) - \Gamma; \end{aligned} \quad (8)$$

where  $D_o$  is the index of dispersion of the crop yield before considering the effect of hail damages. From (8), it is very easy to derive the equilibrium premium that makes a farmer indifferent between purchasing an insurance contract or not:

$$\begin{aligned} \Gamma^* = & P\mu_o\theta\mu_\theta \left[ 1 + \lambda P (D_o\theta\mu_\theta - 2\mu_o(1 - \theta)\mu_{(1-\theta)}) \right] \\ & + \lambda P^2\theta(\sigma_o^2 + \mu_o^2)(\sigma_\theta^2 + (1 - \theta)\mu_\theta^2). \end{aligned} \quad (9)$$

### 2.3 Hedging through anti-hail nets

In case anti-hail nets are adopted, the wealth function is rather simple, because, by assumption, such a preventive measure will fully eliminate any hail damage. Hence, the equation for the expected wealth of a representative farmer adopting anti-hail nets becomes:

$$E[W_N] = P\mu_o(1 - \mu) - \mathbf{w}^T \mathbf{x} - EAC_N; \quad (10)$$

where  $EAC_N$  is the per-hectare equivalent annual cost of an anti-hail net. To see the effect of the adoption of the anti-hail net in (10), it is necessary to decompose  $EAC_N$  into its components. Since  $EAC$  is simply given by the net present value of an investment divided by the present value of annuity factor, it is easily retrieved by making some simplifying assumptions: Anti-hail nets have a given lifetime of  $T$  years, do not require any maintenance expenditure and the probability of hail damages (e.g. the distribution of  $\delta$ ) remains constant over

their entire lifetime.

Let  $r$  denote the interest rate that a farmer obtains for making an investment with a similar risk profile and  $C_N$  the per-hectare cost of anti-hail nets (paid at time zero). Finally, with the present value of annuity factor given by  $\alpha = \frac{1}{r}(1 - \frac{1}{(1+r)^T})$ , we have  $EAC_N = \frac{C_N - PV_N}{\alpha}$ , with  $PV_N$  indicating the present value of not incurring in any loss which, in turn, is given by  $PV_N = P\mu_o\mu\alpha$ , since the return of an anti-hail net investment is given by eliminating the average damage caused by hail-storms. Equation (10) can then be rewritten as  $E[W_N] = P\mu_o - \mathbf{w}^T \mathbf{x} - \frac{C_N}{\alpha}$ , from which it is immediate to get the certainty equivalent expected utility:

$$E[U(W_N)] = P\mu_o - \mathbf{w}^T \mathbf{x} - \frac{C_N}{\alpha} - \lambda P^2 \sigma_o^2. \quad (11)$$

Therefore, as for insurance contracts, anti-hail net investments have two benefit domains: they raise income by eliminating revenue losses due to hail and they reduce the overall risk that farmers face. Note that relative to insurance contracts, hail nets may perform better in both domains insofar hail damages and associated risks can be eliminated, while for insurance contracts there remains a threshold due to the deductible. The choice between purchasing anti-hail nets [equation (11)] or not [equation (3)] is given by the following expression:

$$E[U(W_N)] - E[U(W)] = P\mu_o\mu + \lambda P^2(\sigma_o^2(\sigma^2 + \mu^2 - 1) + \sigma^2\mu_o^2) - \frac{C_N}{\alpha}. \quad (12)$$

Clearly, a risk neutral farmer, with  $\lambda = 0$ , will purchase an anti-hail net if its net present value is positive:  $E[U(W_N)] - E[U(W)] = P\mu_o\mu - \frac{C_N}{\alpha} = \frac{PV_N - C_N}{\alpha} = NPV_N > 0$ . Finally, it remains to evaluate the option between purchasing anti-hail nets [equation (11)] rather than hail insurance [equation (5)]. In this case, farmers need to evaluate the following expression:

$$\begin{aligned} E[U(W_N)] - E[U(W_I)] &= P\mu_o(1 - \theta)\mu_{(1-\theta)} \\ &\quad + \lambda P^2(\sigma_o^2(\sigma_I^2 + (1 - \theta)^2\mu_{(1-\theta)}^2 - 1) + \sigma_I^2\mu_o^2) \\ &\quad - \frac{C_N}{\alpha} + \Gamma. \end{aligned} \quad (13)$$

From (12), it is possible to obtain the equilibrium annualized cost of an anti-hail net which will leave a farmer indifferent between purchasing it or not. Define  $C_N^\alpha$  as  $\frac{C_N}{\alpha}$ , we then have:

$$C_N^{\alpha*} = P\mu_o\mu + \lambda P^2(\sigma_o^2(\sigma^2 + \mu^2 - 1) + \sigma^2\mu_o^2). \quad (14)$$

Similarly, the threshold leaving a farmer indifferent between purchasing an anti-hail net rather than hail insurance can be expressed as the differential between the annualized cost of the net and the insurance premium:  $\Upsilon = C_N^\alpha - \Gamma$ . From (13), we have:

$$\Upsilon^* = P\mu_o(1 - \theta)\mu_{(1-\theta)} + \lambda P^2(\sigma_o^2(\sigma_I^2 + (1 - \theta)^2\mu_{(1-\theta)}^2 - 1) + \sigma_I^2\mu_o^2). \quad (15)$$

### 3 Comparative statics

Equations (9), (14) and (15) identify farmers choice or their indifference between two options. By taking the partial derivative of these equations for selected variables, we want to understand the role each of them has in shifting the preference between hedging strategies. We start with equation (14), defining the equilibrium annualized cost,  $C_N^{\alpha*}$ , that leaves farmers indifferent between purchasing anti-hail nets or not. The variables we are interested in taking the partial derivative are  $P$ , the output price;  $\mu_o$  and  $\sigma_o^2$ , respectively, the average and the variance of the output quantity before any hail damage;  $\lambda$ , describing the degree of absolute risk aversion and  $\mu$  and  $\sigma^2$ , the average and the variance of the proportional output loss caused by hail. Following is the result for equation (14):

$$\begin{aligned} \frac{\partial C_N^{\alpha*}}{\partial P} &= \mu_o \mu + 2\lambda P(\sigma_o^2(\sigma^2 + \mu^2 - 1) + \sigma^2 \mu_o^2). & \frac{\partial C_N^{\alpha*}}{\partial \mu_o} &= P\mu + 2\lambda P^2 \sigma^2. \\ \frac{\partial C_N^{\alpha*}}{\partial \lambda} &= P^2(\sigma_o^2(\sigma^2 + \mu^2 - 1) + \sigma^2 \mu_o^2). & \frac{\partial C_N^{\alpha*}}{\partial \sigma_o^2} &= \lambda P^2(\sigma^2 + \mu^2 - 1). \\ \frac{\partial C_N^{\alpha*}}{\partial \mu} &= P\mu_o + 2\lambda P^2 \sigma_o^2. & \frac{\partial C_N^{\alpha*}}{\partial \sigma^2} &= \lambda P^2 \sigma_o^2 + \mu_o^2. \end{aligned}$$

Farmers will tend to invest more in purchasing anti-hail nets if their mean yield (not accounting potential hail damages) grows and when the mean and variance of hail damages increase. All the derivatives for  $\mu_o$ ,  $\mu$  and  $\sigma^2$ , in fact, have only positive terms. For the derivative of equilibrium annualized costs,  $C_N^{\alpha*}$ , w.r.t. price  $P$  and absolute risk aversion  $\lambda$  to be positive, we have identical conditions, namely  $(\sigma_o^2(\sigma^2 + \mu^2 - 1) + \sigma^2 \mu_o^2) > 0 \Rightarrow \sigma^2(1 + \frac{1}{\rho_o^2}) + \mu^2 > 1$ , where  $\rho_o = \frac{\sigma_o}{\mu_o}$  is the coefficient of variation of  $o$ . Having assumed that anti-hail nets will eliminate any hail damage and its associated risk, it is also reasonable to assume that their demand (i.e. the willingness to pay (WTP) for them) is positively influenced by the magnitude of risk aversion. However, since  $\mu \in [0, 1]$ , for very low levels of such expectation, together with low levels of its variance, it might be that an increase in  $\lambda$  – so as in  $P$  – reduces the WTP for anti-hail nets. It is interesting, on this regard, to note the role of  $\frac{1}{\rho_o^2}$  and, particularly, the effect of  $\sigma_o^2$ . A high variance of yield,  $\sigma_o^2$ , increases the probability of risk aversion to negatively affect the WTP for anti-hail nets. Finally, looking at the derivative of  $C_N^{\alpha*}$  for  $\sigma_o^2$ , it is possible to observe that the condition for it to be positive is the most stringent one:  $\sigma^2 + \mu^2 > 1$ . Therefore, an increase in the variance of yield is the factor that is most likely to negatively affect the WTP for anti-hail nets. This finding is not dramatically surprising. When the hail damage and the associated risk (i.e. its variance) are particularly low, the risk inherent in (pre-hail damage) yields is predominant and, therefore, it reduces the WTP for anti-hail nets. On the contrary, when the expected damages from hail and its variance grow over a certain threshold, they contribute to increase the overall risk and, therefore, the effect of yield risk turns out to have a positive effect.

Repeating the same exercise for equation (9), defining the premium that leaves a farmer indifferent between purchasing an insurance or remaining unhedged, yields similar results. In this case, however, the partial derivative for  $\mu$  and  $\sigma^2$  have been substituted by the partial derivatives of  $\Gamma^*$  for  $\theta$ , the probability of the hail damage to be above the deductible threshold, for  $\mu_\theta$ , the average hail damage provided this is above the mentioned threshold and for  $\mu_{(1-\theta)}$ , the average damage provided it is below the threshold.

$$\begin{aligned}
\frac{\partial \Gamma^*}{\partial P} &= 2\lambda P\theta[\mu_o\mu_\theta(D_o\theta\mu_\theta - 2\mu_o(1-\theta)\mu_{(1-\theta)}) \\
&\quad + (\sigma_o^2 + \mu_o^2)(\sigma_\theta^2 + (1-\theta)\mu_\theta^2)] + P\mu_o\theta\mu_\theta. \\
\frac{\partial \Gamma^*}{\partial \mu_o} &= 2\lambda P\theta(P\mu_o(\sigma_o^2 + (1-\theta)\mu_\theta^2) - 2\mu_o\mu_\theta(1-\theta)\mu_{(1-\theta)}) + P\theta\mu_\theta. \\
\frac{\partial \Gamma^*}{\partial \sigma_o^2} &= \lambda P^2\theta(\mu_\theta^2 + \sigma_\theta^2). \\
\frac{\partial \Gamma^*}{\partial \lambda} &= P^2\theta[\mu_o\mu_\theta(D_o\theta\mu_\theta - 2\mu_o(1-\theta)\mu_{(1-\theta)}) \\
&\quad + (\sigma_o^2 + \mu_o^2)(\sigma_\theta^2 + (1-\theta)\mu_\theta^2)]. \\
\frac{\partial \Gamma^*}{\partial \mu_{(1-\theta)}} &= -2\lambda P^2\mu_o^2\theta\mu_\theta. \\
\frac{\partial \Gamma^*}{\partial \mu_\theta} &= \theta P\mu_o [1 + \lambda P(D_o\theta\mu_\theta - 2\mu_o(1-\theta)\mu_{(1-\theta)})] \\
&\quad + \lambda P^2\theta^2\sigma_o^2 + 2\lambda P^2\theta(1-\theta)(\sigma_o^2 + \mu_o^2)\mu_\theta. \\
\frac{\partial \Gamma^*}{\partial \theta} &= P\mu_o\mu_\theta [1 + \lambda P(D_o\theta\mu_\theta - 2\mu_o(1-\theta)\mu_{(1-\theta)})] \\
&\quad + \lambda P^2 [\mu_o\theta\mu_\theta(D_o\mu_\theta + 2\mu_o\mu_{(1-\theta)}) + (\sigma_o^2 + \mu_o^2)(\sigma_\theta^2 + (1-2\theta)\mu_\theta^2)].
\end{aligned}$$

Compared to the previous case, we have a positive effect on the equilibrium premium, or, else, on the WTP of a farmer for insurance, for any increase in pre-hail damage risk ( $\sigma_o^2$ ). Conversely, and reasonably, an increase of the average damage falling below the deductible threshold ( $\mu_{(1-\theta)}$ ) decreases the WTP of a farmer for insurance products. Note that, in this case, such increase is not supposed to influence the mean average hail damage above the deductible threshold ( $\mu_\theta$ ). All the other derivatives have a unique negative term inside them, namely  $-2\mu_o^2(1-\theta)\mu_\theta\mu_{(1-\theta)}$ . Leaving aside the derivative for  $\theta$ , it can be checked that for  $\mu_\theta \geq 2\mu_{(1-\theta)}$ , all such derivatives are positive. Furthermore, the left hand side of this inequality is augmented by other positive terms, so that the condition for positiveness is even milder. Finally, although the derivative for  $\theta$  has the term  $\lambda P^2(\sigma_o^2 + \mu_o^2)(1-2\theta)\mu_\theta^2$ , that could be negative for  $\theta > \frac{1}{2}$ , this does not seem to be a very realistic value of  $\theta$  since it implies that a farmer faces a probability higher than 50% to suffer a hail damage above the deductible. Furthermore, it is rather intuitive to expect an increase in the probability to get a damage above the deductible to positively affect the WTP for an insurance contract.

Summarizing, an increase in all variables entering the equations determining the cut-off cost of anti-hail nets or the cut-off premium have a positive effect on such cut-off values. The exception is the effect of  $\mu_{(1-\theta)}$  on insurance premium, as largely expected, and of  $\sigma_o^2$  on the net cost. The substantial coincidence of the role of variables on both the equilibrium cut-off values is also an expected outcome given the similarity in the purpose of the two instruments.

More intriguing is to understand the effect of our set of variables of interest on the cut-off differential between the anti-hail net annualized cost and the insurance premium. Said in another way, the role these variables have on determining a farmer's choice between anti-hail nets rather than insurance as a risk hedging strategy. We then repeat the same exercise done previously substituting equation (9) with equation (15), with the only addition of the partial derivative for  $\sigma_I^2$ , the variance of hail damage in presence of insurance:

$$\begin{aligned}
\frac{\partial \Upsilon^*}{\partial P} &= \mu_o(1-\theta)\mu_{(1-\theta)} + \lambda(\sigma_o^2(\sigma_I^2 + (1-\theta)^2\mu_{(1-\theta)}^2 - 1) + \sigma_I^2\mu_o^2). \\
\frac{\partial \Upsilon^*}{\partial \mu_o} &= P(1-\theta)\mu_\theta + \sigma_I^2. \\
\frac{\partial \Upsilon^*}{\partial \sigma_o^2} &= \lambda P(\sigma_I^2 + (1-\theta)^2\mu_{(1-\theta)}^2 - 1). \\
\frac{\partial \Upsilon^*}{\partial \lambda} &= (\sigma_o^2(\sigma_I^2 + (1-\theta)^2\mu_{(1-\theta)}^2 - 1) + \sigma_I^2\mu_o^2). \\
\frac{\partial \Upsilon^*}{\partial \sigma_I^2} &= \lambda P(\sigma_o^2 + \mu_o^2). \\
\frac{\partial \Upsilon^*}{\partial \mu_{(1-\theta)}} &= P\mu_o(1-\theta) + \lambda P\sigma_o^2(2\theta(1-\theta)\mu_\theta + (1-\theta)^2). \\
\frac{\partial \Upsilon^*}{\partial \mu_\theta} &= \theta(1-\theta)(\lambda P\sigma_o^2 + \mu_o)(\mu_{(1-\theta)} - \mu_\theta). \\
\frac{\partial \Upsilon^*}{\partial \theta} &= -P\mu_{(1-\theta)}(\mu_o + 2\lambda\sigma_o^2(1-\theta)\mu_{(1-\theta)}) \\
&\quad - \lambda P(\sigma_o^2 + \mu_o^2)[\sigma_\theta^2 + (1-2\theta)(\mu_\theta^2 - 2\mu_\theta\mu_{(1-\theta)})].
\end{aligned}$$

From these partial derivatives, it is possible to observe that the effect of the analysed variables on the cut-off differential between the annualized cost of anti-hail nets and the insurance premium is similar to the effect these variables have on the cut-off cost of nets over no hedging, i.e. the partial derivatives of equation (14). In particular, we have that an increase in the mean yield,  $\mu_o$ , has a positive effect on  $\Upsilon^*$ , whereas the effect of an increase in the crop price,  $P$ , in the variance of yield,  $\sigma_o^2$  and in the risk aversion parameter,  $\lambda$ , is less certain since all such derivatives have a negative term inside. The most stringent condition for positiveness can be found in the derivative w.r.t.  $\sigma_o^2$  and it is represented by the inequality  $\sigma_I^2 + (1-\theta)^2\mu_{(1-\theta)}^2 > 1$ . As mentioned, this mirrors the condition this variable had in the analysis regarding the choice of anti-hail nets alone. The same reasoning, therefore, can be applied in the present case and an increase in

yield variance is the factor that is most likely to negatively affect the choice for anti-hail nets relative to insurance.

Note that the condition for the partial derivative w.r.t.  $P$  and  $\lambda$  to be positive is just a weaker version of the just mentioned inequality with the left hand side being augmented by necessarily positive terms. Another element shifting the preferences towards anti-hail nets is the increase in the variance of hail damage in presence of insurance and this comes without surprise. It is easy to note that the partial derivative of  $\Upsilon^*$  for  $\sigma$  would lead exactly to the same result. Necessarily positive is also the following partial derivative, the one for  $\mu_{(1-\theta)}$ , and this is expected too, since an increase of the mean hail damage below the deductible threshold increases the worth of anti-hail nets compared to insurance. The opposite can be said for  $\mu_\theta$ , with the partial derivative being negative since  $\mu_\theta > \mu_{(1-\theta)}$ . Recalling that both insurance and anti-hail nets provide a complete “protection” for damages above the deductible, this result is not so straightforward. Furthermore, even the partial derivative for  $\sigma_\theta^2$  would be negative.<sup>3</sup> Therefore, an increase of the mean damage above the deductible, and of its variance, shifts the preference towards insurance rather than anti-hail nets. Finally, the sign of the partial derivative for  $\theta$  is difficult to predict since either positive and negative terms are present. However, for  $\theta < 0.5$  and  $\mu_\theta > 2\mu_{(1-\theta)}$ , both plausible realizations, the derivative is necessarily negative.<sup>4</sup> This basically confirms the results of the derivatives for  $\mu_\theta$  and  $\sigma_\theta^2$ .

## 4 A simulation among apples farmers in South Tyrol

In this section, we implement a simulation of the model with real data from apple production in South Tyrol. The section is divided into two main parts, with the first using average data for the whole area and the second relying on premia and average risk data for each municipality in South Tyrol. We used the FADN-RICA (Farm Accountancy Data Network) database to get yields and prices. In addition, the South Tyrolian association for the protection against weather shocks (“Hagelschutzkonsortium” or HSK) provided us with insurance related data such as yearly paid premia and indemnities received for the period 1975-2013. This association bargains on behalf of associated farmers to obtain favourable insurance contracts, collects premia and helps farmer to obtain the EU contributions.

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<sup>3</sup>It can be checked that such partial derivative would be equal to  $-\lambda P(\sigma_o^2 + \mu_o^2)$ , identical to the negative of the partial derivative for  $\sigma_I^2$ .

<sup>4</sup>Note that both these conditions have already been met when discussing insurance alone.



## 4.1 Model calibration

As stressed before, our model is a very simple representation of reality. To implement it for simulations, it is necessary to reformulate some of its fundamental equations to better resemble the case at hand. Two specific assumptions of our model do not seem to hold in the present case: the full protection from hail damages guaranteed by anti-hail nets and the full repayment of hail damages from insurance contracts when these last overcome a given threshold. We start with the latter assumption. From the HSK website, it is possible to see that the most common collective insurance contract has the deductible structure represented in Table 1.

Table 1: Deductible Structure

Damage (%)	Deductible (%)	Indemnity (%)
$\leq 30$	$\delta \times 100$	0
31	28	3
32	26	6
33	24	9
34	22	12
35	20	15
36	18	18
37	16	21
38	14	24
39	12	27
$\geq 40$	10	$\delta \times 100 - 10$

Having represented  $\delta(\eta)$  as a continuous function so as the indemnity function  $I(\delta(\eta))$ , we can write this last as follows:

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

From the data provided by HSK for the period 1975-2013, it is possible to derive the mean proportional indemnity paid by insurance companies as the ratio of paid indemnities over insured values. This amount to  $E[I] = 0.07396$ . From the Law of Total Expectation and considering the outcome space of proportional damages to be divided into three partitions -  $A_1 = [0, 0.31]$ ,  $A_2 = [0.31, 0.4]$ ,  $A_3 = [0.4, 1]$  - we can easily derive the following equation:

$$(3E[\delta|\delta \in A_2] - 0.9)Pr(\delta \in A_2) - (E[\delta|\delta \in A_3] - 0.1)Pr(\delta \in A_3) = 0.07396. \quad (16)$$

Having considered the damage as a continuous variable poses a problem, since the probability of a specific value, e.g.  $\delta = x$ , is necessarily equal to zero. This might underestimate the possibility of no hail occurrences, or else,  $\delta = 0$ . By

lacking reliable data, we have decided to set exogenously such probability letting it vary in order to test the sensitivity of the model. Therefore, if we define  $\Delta = Pr(\delta = 0)$ , equation (16) must be modified by multiplying the LHS for  $(1 - \Delta)$ . Having done this operation, equation (16) can then be used to find the appropriate parameters values of a given distribution. Furthermore, given that the mentioned distribution is nothing else than the distribution of hail damages,  $\delta$ , it is then possible to find the appropriate values for  $\mu, \sigma^2, \mu_I$  and for  $\sigma_I^2$ .

Before further discussing this step, it is necessary to describe the second modification relative to our theoretical setting, which means to relax the assumption that anti-hail nets offer full protection from hail damages. There are several reasons for which this is not very realistic. We note that anti-hail nets must be closed during the flowering period to allow for insect-driven pollination and during harvest. A hailstorm in this last phase is very likely to cause serious damages since it could easily compromise the appearance of fruits and, consequently, their market value. To reasonably quantify the damage exposure of apples covered by anti-hail nets, we use the coefficient that determines the premium to be paid by a farmer willing to insure his portion of land covered by anti-hail nets. From the HSK data, we know this being equal to 0.02<sup>5</sup>. However, we must take into account that the same deductible structure applying for standard insurance contracts is also valid for those related to plots covered by anti-hail nets. Not having enough information about insured values and indemnities received for this specific typology of insurance contract, it is impossible to estimate reliably the distribution function of the residual damage. Although potentially harmful, we need therefore to make some strong and simplifying assumptions. Let us start by considering some simple equalities defining the risk of damage:

$$\begin{aligned} TR &= RR + IR; \\ IR &= PP - OM; \\ TR &= RR + PP - OM; \end{aligned}$$

where  $TR$  is the total risk ( $\mu$  in our model),  $RR$  is the residual risk ( $\mu_I$ ) or the portion of risk not covered by the insurance due to the deductible and  $IR$  is the covered risk, equal therefore to the expected indemnity ( $E[I]$ ). In a competitive market, this last element is equal to the paid premium ( $PP$ ) minus the amount required by insurance companies to cover their operating costs. From the HSK data we can retrieve this last element<sup>6</sup>, i.e.  $OM = 0.1538$ , a rough 15% of mark-up, where  $OM$  stays for operating margin. Therefore, for orchards covered by anti-hail nets, we have  $E[I_N] = 0.02(1 - 0.1538) = IR_N$ . However, we are interested in retrieving the value of  $TR_N$ , or else, the value

<sup>5</sup>This implies that a farmer willing to insure one hectare of apples orchard covered by anti-hail nets will have to pay a premium equal to  $0.02 \times P\mu_o$  where  $\mu_o$  is the expected output computed as the trimmed mean of the last 5 years yields whereas  $P$  is the price as determined by central authorities, as stated in the Ministry Decree 28405\17.

<sup>6</sup>This value relates to contracts not specific for plots covered by anti-hail nets. We are therefore assuming a constant mark-up.

of the expected total risk ( $\mu_N$ ) since we assume that plots covered by anti-hail nets are not insured.<sup>7</sup> Since  $IR = TR - RR$ , if we hypothesise a constant ratio of  $\frac{IR}{RR}$  between plots covered and not covered by anti-hail nets, we then have  $\frac{IR_N}{RR_N} = \frac{\mu - \mu_I}{\mu_I} \Rightarrow RR_N = \frac{\mu_I}{\mu - \mu_I} IR_N \Rightarrow TR_N = IR_N(1 + \frac{\mu_I}{\mu - \mu_I}) = \mu_N$ .

By introducing a residual expected damage in presence of anti-hail nets, equation (11) must be restated:

$$E[U(W_N)] = P\mu_o(1 - \mu_N) - \mathbf{w}^T \mathbf{x} - \frac{C_N}{\alpha} - \lambda P^2(\sigma_o^2 \sigma_N^2 + \sigma_N^2 \mu_N^2 + \sigma_o^2 \mu_N^2). \quad (10B)$$

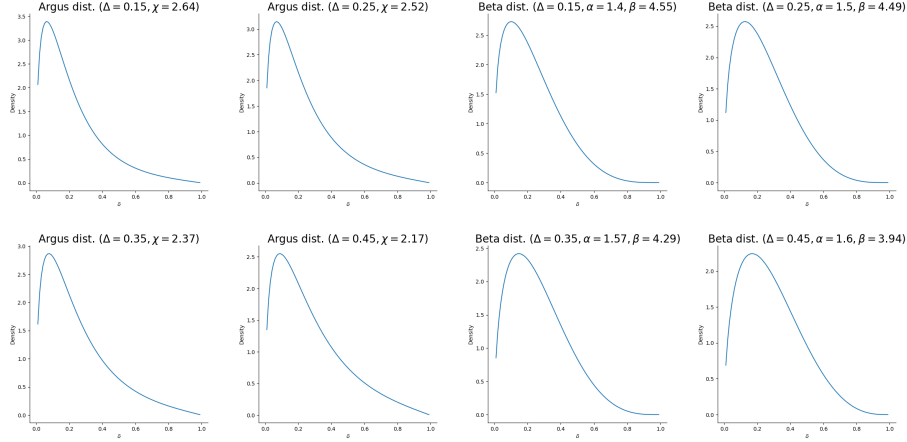
This looks similar to equations (3) and (5). Having introduced the mean residual damage, also its variance,  $\sigma_N^2$ , must enter into the equation. This poses the problem of its definition. Not having any reliable information about the distribution of the residual damage with anti-hail nets, we need to apply a very strong simplifying assumption. In particular, we assume a constant index of dispersion between the distribution of  $\delta$  and the one of the residual damage with anti-hail net, such that  $\sigma_N^2 = \frac{\sigma^2}{\mu} \mu_N$ . The last modification to equation (11) has been to introduce the labour cost required to open and close the net. Since this must be sustained annually, it can be simply added to  $EAC$ . These costs have been estimated at 600€ per hectare (i.e. 30 hours of work per season times 20€ per hour [Whitaker et al., 1999]).

Once exhausted the problem of appropriately reformulating equation (11), let us go back to the task of identifying a reliable distribution for  $\delta$ . The Beta distribution, given its flexibility, is a good candidate and, in fact, it has been already used for similar purposes: e.g. Babcock [2015]. Besides it, however, we found that the Argus distribution can also solve equation (16) satisfactorily and, since it has a single parameter, it is easier to handle. Regarding the values of  $\Delta$ , we have chosen to test four possibilities:  $\Delta \in [0.15, 0.25, 0.35, 0.45]$ , implying a respective 15%, 25%, 35% and 45% of probability of not having any damage in a cropping season. Figure 1 shows the probability density function of  $\delta$  for both distributions and for the different values of  $\Delta$ , once having found the appropriate values of their shape parameters,  $\chi$  for the Argus and  $\alpha$  and  $\beta$  for the Beta, by solving equation (16).

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<sup>7</sup>The reason to leave out from our analysis the possibility to combine anti-hail nets with insurance is mainly due to its extremely scarce diffusion among South Tyrolean farmers (Private communication with insurers).

Figure 1: Distributions of  $\delta$



Given these distributions, the damage related parameters in case a farmer does not adopt any protective measure are easily derived by computing their first two central moments. After that, computing the variance of the residual damage with anti-hail nets is straightforward. The function determining the proportional damage when insurance is purchased is simply found as the difference between  $\delta$  and the indemnity received from insurance:

$$\delta_I = \begin{cases} \delta, & \text{for } \delta \leq 0.31; \\ 0.9 - 2\delta, & \text{for } 0.31 \leq \delta \leq 0.4; \\ 0.1, & \text{for } \delta \geq 0.4. \end{cases}$$

The first two central moments are easily computed by making use of the Law of Total Expectation and of the Law of Total Variance. Table 2 reports all the damage related parameters that have been computed.

Table 2: Values of damage-related parameters

Parameters	Values			
	$\Delta = 0.15$	$\Delta = 0.25$	$\Delta = 0.35$	$\Delta = 0.45$
	<b>Argus Distribution</b>			
$\mu$	0.1878	0.176	0.1639	0.1513
$\sigma^2$	0.0339	0.0367	0.0393	0.0417
$\mu_I$	0.1143	0.1025	0.0903	0.0776
$\sigma_I^2$	0.0072	0.0077	0.008	0.0079
$\mu_N$	0.0433	0.0405	0.0377	0.0347
$\sigma_N^2$	0.0078	0.0084	0.009	0.0096
	<b>Beta distribution</b>			
$\mu$	0.2	0.1878	0.174	0.1587
$\sigma^2$	0.0291	0.0319	0.0349	0.0379
$\mu_I$	0.1229	0.1113	0.0985	0.0848
$\sigma_I^2$	0.0057	0.0068	0.0076	0.0079
$\mu_N$	0.0439	0.0415	0.039	0.0363
$\sigma_N^2$	0.0064	0.0071	0.0078	0.0087

Finally, we need to specify the values of all the remaining elements in equations (3), (5) and (10B). Table 3 reports them together with their source of information.

Table 3: Model's parameters values other than damage related

Parameters	Value	Source
$P$	43.98 €/100 Kg	FADN-Rica dataset (period 2008-2015), in constant 2015 euros
$\mu_o$	553.12 100 Kg/ha	FADN-Rica dataset (period 2008-2015)
$\sigma_o^2$	169.339 100 Kg/ha	FADN-Rica dataset (period 2008-2015)
$\mathbf{w}^T \mathbf{x}$	2757.28 €/ha	FADN-Rica dataset (period 2008-2015), in constant 2015 euros
$\gamma$	0.0314	Hagelschutzkonsortium data (period 1975 - 2013)
$\Gamma$	763.84 €/ha	Computed as $\gamma P \mu_o$
$C_N$	25000 €/ha	Hagelschutzkonsortium, (private communication)
$T$	20 years	[Whitaker et al., 1999]
$r$	0.03254	Investing.com: Italy's 20 years bond yield for the period 2013-2018
$EAC$	2320.10 €/ha	Computed as $C_N \times \left( r \left( 1 - \frac{1}{(1+r)^T} \right) \right)$ plus 600€ of labour costs

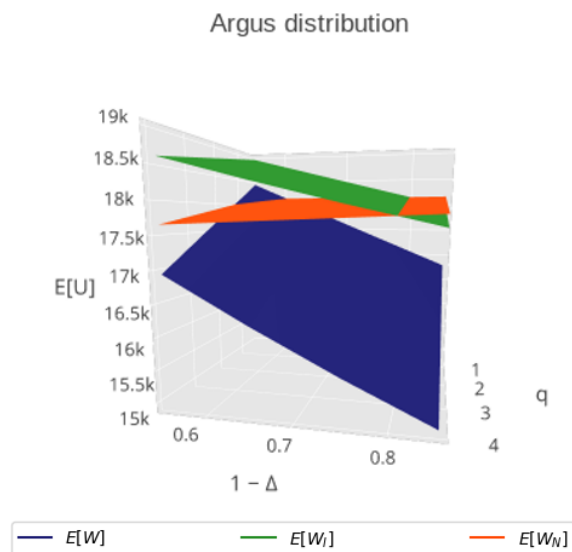
Note that  $\gamma$  is the coefficient determining the premium paid by the farmer as a proportion of the insured value. This parameter only considers the proportion effectively paid by the farmer, excluding therefore the EU and the State contribution. The only missing value is  $\lambda$ , equal to one half the Arrow-Pratt measure of absolute risk aversion. Instead of providing a single value, we will let it vary inside a given range in order to see if significant changes are observed. Given the relation between the relative and the absolute risk aversion coefficient and given that Anderson and Dillon [1992] set a reasonable interval to be  $[0.4, 4]$  for the former, we have:

$$\lambda = \frac{1}{2} \frac{q}{P \mu_o (1 - \mu_x)}, \quad \text{for } q \in [0.4, 4], x \in \{\emptyset, I, N\}.$$

## 4.2 Model's results at provincial level

First, we compute the certainty equivalent expected utility for the three different hedging strategies varying the values of parameter  $q$  (determining the degree of absolute risk aversion) and  $\Delta$  (giving the probability of no damage). Figure 2A shows the results for the Argus distribution.

Figure 2A: CE Expected utilities for different values of  $q$  and  $\Delta$

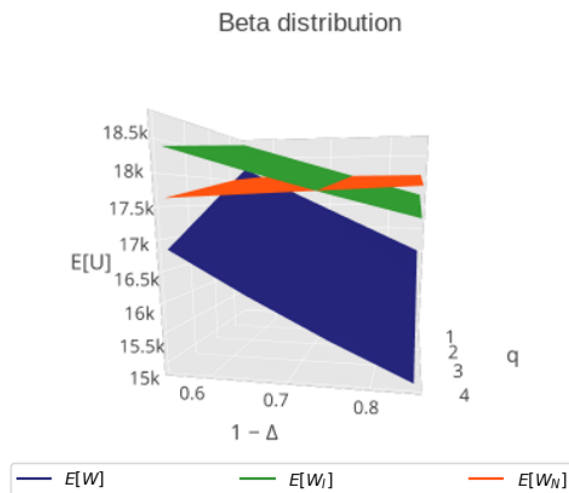


From Figure 2A, it is possible to observe that CE expected utility is increasing in  $\Delta$  (and thus decreasing in  $1 - \Delta$ ) for all the hedging strategies but anti-hail nets. From Table 2 we see that the expected damage decreases for larger values of  $\Delta$  and this explains the higher utility under insurance and no hedging. The variation in the expected damage in case of anti-hail nets is minimal and such positive effect is counterbalanced by the negative one due to the increase in the variance of damages. Regarding this last point, it must be noted that the CE expected utility is decreasing in  $q$  for all the hedging strategies. However, the effect of  $q$  is far more mild in magnitude compared to the one of  $\Delta$ , except for the no-hedging strategy. The reason for this behaviour becomes clear from Table 2, where we notice a very low variance of hail damage with insurance and with anti-hail nets, while it is more than tenfold without hedging.

It is important to notice that the no-hedging strategy is always dominated by at least one of the two hedging strategies and almost always by both. Whereas anti-hail nets guarantee a stable CE expected utility for varying levels of  $q$  and  $\Delta$ , insurance is sensitive to  $\Delta$ . Given the inverse correlation between  $\Delta$  and expected damage, it is possible to affirm that anti-hail nets are better than insurance in terms of CE expected utility where the risk of damage is larger, with the switching point occurring at a value of  $\Delta$  close to 0.2.

Table 2B shows the same graph but for the Beta distribution.

Figure 2B: CE Expected utilities for different values of  $q$  and  $\Delta$

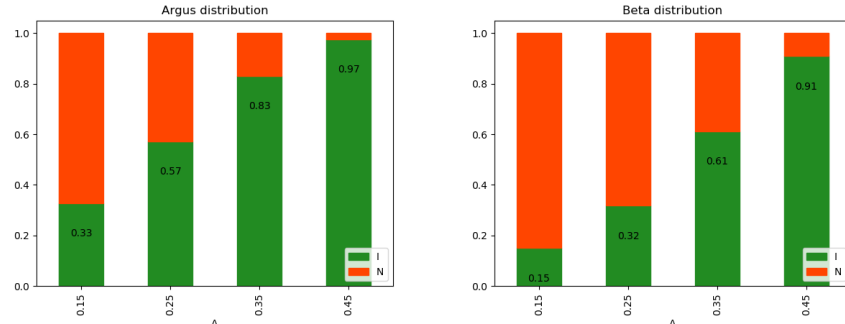


The qualitative result is not affected by the underlying distribution (Argus vs. Beta). The main differences are the lower levels of CE expected utility for insurance and no hedging due to higher values of expected damage. This causes the intersection between the insurance and the anti-hail nets planes to occur at a higher value of  $1 - \Delta$ , in this case close to 0.73. Again, the higher yearly cost of anti-hail nets compared to the subsidized insurance premium requires a higher risk for this strategy to be optimal, but under the Beta distribution it is more likely for this to happen.

It is interesting to further analyse the behaviour of the CE expected utility functions for varying levels of  $P$  and  $\mu_o$ . Clearly, there is a variance in the mean output per hectare different farmers are able to obtain and in the price they manage to sell their product which is strongly affected by the quality (grade). From the HSK data, it can be retrieved a reasonable range for  $P$  of  $\pm 15\text{€}$  from its mean value. For the yield per hectare we opted for a  $\pm 150\text{Kg}$  from its mean value. Although the values of  $P$  and  $\mu_o$  are reasonably interdependent, we are presently assuming their independence for mere convenience. For this analysis, the value of the risk aversion parameter will be kept constant and equal to one, as originally estimated by Arrow [1965]. For varying levels of  $\mu_o$ , the variance of the yield will be changed too in order to keep constant the index of dispersion as for our average data. The first step is to understand, for varying levels of  $\Delta$ , the proportion of farmers that would chose each of the hedging strategies. For doing this, we drew 100,000 tuples of  $P$  and  $\mu_o$  from truncated normal distributions in the mentioned ranges. This simulates an hypothetical population of farmers. At this point, we computed the CE expected utility for each hedging strategy. The strategy guaranteeing the higher utility received a score of one, the others

zero. Finally, we simply computed the proportion of received scores. Figure 3 shows the results for either the Argus and the Beta distributions.

Figure 3: Proportion of land hedged through different strategies

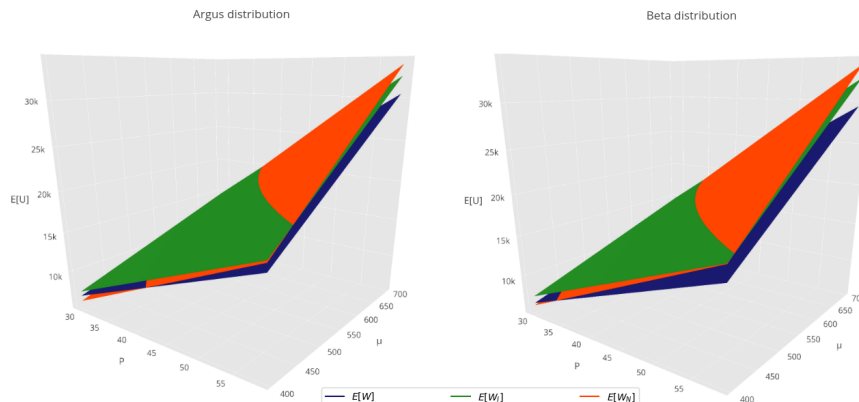


From Figure 3 we have a confirmation of what observed before. For higher values of  $\Delta$ , insurance is preferred to anti-hail nets, whereas no hedging is never dominant. This exercise serves two purposes. The first is to show how sensitive is the model to variations in the distribution of damage. The second is to benchmark the model with actual data. From the HSK data, we know that roughly 18.000 hectares are dedicated to apple trees in South Tyrol. Among them, in 2018, 7.000 were covered by anti-hail nets, 9900 were insured and the remaining 1100 hectares were left unhedged. In percentage terms we have therefore a rough 39% of acreage under nets, 55% insured and 6% unhedged. The model is unable to capture the proportion of unhedged acreage, but the persistence of un-hedging even with highly subsidized insurance contracts is a well establish puzzling fact [Babcock, 2015]. Putting it aside, we can observe that a value of  $\Delta$  equal to 0.25 for the Argus distribution, or  $\Delta$  equal to 0.35 for the Beta, offers a rather good match with actual farmers' behaviour.

We close this section by looking directly at the role of  $P$  and  $\mu_o$ . By letting them vary inside the previously mentioned ranges, we want to see their effect on CE expected utility for the three hedging strategies. The value of the risk parameter is fixed at one, whereas  $\Delta$  is set equal to 0.25 for the Argus distribution and to 0.35 for the Beta.



Figure 4: CE expected utility for varying levels of  $P$  and  $\mu_o$



From Figure 4, we can observe that the profitability of hedging strategies compared to no hedging is a growing function of both  $P$  and  $\mu_o$ . Furthermore, the same relation holds for the comparison between anti-hail nets and insurance. Since the per hectare cost of nets is fixed and independent from output value, the profitability of nets is increasing in  $P \times \mu_o$ .

### 4.3 Model's results at the municipality level

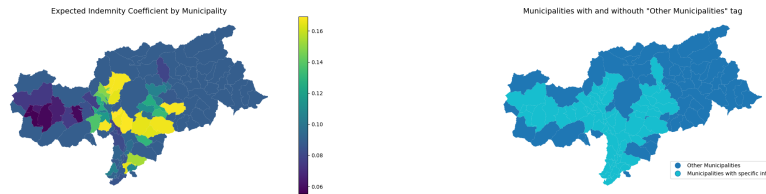
In the previous section, we basically assumed a uniform risk of damage from hailstorms for the whole South Tyrol area. The aim of this section, instead, is to use the information available at the municipality level to relax this assumption and to perform the previous analysis on a finer scale. Note, however, that the information about production costs, average yield and price will be kept equal for each municipality since no data is available at this level. What changes, instead, is the risk distribution. The risk aversion parameter will be kept constant at one, but we now drop the use of the Beta distribution due to the greater simplicity of the Argus distribution. Finally, although different hail risks at municipal level most likely imply a specific value of  $\Delta$  for each municipality, this will be kept constant and equal to 0.25 as we have no reliable data to estimate it. The choice of this value is due to its ability to represent the actual distribution of hedging strategies at provincial level as previously discussed.

With the HSK data, it is possible to retrieve the coefficient determining the premium paid by farmers given their insured value,  $\gamma$  in Table 3, for each municipality and the years 2015-2018. Among the different contract types, we will consider the Pluri 80, offering a minimal coverage for weather shocks other than hail. The only other sources of damages allowing for an indemnity are: strong wind, excess of rain and excess of snow. Since there is no possibility to determine the proportion of risk imputable to such other shocks, we simply assume they

only contribute a negligible amount. To minimize bias due to exceptional years, we will average data for the four years at disposal. More specifically, we have data regarding the premium coefficient required by the insurance companies and the one effectively asked to farmers, net of the EU and State contribution. This last corresponds to  $\gamma$  in Table 3, whereas the first basically represents the expected indemnity plus the insurers' operating costs. We will deflate such values by 15%, the assumed mark-up of insurers to find the appropriate value for the RHS of equation (16) for each municipality. Note that the deductible structure of the Pluri 80 contract relates to the structure presented in section 4.2. Therefore, the same method for estimating the distribution of damage can be applied.

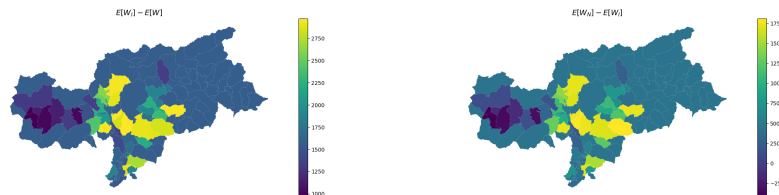
The left side of 5 represents all the 116 municipalities in the South Tyrol area with the associated 4 years average premium coefficients deflated by the operating costs. Obviously, higher coefficients imply higher risk of hail damages. Roughly half of the municipalities are not specifically mentioned in the HSK table and they are grouped under the "Other municipalities" tag and the right side of Figure 5 shows them. All these municipalities will obviously have the same values either for the premium coefficients and for the subsequent results of our analysis.

Figure 5: South Tyrol municipalities with coefficients of expected indemnities



It is instructive to examine the difference in CE expected utility between the three strategies for each municipality. This is reported in Figure 6 where, on the left side, it is possible to observe the difference between insurance and the no-hedging strategy, whereas, on the right side, the difference between anti-hail nets and insurance.

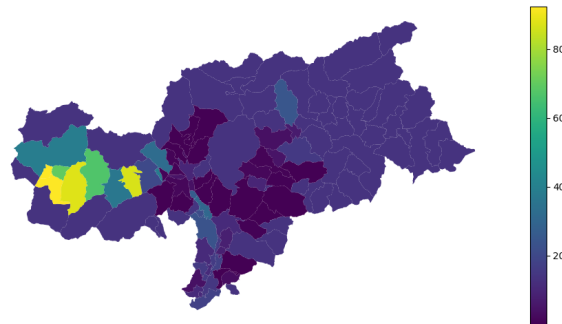
Figure 6: Difference in CE expected utilities among the possible strategies



The correlation between risk (Figure 5 - left side) and the differential between insurance and no hedging (Figure 6 - left side) and between anti-hail nets and insurance (Figure 6 - right side) is immediately visible, with the colours being almost identical. Differently from the analysis at provincial level, even for  $\Delta = 0.25$ , for the most of municipalities anti-hail nets provide a higher CE expected utility than insurance. Only for the municipalities with a very low level of risk, located towards the west of South Tyrol, this does not hold. Also at municipality level, no-hedging never prevails, in terms of expected utility, over the other strategies.

Finally, we repeat the same exercise done at the end of the previous section by assuming that both the quantity and the obtainable price are variables distributed according to a truncated normal distribution among our reference population of apples growers. The mean and standard deviation remain as assumed in the previous section. Our focus is to individuate the percentage of acreage that would be more convenient to protect through insurance rather than through anti-hail nets for each municipality. This is shown in Figure 7.

Figure 7: Percentage of land hedged through insurance rather than through anti-hail nets



Again, it is possible to observe a clear negative correlation between the percentage of acreage virtually hedged through insurance and the risk of hail damages (note the inverted colouring of this map compared to the previous ones). Furthermore, it is interesting to note the wide range of values going from zero to almost 100%. In most municipalities, however, insurance would be adopted to cover less than half of the land dedicated to apple trees. No hedging, instead, would be absent since, even for minimal values of either output and price in the hypothesized intervals and for municipalities with a very low level of hail risk, insurance would remain more profitable.

## 5 Conclusions

The present paper has presented a simple model rooted into standard expected utility theory with the aim to evaluate different hedging strategies against the risk of hail damages in agriculture. Although the model covers a very narrow topic, the proposed framework could be easily extended to encompass other risk shocks. Whenever a shock could be hedged through an insurance contract or through some other technical device, the present model might be useful to understand the conditions favouring one instrument rather than the other. The paper has been divided into three main parts with the first presenting the model, the second performing a comparative static analysis to understand the specific role of each element in the model and the third presenting a simulation using data of apples growers in the Italian area of South Tyrol.

Regarding the results, the comparative statics exercise suggests that the value of hedging strategies compared to no hedging is an increasing function of the overall damage risk, of risk aversion and of the output quantity and price, that, together, could be defined as production worth. All these findings are perfectly in line with previous models: e.g. Coble et al. [1996] and Sherrick et al. [2004]. Although less clearly, the comparative statics exercise has indicated that the difference between the value of anti-hail nets and insurance is also an increasing function of the analysed factors. This offers a potentially interesting ground for an empirical test through econometric estimation. In the present paper we have not followed this route, but we have performed a simulation that has basically confirmed such findings. An exception is represented by risk aversion, since our theoretical model was predicting that the profitability of nets compared to insurance was increasing in such value, whereas the simulation results were the opposite. However, this is due to the simplifying assumption of the theoretical model which excludes any hail damage in presence of anti-hail nets.

With regard to the simulation, it must be stressed that the data used to calibrate the damage function were very scarce and this fact rise some concerns on its validity. Nonetheless, for some chosen values of  $\Delta$ , the probability of no damages to take place, the simulation captures rather well the actual adoption of insurance and anti-hail nets. If we consider the variation of  $\Delta$  and the use of two different distribution functions as a sensitivity exercise, it must be stressed how sensitive predictions are to the shape of the damage distribution. This implies that any economic estimation with a similar objective would clearly benefit from a better cooperation between economists, agronomists and meteorologists to improve the estimation of the damage function.

As a last remark it worth to discuss the role that the potential diffusion of anti-hail nets could play on the actuarial soundness of hail insurance markets. As seen, the profitability of nets is an increasing function of the risk to which a plot is subject to. This implies that the competition between these two sources of hedging does not seem to pose any problem to actuarial soundness.

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