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Adaptation to Climate Change:

Farmers' Risk Preferences and the Role of Irrigation

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Abstract: We adopt a *moment based approach* to investigate how individual producers' optimize input usage, in particular irrigation water, taking into account their risk preferences. We rely on a panel data of 122,800 Italian farms, spread over 1981 to 2003. We capture both variation over farms and over time. We show that risk aversion has increased over time, while down-side risk aversion has been more stable and that farmers specializing in different crops exhibit different risk aversion and use irrigation water with diverse efficiency. Higher downside risk aversion is a key determinant in the decision to adopt irrigation technology.

Keywords: risk attitude, method of moments, irrigation, production uncertainty.

1. Introduction

With regard to water resources, climate change is expected to result in increased variability, enhanced uncertainty, and generally increased scarcity (Strzepek et al., 2011). Our fundamental enquiry concerns the role of farmers' risk preferences in determining how water management might facilitate adaptation to climate change in agriculture. We focus on irrigation technology adopted as risk management strategies. We pay particular attention in the analysis of farmers' preferences for risk, as they are a key determinant of their investment decision and response to water management policies such as water conservation ones. We discuss these issues in the context of the Italian peninsula, a very heterogeneous territory in term of topographic features and availability of water resources. Climate-related risks expose the agricultural sector to significant uncertainties. However, this is a dimension frequently overlooked in the literature. This omission may seriously limit our understanding of farmers reaction to and thus the impacts of different policy intervention.[1] Risk considerations are necessary in the analysis of the agricultural sector as there exist a number of possible cases where intelligent policy formulation should consider not only the marginal contribution of input use to the mean of output, but also the marginal reduction in the variance of output (Groom et al., 2008). However, variance does not distinguish between unexpected bad events and unexpected good ones. On this basis, it seems important to consider also skewness in risk analysis (Di Falco and Chavas, 2009). Koundouri et al., 2006 argue that the issue of risk has rarely been addressed adequately in the literature concerning farmers' decision.

This paper contributes to the literature by adopting a unique panel dataset to address the following questions. First, we argue that farmers have different individual risk preferences, and they will choose which crop to produce and the inputs' combination for the related production function in a coherent way with respect to their own risk preferences. Secondly, we investigate how farmers' investment decision are influenced by their risk preferences, in particular we want to assess what is the role of irrigation in adapting to climate change.

One of the limits of the previous literature is that it mostly relies on cross-section of farmers. This hinders the comprehension of factors such as learning by doing, information gathering and accumulation of resources that may affect farmers' decision (Sunding and Zilberman, 2001; Koundouri et al. 2006).[2] Our dataset comprises farm level data for more than 122,800 Italian farms and refer to the period 1981 to 2003.

Recent literature shows the importance to consider higher moments, in particular skewness, in the analysis of climate related risk in agricultural production. This literature builds on the *moment based approach* first developed by Antle (1983, 1987), Antle and

[1] Groom et al. (2008) argue this point referring specifically to water conservation policies.
[2] Besley and Case (1993) and Koundouri et al., (2006) discuss limits and opportunities in using simple cross section data.

[2] Besley and Case (1993) and Koundouri et al., (2006) discuss limits and opportunities in using simple cross section data. Hynes and Garvey highlight the advantages of panel data techniques over static frameworks in analyzing the determinants of Irish famers' participation to an agri-environment program (REPS).

Goodger's (1984) and Chavas (2004). Our analysis relies on this method. This approach uses a moment-based specification of the stochastic production function and allows capturing the effect of production decisions on the mean, the variance, the skewness and possibly higher moments of production and welfare. This allows investigating environmental risk exposure in terms of crop yields' failure, and more specifically farmer's risk attitude and exposure to downside risk (captured by skewness). Through this method we capture farmers' preference for risk. These are estimated as part of a structural econometric model in which neither the impact of inputs on risk nor the form of the utility function is restricted (Groom et al., 2008). This method is based on populations' characteristics and for this reason overcomes the problem of aggregation from the individual to the population. The estimated results have thus more relevance for policy analysis (Antle, 1983 and 1987; Koundouri et al., 2006; Groom et al., 2008; Foudi and Erldlenbruch, 2011).

The paper proceeds as follows: Section 2 presents the theoretical framework, which follows Koundouri et al. (2006) to analyze the representative agent production model under risk. In Section 3 we describe the estimation approach. Data are described in Section 4. We discuss our results in Section 5. Section 6 concludes and mentions the extensions to this work.

2. Theoretical Model of Producer Behavior under Climate Variability in Agriculture

We develop the representative agent production model under risk. We look at the optimization problem of the farmer, who takes decisions on whether to adopt more efficient irrigation technology.[3] The theoretical framework follows Koundouri et al. (2006). We extend their original framework by modeling explicitly the fact that different farmers' group may have different risk aversion, which has direct implications on the utility functions associated to each group.

We assume that climate is the primary source of production risk. In the short run, farmers choose and combine variable inputs in agricultural production, such as water, to hedge against production risk. Land is assumed to be a fixed factor. We believe that the land allocation decisions among different crops depend on some individual characteristics of the farmers, who select their crop also depending on their risk eversion. In the empirical section we investigate if the risk attitude of a farmers' group can be inferred by looking at the main crop it cultivates. We assume that farmers are price-takers and their production decisions and input allocation decision will affect neither output nor input prices.

Let U(·) be the von Neumann-Morgenstern utility function representing farmers preferences under climatic risk. Farmers may have different risk preferences, which impacts the concavity of the utility function. We assume that we have two main groups of farmers characterized by different curvatures of the utility function. The more concave the utility function, the more risk averse the farmers will be. Depending on their individual risk preference farmers will be represented by one or another utility function, with different degrees of deviations from the risk-neutrality case. The risk averse agent's problem is to maximize the expected utility of profit.

$$\max_{\boldsymbol{x},x_w} E[U^g(\pi^g)] = \max_{\boldsymbol{x},x_w} \int [\, U^g(p^g f(\varepsilon, h(\alpha)x_w, \boldsymbol{x}) - r_w x_w - r'_{k-1}\boldsymbol{x}\,]\; dG(\varepsilon) \tag{1}$$

Production risk, captured by the error term ε, is the only source of risk, as input and output prices (r and p respectively) are considered non-random by the farmer (Koundouri et al., 2006; Groom et al., 2008 and Di Falco et al., 2014). Therefore, climatic risk affects crop yield through the variable ε whose distribution G(.) is not affected by farmer actions. We assume that the production function f(.) is continuous and twice differentiable. **x** is the K

[3] Farmers may also be subject to a constraint set by the authority, such as a temporary restriction upon water use (water quota). Groom et al. (2008) assume that regulation for risk takes the form of temporary water quota imposed by the regulator.

vector of inputs. Irrigation water (x_w), is an essential input in the production process of both farmers' groups. This input has an associated unit price r_w. Farmers are heterogeneous with respect to the irrigation water input not only because they use different irrigation technologies but also because they manage these technologies with different levels of efficiency. These depend on farmer management skills and other farmer characteristics incorporated in the vector α.[4] The production function is thus written as: $q=f[(h(\alpha)x_{w,}\mathbf{x}]$ We then have $\mathbf{x'} = (x_1,.., x_{K-1}, x_w)$ and $r' = (r_1,.., r_{K-1}, r_w)$. We denote r'_{k-1} the vector of input prices excluding the price of irrigation water. g identifies the utility function whose concavity is associate to one of the two type of farmers' group. We assume there are two groups of farmers (g=A, B). We argue that each farmer reveals his risk preference type by growing a given crop (e.g. vegetable) rather than another (e.g. cereals). Each group is represented by a utility function with a different curvature. As both producers groups are assumed risk averse, this means that the utility function of producers in group A is a concave transformation of the utility function of farmers in group B. That is, it exists some increasing, strictly concave function G(·) such that:

$$U^A(\pi) = G(U^B((\pi)) \tag{2}$$

Another way to formalize the notion that agent A with utility function $U^A(\pi)$ is more risk averse than an agent with utility function $U^B(\pi)$ is to require that:

$$-\frac{U^{A''}(\pi)}{U^{A'}(\pi)} > -\frac{U^{B''}(\pi)}{U^{B'}(\pi)} \qquad \text{for all levels of net revenue } \pi. \tag{3}$$

To be noted that these expressions are the Arrow-Pratt measures of absolute risk aversion for the agents in group A and group B respectively. In the empirical part of the paper we will test the hypothesis whether farmers growing different crops consistently display different risk preferences. The production function $f(\cdot)$ is assumed to be the same across group types, for this reason it does not present the index *g*.

The optimal quantity of irrigation water for a profit-maximizing farmer is derived by solving the agent's problem through the following first order condition:

$$E[r_w U'^g] = E\left\{p^g \frac{\partial f(\varepsilon, h(\alpha)x_w, \boldsymbol{x})}{\partial x_w}\right\} U'^g) \Leftrightarrow \tag{4a}$$

$$\frac{r_w}{p^g} = E\left\{\frac{\partial f(\varepsilon, h(\alpha)x_w, \boldsymbol{x})}{\partial x_w}\right\} + \frac{cov[U'^g; \partial f(\varepsilon, h(\alpha)x_w, \boldsymbol{x})/\partial x_w]}{E[U'^g]} \tag{4b}$$

Where $U'^g = \partial U'^g(\pi^g)/\partial \pi^g$. The program to find the optimal quantity of input x_k depends upon input and output prices (r and p) and on the shape of functions $U(\cdot)$, $f(\cdot)$ and $G(\cdot)$. The left-hand side of Equation (4b) (r_w/p^g) is the input price to output price ratio. For a risk-neutral farmer this term equals the expected marginal product of the irrigation water input, namely the first term in the right-hand side of Equation (4b). The second-term in the right-hand side of is different from zero if the farmer is risk averse. Thus this term measures deviations from the risk-neutrality case. This term is proportional and is opposite in sign to the marginal risk premium with respect to the irrigation water input (Koundouri et al., 2006; Groom et al., 2008). Once the farmers have chosen a specific crop they will decide whether to adopt or not the (modern) irrigation technology. The decision to adopt can be modeled as a binary choice, where within each farmer group the farmer can choose to adopt (D=1) or not (D=0) an irrigation technology increasing water use efficiency (i.e. $h^1(\alpha) > h^0(\alpha)$ for $0<\alpha<1$). This step

[4] Notation follows Koundouri et al., 2006.

allows incorporating into the above general model the farmer's decision whether or not to adopt a new, more efficient irrigation technology. From now on we assume that the optimization problem is repeated for each group of farmers (A and B). For this reason we omit the superscript g. The adoption of the irrigation technology will reduce production risk during years of drought and also reduce the risk associated to the imposition of a water quota or other restrictive water management policies. The new irrigation technology is modeled such that the same level of output will require less water input. Thus farmers' expectations to incur into adverse climatic conditions and/or policies restricting the access to the water resources should be an element influencing her willingness to adopt (enhanced) irrigation technology. We assume conditions of certainty with regards to the use of the new equipment (i.e., future costs and benefits are perfectly known at the time of adoption),[5] and that adopting the new technology implies a fixed cost ($I_1 > 0$ and $I_0 = 0$). We denote x^1 and x^0 the optimal input choices for farmers adopting and non-adopting the new technology respectively. Adoption of the new technology might change the marginal cost of water input $r_w^1 \neq r_w^0$.

The farmer will adopt the new and more efficient irrigation technology if the expected utility with adoption is greater than the expected utility without adoption, i.e.,

$$E[U(\pi^1)] > E[U(\pi^0)] \tag{5}$$

The maximization problem for a farmers' adopting/non adopting the more efficient irrigation technology is:

$$\max_{\boldsymbol{x^i}, x_w^i} E\left[U(\pi^i)\right] = \max_{\boldsymbol{x^i}, x_w^i} \int \left[\, U(pf\left(\varepsilon, h^i(\alpha)x_w^i, \boldsymbol{x^i}\right) - r_w^i x_w^i - r'_{k-1}\boldsymbol{x^i} - \mathrm{I}^{\mathrm{i}} \,\right] dG(\varepsilon) \tag{6}$$

With i=1 if the farmer adopts the new irrigation technology, i=0 if the farmer is a "non adopter". From equations (6) we can derive the FOCs for the optimal irrigation water input x_w^i for the farmers adopting and non-adopting the more efficient irrigation technology:

$$\frac{r_w^i}{p} = E\left\{\frac{\partial f\left(\varepsilon, h^i(\alpha)x_w^i, \boldsymbol{x^i}\right)}{\partial x_w^i}\right\} + \frac{cov\left[U'; \partial f\left(\varepsilon, h^i(\alpha)x_w^i, \boldsymbol{x^i}\right)/\partial x_w^i\right]}{E[U']} \tag{7}$$

Equation (7) yields the optimal quantity of water irrigation input in term of input and output prices, for adopters (i=1) and non-adopters (i=0). We expect risk-averse farmers bearing profit uncertainty within each producers group to have a higher probability of adoption. The derivation of an analytical solution to (5) requires defining technology parameters, farmers' preferences, and the distribution of the error term ε. In order to avoid making a serious of assumption on these elements, we adopt the Antle's *moment based approach* that allows estimating farmers' attitude towards risk by using a flexible estimation approach.

3. Empirical Model

We use a flexible estimation approach where uncertainty is considered by using moments of the profit distribution as determinant of farmer's decision regarding the input mix. The key feature of this approach is that the producer problem can be written as a function of input levels alone (Groom et al., 2008) and the researcher can avoid making strong assumptions on technology parameters farmers' preferences and the distribution of the error term.

We maximize a function of moments of the profit distribution by estimating the distribution of the error term ε, which includes only climatic risks. Those moments have

[5] Koundouri et al., 2006 extend this model to incorporate incomplete information regarding the new irrigation technology, in a context of production uncertainty and no constraint set by the authorities on water resources use.

themselves **x** as an argument. This method has the main advantage of not requiring the specification of functional forms for profit $\pi(\cdot)$, the distribution of risk $G(\cdot)$ and $U^g(\cdot)$.

Risk-averse farmers have an incentive to reduce their risk exposure. How the adoption of irrigation technology can influence risk exposure? The effects of specific inputs on the mean and variance of output has been analyzed in previous literature. However it is of interest to go beyond mean and variance effects and capture how inputs contribute to the higher moments of the profit distribution. Adopting irrigation water may indeed affect the third central moment (skewness) of the distribution of profit. Under downside risk aversion farmers are adversely affected by down side risk (e.g. risk of crop failure). A downside averse decision maker will invest in adaptation strategies to reduce such risk (Menezes et al., 1980; Antle, 1983; Di Falco and Chavas, 2009). The farmer's program becomes:

$$\max_{X} E[U(\pi)] = F[\mu_1(X), \mu_2(X), \ldots, \mu_m(X)] \tag{8}$$

where μ_j=E(∩- μ_1)^j (j=2,...,m) is the mth moment of profit. These are obtained following the sequential procedure described in Kim and Chavas (2003).

First, we estimate the conditional expectation of profit using a quadratic functional form.

$$\pi_{it} = f(\boldsymbol{x}_{it}; \beta) + \alpha_i + \gamma_{it} \quad where \quad \alpha_i + \gamma_{it} = u_{it} \tag{9}$$

The mean effect (Equation (9)) is obtained regressing total observed profit from crops production (π_{it}) on all levels, squares and interaction of input expenditures, captured by the vector x_{it} (irrigation water, fertilizers and plant protection products).[6] α_i are random-individual specific effects and u_{it} is the idiosyncratic error term. The choice of the linear quadratic form is coherent with the literature (Kumbhakar and Tveteras, 2003; Koundouri et al., 2006; Groom et al., 2008). We estimate equation (9) through a within estimator by using the fix effect model. Standard errors are clustered at the province's administrative level.

Second, the residuals of the first estimation are used to compute conditional higher moments: the square and cube of the estimated error from the mean effect regression is used as a consistent estimate of the second and third central moment of the profit distribution (variance and skewness respectively). The two moments so obtained are regressed on the same explanatory variables included in the estimation of the mean effect:

$$\hat{u}_{it}^2 = w(\boldsymbol{x}_{it}; \delta) + \breve{u}_{it} \quad \text{and} \quad \hat{u}_{it}^3 = s(\boldsymbol{x}_{it}; \phi) + \tilde{u}_{it} \tag{10a and 10b}$$

We assume that farmers are concerned only with the first three moments of the distribution of profit.[7] We use the estimated coefficients from Equations (9), (10a) and (10b) (i.e. vectors $\widehat{\beta}$, $\widehat{\delta}$, $\widehat{\phi}$) to compute nine analytical expression for derivatives of the each moment with respect to each input. Finally, we estimate the system of Equation (11):

$$\frac{\partial \mu_1(\boldsymbol{x})}{\partial x_k} = \theta_{1k} + \theta_{2k} \frac{\partial \mu_2(\boldsymbol{x})}{\partial x_k} + \theta_{3k} \frac{\partial \mu_3(\boldsymbol{x})}{\partial x_k} + u_k \tag{11}$$

where θ_{jk} = -1/j!*$\partial F(\boldsymbol{x})/\partial \mu_j(\boldsymbol{x}) \,/\partial F(\boldsymbol{x})/\partial \mu_1(\boldsymbol{x})$; (j=1,2,3).

This system of Equations comes from the fact that the first order conditions of the farmer's program can be approximated using a Taylor expansion in matrix form: we estimate

[6] All variables are scaled by their standard deviation.

[7] Groom et al., (2008) found that estimation coefficients for the 4th moment of the distribution of profit (kurtosis) were not significant. Koundouri et al. (2006) estimate the 4th moment, but recognize that most distribution functions are well approximated by their first three moments.

for each input k its marginal contribution to the expected profit (given by $\partial\mu_1(\boldsymbol{x})/\partial\boldsymbol{x}_k$). This is written as a linear combination of the marginal contributions of input k to the variance ($\partial\mu_2(\boldsymbol{x})/\partial\boldsymbol{x}_k$) and the skewness ($\partial\mu_3(\boldsymbol{x})/\partial\boldsymbol{x}_k$) (Antle, 1983,1987; Antle and Goodger, 1984, Groom et al., 2008; Koundouri et al., 2006).

The most important feature of this model is that the parameters θ_{2k} and θ_{3k} are directly interpretable as the Arrow-Pratt (AP) and down-side (DS) risk aversion coefficients, respectively (Groom at al., 2008). Notably, the AP coefficient is approximated by:

$$AP = -\frac{E(\partial^2 U/\partial\pi^2)}{E(\partial U/\partial\pi)} \cong -\frac{\partial F(\boldsymbol{x})/\partial\mu_2(\boldsymbol{x})}{\partial F(\boldsymbol{x})/\partial\mu_1(\boldsymbol{x})} = \boldsymbol{2\theta_2} \tag{12}$$

while the DS risk coefficient is approximated by:

$$DS = -\frac{E(\partial^3 U/\partial\pi^3)}{E(\partial U/\partial\pi)} \cong -\frac{\partial F(\boldsymbol{x})/\partial\mu_3(\boldsymbol{x})}{\partial F(\boldsymbol{x})/\partial\mu_1(\boldsymbol{x})} = \boldsymbol{-6\theta_3} \tag{13}$$

The population average AP and DS risk aversion measures (calculated as indicated in Equations (12) and (13)) have been obtained estimating System (11) through a 3SLS model.[8] We used as exogenous instruments the maximum and minimum average temperature and the cumulated precipitation during the growing season (1st of March to 31st of September). These exogenous variables are appropriate instruments as they are assumed to be exogenous to risk attitude, but correlated with irrigation, plant protection and fertilizers choices. Through the 3SLS procedure we exploit inter-equations correlation of errors, as we believe that errors across the three equations of the system are correlated. Notably, the three input analyzed (fertilizers plant protection and water) are used jointly and their use is determined for a given location by the farmer. The risk parameters are constrained such that $\hat{\theta}_{2k} = \hat{\theta}_2$ *and* $\hat{\theta}_{3k} = \hat{\theta}_3$. Contrary to Antle (1987) and Koundouri et al., (2006) we associate neither the AP and DS coefficients nor the risk premium to specific inputs (i.e. the index k is dropped in Equations (12), (13) and (14). We embrace the view of Groom et al., (2008): although each input can affect the moments of profit in different ways, the AP and DS coefficients are related to the preferences over the moment of profit. For this reason the preferences over moments of profit should remain the same across inputs (Groom et al., 2008). We thus restrict the parameters as follows: $\theta_{jk} = \theta_j$, hence $AP_k = AP$, $DS_k = DS$ and $RP_k = RP$.

A positive and significant AP coefficient indicates that the decision maker is risk averse: the agent has incentive to reduce its risk exposure. Any increase in the variance of profit would in fact increase private cost of risk bearing. A positive and significant DS coefficient indicates that the decision maker is averse to risk distribution towards low outcomes (e.g. crops' failure), holding both the mean and the variance constant (Menezes et al., 1980; Antle, 1983; Di Falco and Chavas, 2009). This implies that an agent with a positive and significant DS coefficient try to implement management strategies that affect positively the skewness of the distribution of profits (e.g., reducing the probability of crop failure). These considerations are related to our understanding of farmer's behavior in a risky environment. Risk averse farmers would be more willing to adopt strategies to reduce the variance of profit and/or exposure to downside risk. The AP and DS coefficients can be used to compute the risk premium (RP), which helps us evaluating the cost of overall risk bearing capturing both the variance and the skewness on the cost of risk. Under risk aversion the risk premium depends on all relevant moments of the profit distribution (Di Falco and Chavas, 2009). Assuming that

[8] For a robustness check, results were also obtained using a seemingly unrelated regression model (SUR). Results were consistent.

the farmers are concerned only by the first three moments of the distribution of profit we can write the RP as follows:

$$RP = \mu_2 \frac{AP}{2} - \mu_3 \frac{DS}{6} \quad (14)$$

μ_2 and μ_3 are respectively the second- and third- order moments of the distribution of profit. The RP can be further used to proxy risk attitudes. It can then be used to explain the determinant of irrigation as a function of risk attitude, and other farm characteristics.

We incorporate the estimated risk parameters into a discrete model of technology adoption, along with climate variables and farmer's characteristics. We implement a population-averaged probit regression.[9] The estimation results are provided in Table (5). We incorporate the estimated risk parameters, as well as long term climate realizations and other control variables, in a discrete choice model, in order to analyze how production risk and farmer's risk attitude affect the decision to adopt irrigation technology. The literature shows that risk preferences affect the probability of adoption of irrigation technologies and provide evidence that farmers invest in new technologies as a means to hedge against input related production risk (Koundouri et al., 2006).

4. Data

We compile a rich dataset comprising farm level data from the Italian Farm Accountancy Data Network (RICA). Farm data include more than 122,800 farms and refer to the period 1981 to 2003. Data are unbalanced with farms included into the dataset for a maximum of 22 consecutive years.[10] The Farm Accountancy Data Network (FADN), carried out by INEA since 1965, is the only EU statistical survey that aim to collect information appropriate for the study of agricultural income production mechanisms, and, more generally, to the study of the economic aspects of farms (Cardillo et al., 2012). RICA is a source of microeconomic data to feed in the Farm Accountancy Data Network (FADN) of the European Union. Data reliability is high due to some specific features of the RICA survey: in Italy there is a legal obligation for private subjects to answer to statistical surveys. RICA's on-field data collecting is carried out by specialized operators, often belonging to farmers' associations. Table (1) presents summary statistics for key variables included in the empirical analysis.

Variables	Mean	Std. Dev.	Min	Max
Farm id	55,398	36,485	1	122,801
Year	1992	6.4	1981	2003
Economic Dimension Index	4.4	1.2	0	7
Altitude (masl)	281.6	286.6	0	2,000
Land Quality Index	2.0	0.3	1	3
Nb of crops reported	4.7	2.2	1	31
Surface allocated (ha)	20.7	43.2	0	4,396
Surface irrigated (ha)	5.7	20.1	0	3,494
IRRIG (dummy)	0.55	0.50	0	1
gross value of production	83,723	205,215	0	24,800,000
net profit / loss	45,861	125,357	-68,453,40	19,687,250
irrigation expenditure	326	1,909	0	147,847
fertilizers expenditure	2,879	5,916	0	598,940

[9] We avoid potential efficiency loss, which could be an issue in performing a pooled model, by taking into account the dependence over time. The population average model has different conditional mean than that for random effects model, unless the random effects are multiplicative or additive (Cameron Trivedi, 2010).

[10] Nine farms, all in the Tuscany region, are observed over a 22 years period.

plant protection expenditure	1,995	7,736	0	1,609,241
Min Temperature (°C) growing season	12.4	2.3	1.4	19.4
Max Temperature (°C) growing season	22.4	2.2	9.6	28.3
Rainfall (mm) (mm/growing season)	61.2	31.4	0.11	363.1
Min Temperature (°C) GS climatologies	12.4	2.0	5.8	16.6
Max Temperature (°C) GS climatologies	22.4	1.8	15.8	25.5
Rainfall (mm) (mm/GS) GS climatologies	60.6	25.0	21.8	177.9

Monetary values are expressed in euro (EUR). We consider the period 1st of March - 31st September as the "growing season". The term "GS climatologies" indicates the 30-year averages (climatologies) of the associated climate variable in each Italian municipality.

Table 1: Descriptive statistics

We integrated the farm level dataset with climatic variables: monthly average, maximum and minimum temperatures and cumulated precipitation, averaged at municipality administrative level from numerous meteorological stations located across the Italian territory. Meteorological time series are collected and elaborated by the Italian Environmental Agency. We associated the climate data to each farm, accordingly to the municipality it belongs to.[11]

5. Results

The first aim of our estimation procedure is to obtain the sample-average risk parameters. We report the results for three main inputs: fertilizers, plant protection and irrigation water. Table (2) reports the estimation results of the farmers' risk attitude. In a second step, the estimated risk parameters will be incorporated into a discrete model of technology adoption, along with climate variables and farmer's characteristics.

	Cereals.	**Arable Land**	**Field Vegetables**
AP	2.064*** [.0254]	0.687*** [.0067]	0.235*** [0157]
DS	2.541*** [.0123]	0.183*** [.0010]	0.026*** [.0012]
Intercept: Irrigation Water	0.018***[.0002]	0.006***[.0001]	-0.009***[.0008]
Intercept: Fertilizer	0.088***[.0008]	0.028***[.0005]	0.188***[.0009]
Intercept: Plant Protection	0.069***[.0012]	0.100*** [.0007]	0.073***[0048]
Wald test for equality between AP and DS $\chi2$ (2):	14,310 Pr > $\chi2$ = 0.0000	50,220 Pr > $\chi2$ = 0.0000	4,465 Pr > $\chi2$ = 0.0000
Breusch-Pagan LM Test for Overall System Heteroscedasticity $\chi2$ (3):	23,500 Pr > $\chi2$ = 0.0000	20,000 Pr > $\chi2$ = 0.0000	5,960 Pr > $\chi2$ = 0.0000
Number of farms	11,543	15,928	4,913

Estimation method: 3SLS. Instruments used: growing season's minimum temperature, maximum temperature and rainfall. Standard errors in brackets. * p < 0.10, ** p < 0.05, *** p < 0.01.

Table 2. Estimation Results

Table (2) shows the AP and DS parameters for different categories of farms, grouped accordingly to their main farming activity.[12] Previous literature suggests that conclusions on risk attitude of a given group of farmers can't be extended to producers predominately growing other crops (Groom et al., 2008). Farmers specializing in vegetables exhibit lower

[11] When the match at municipality level was not possible, we did it at province's administrative level.

[12] Conoff and O'Neill (2012) survey a range of studies that calculates the Arrow Pratt measure of relative risk aversion and finds that the estimated values ranges from -142 to +11.

risk aversion than those specializing in cereals and arable land crops.[13] This indicates that farmers are willing to sacrifice a portion of their expected profit in order to avoid the risk associated with fertilizers, plant protection and irrigation water used as input in the production function. However, producers of different crops are willing to do so to different extents. The significant and positive DS measure indicates that farmers exhibit down-side risk aversion: they are averse to a profit distributions skewed towards negative values. Farmers are willing to edge against disastrous events, especially those specializing in cereals. Farmers specialized in field vegetables production exhibit less risk aversion also with respect to extreme events.

By analyzing the constant terms we can infer that over the whole period, farmers have used inputs efficiently. Estimates of the intercepts that are different from zero can be interpreted as deviations from profit maximizing choice of the particular input (Groom et al., 2008; Antle, 1987). Cereals producers have been generally less efficient than farmers specialized in arable land crops and field vegetables, especially in the use of irrigation water. The constant term associated to irrigation water input for cereals is positive, significant, and higher than the constant associated to irrigation water for the farmers specialized in vegetables and arable land. This may imply that cereals producers have overused irrigation water. One of the explanations may be that in many areas in Italy poorer soil types of marginal quality are often cultivated with remaining or lower quality cereals seeds. In these areas, farmers most likely do not adopt efficient farming practices they adopt elsewhere.

	Whole Sample	1981-1991	1993-2003
AP	2.064*** [.0254]	-0.175 [.1149]	1.992*** [.0049]
DS	2.541*** [.0123]	2.948*** [.1674]	2.416*** [.0027]
Irrigation Water Intercept	0.018*** [.0002]	0.038*** [.0008]	0.019*** [.0001]
Fertilizer Intercept	0.088*** [.0008]	0.059*** [.0018]	0.098*** [.0003]
Plant Protection Intercept	0.069*** [.0012]	0.105*** [.0016]	0.039*** [.0003]
Number of farms	11,543	7,671	7,681

Estimation Method: 3SLS. Standard errors in brackets. *** p<0.01, ** p<0.05, * p<0.1.

Table 3. Evolution of Risk Aversion over Time (Cereals Excluding Rice)

Table (3) reports the AP and DS parameter for cereals producers, dividing the sample into two separated decades: the period 1981 to 1991 and 1993 to 2003. The choice of the cutoff year is not arbitrary: in 1992 the Common Agricultural Policy (i.e. the agricultural policy of the EU) was reformed to shift from product support (through prices) to producer support (through income support). These changes aimed at improving competitiveness of EU agriculture, developing a more free agricultural market and stabilizing the EU budget expenditure. Following the reform the level of support to cereals producers reduced of about 30%, with cereals granted prices lowered by 35%, to levels closer to the equilibrium market price. Compulsory set-aside measure and other accompanying measures were also introduced, such as agri-environment programs.[14] Given the nature of these changes, we can speculate that the reform may have affected European farmers' risk attitude. In particular we expect that before the MacSharry reform farmers may have more incentive to undertake riskier production decision. Our results confirm this hypothesis: the risk preferences over the second moment of the distribution of profits (variance) have changed over time.

[13] This is coherent with the tendency of the Italian Insurances Companies to consider cereals producers more risk averse than vegetable producers.

[14] Agri-environment measures are designed to encourage farmers to protect and enhance the environment of their farmland. These programs include water use reduction measures, designed to preserve water resources by reducing irrigation and/or reducing water loss from the soil (European Commission, 2005).

Results reported in Table (3) shows that cereals producers have become more risk averse after 1992, thus increasing their willingness to give up a higher fraction of their expected profit in order to receive a given level of profit in the future with certainty. However, preferences over down side risk (profit skewness) have remained rather stable over time.15 This result seems to support recent studies showing the possibility that a negative shock (such as the recent financial crisis) can trigger large increases in agents' risk aversion over relatively short period of time (Guiso et al., 2013; Malmendier and Nagel, 2011) and that stress modulates risk taking, potentially exacerbating behavioral bias in subsequent decision making (Porcelli and Delgado, 2009).

We now turn to the analysis of the determinants of irrigation adoption. Table (4) presents the estimation results of the population-averaged probit regression. By including the estimated risk parameters in a discrete choice model we analyze how production risk and farmer's risk attitude affect the decision to adopt irrigation. The literature shows that risk preferences affect the probability to adopt irrigation technologies and farmers invest in new technologies as a means to hedge against input related production risk (Koundouri et al., 2006).

We find that cereals and vegetables producers located at higher altitudes are less likely to adopt irrigation schemes. This probably reflects higher irrigation costs. In these countries or regions, however, the areas of irrigated agriculture tend to be increasing, as farmers invest in irrigation equipment, primarily in order to reduce risk and increase yields of certain drought-prone crops (Baldock et al., 2000). A higher land quality index is positively correlated with the probability of adopting irrigation. This could be explained because of a possible higher marginal return of irrigation in areas with higher soil quality. Interesting, crops diversification (i.e. number of crops cultivated) has a positive significant impact on the probability of adopting irrigation for cereals producers but is not significant for open field vegetables producers. In general, higher expenditure in other key inputs of the production function, such as fertilizers, has a positive significant impact on the probability to adopt irrigation. We analyze LT averages of climate variables as a proxy of farmers attitude to climate change LT average maximum temperature is a significant determinant of the probability to adopt irrigation for cereals producers, while the coefficients are not statistically significant for vegetable producers. However, higher minimum temperatures are negatively correlated with the probability to adopt irrigation. This could be explained by the heterogeneity of the territory under analysis: farmers in regions with the higher LT minimum temperature are mostly located in southern areas, where irrigation is more expensive. These farmers may rely on other adaptation strategies than adopting irrigation, such as growing crops more heat-tolerant. Higher LT average rainfall makes farmers more likely to adopt irrigation in the case of cereals producers but less likely in the case of vegetable producers. This result shall be further investigated, for example using location dummy variables, as it may relate to the geographic concentration of the producers. In one case the driving effect may be the fact that irrigation is adopted as a complement to rainfall (in this case we would expect a negative significant coefficient, as we obtained for vegetables producers). In other regions the price effect may prevail as in areas traditionally more water-abundant irrigation may be cheaper.

We now discuss the results for the risk parameters in Table (6). Columns (3) and (4), provide insights on the coefficients associated to the variance and skewness of the revenue distribution. These capture how farmers adapt to weather effects, as we assumed that climate is the primary source of production risk (see Section (2)), modeled through the econometric error term. The most interesting results come from the analysis of the skewness parameters, interpreted in light of the results presented in Table (2). Cereals producers display the higher

[15] This conclusion has interesting implication and opens the venue to further research, as agent's risk attitude is often assumed time-invariant.

downside risk aversion (Table (3)). This is coherent with a positive and significant skewness coefficient for cereals producers: agents with the higher DS risk aversion are more likely to adopt adaptation strategies that reduce the probability of crop failure (e.g. to adopt irrigation technology). The skewness coefficient of vegetable producers is also positive but not statistically significant, which may be related to the lower DS risk parameter displayed by this producers' group (Table (3)). The coefficients of parameters associated to the variance of revenue distribution are statistically significant but negative for both producers groups. This might be an indication that farmers are investing in adaptation strategies other than irrigation to reduce risk exposure. Columns (1) and (2) show the results of estimations including risk premiums as explanatory variables, instead of the variance and skewness of the revenue distribution. The coefficient is significant in the case of cereals producers but not for vegetable producers. We obtained a negative coefficient for cereals producer, which may be counterintuitive. This may be due to the fact that the more risk averse cereals producers are located in areas with more arid climate and thus a more expensive and/or regulated access to irrigation water. These results evidence the importance of understanding the group-specific characteristic of the impacted farmers (which are in turn determined by local climate, territorial characteristics and main farming activity) when designing effective adaptation policies involving irrigation technology and more in general the access to water resources.

	Dependent Variable: Irrigation Dummy			
	[1] **cereals producers**	[2] **vegetables producers**	[3] **cereals producers**	[4] **vegetables producers**
Altitute (masl)	-0.0027***	-0.0013***	-0.0027***	-0.0013***
Land Quality	0.2069***	0.1162***	0.2095***	0.1039**
Number of Crops	0.0254***	0.0132	0.0214***	0.0100
Fertilizers (€)	0.000014***	0.00003*	0.00002***	0.0000
Plant Protection (€)	0.000	0.000	0.00001***	-0.00003**
Max Temperature: LT Average	0.0509***	-0.0614	0.0537***	0.0456
Min Temperature: LT Average	-0.2093***	-0.1950***	-0.2114***	-0.1821***
Precipitation LT average	0.0092***	-0.0120***	0.0089***	-0.0118**
Risk Premium	-0.0098**	-0.0001	-	-
Variance	-	-	-1.0544***	-0.1055**
Skeweness	-	-	0.2157***	0.0054
Constant	0.5446*	3.2454***	0.5075*	3.4267***
Farms	11,544	4,913	11,544	4,913

Estimation Method: population-averaged probit regression. Semi-robust standard errors in brackets.
*** p<0.01, ** p<0.05, * p<0.1.

Table 4: Estimation Results Irrigation Probit

6. Conclusion and Extensions

An important contribution of this paper to the literature is the use of the rich panel data structure to capture both the within and between variation in risk preference. Our results found variation across time in the key parameters attached to risk preference, more evident for aversion to the second moment of the distribution of profit, while aversion to extreme events exhibits more time invariant characteristics. These findings open future venue of research, as it is mostly assumed that Individual risk aversion is time invariant. For example, recent research tests whether investors' risk aversion has been affected, within a rather short period of time, by the recent financial crisis and if stress modulates risk taking, potentially

exacerbating behavioral bias in subsequent decision making (e.g. Guiso et al., 2013; Malmendier and Nagel, 2011; Porcelli and Delgado, 2009).

Our data permits to conduct similar analysis for different farmers' group. We compared the risk preferences derived for vegetables and arable land with that of cereals, confirming previous findings in the literature suggesting the existence of heterogeneous risk attitudes between different producers' categories. The differences in policy measures such as the agriculture support prices in Europe across vegetables and cereals categories can also be used to further study policy lessons on farm level input choice responses.

We found consistent results between farmers' risk parameters and the drivers for adopting irrigation technology. In particular, higher downside risk aversion is a key determinant in the decision to adopt irrigation technology.

Our results stress the importance of understanding the group-specific characteristic of the impacted farmers (which are in turn determined by local climate, characteristics of the territory and the main farming activity, among others) when designing effective adaptation policies in the agricultural sectors.

There are significant variation in irrigation practices and efficiency levels of the same across regions in Italy. Given the scale of data we have, it will be possible to extend our study to conduct sub-sample analysis of contrasting regions and derive heterogeneous parameters associated with risk preferences and farm input adaptive mechanism to climate change. This will also allow us to better study how farmers use irrigation as a coping mechanism to climate change.

7. Main References

Antle, J.M (1983). Testing the Stochastic Structure of Production: A Flexible Moment-Based Approach. *Journal of Business and Economic Statistics*. 1:192-201.

Antle, J.M. (1987) Econometric estimation of producers' risk attitudes. *American Journal of Agricultural Economics* 69: 509-22.

Antle, J.M. (2010) Asymmetry, Partial Moments, and Production Risk. *American Journal of Agricultural Economics* 92(5): 1294-1309.

Chavas, J.P. and S. Di Falco (2012b) On the Role of Risk versus Economies of Scope in Farm Diversification with an Application to Ethiopian Farms. *Journal of Agricultural Economics*

Chavas, JP. (2004). Risk Analysis in Theory and Practice. New York: Elsevier.

Di Falco, S. and J.P. Chavas (2009). On Crop Biodiversity, Risk Exposure and Food Security in the Highlands of Ethiopia. *American Journal of Agricultural Economics* 91(3)

Di Falco, S. and J.P. Chavas (2006) Crop Genetic Diversity, Farm Productivity and the Management of Environmental Risk in Rainfed Agriculture. *European Review of Agricultural Economics* 33(3): 289-314

Directive 2000/60/EC of the European Parliament and of the Council (2000) European Water Framework Directive - WFD.

Foudi, S. and K. Erdlenbruch (2011). The Role of Irrigation in Farmers' Risk Management Strategies in France. *European Review of Agricultural Economics*, 39: 439-457.

Groom, B., P. Koundouri, C. Nauges, and A. Thomas (2008). The story of the moment: Risk averse Cypriot farmers respond to drought management. *Applied Economics* 40: 315-26.

Hynes, S. and E. Garvey (2009). Modeling Farmers' Participation in an Agri-environmental Scheme using Panel Data: an Application to the Rural Environmental Protection Scheme in Ireland. *Journal of Agricultural Economics* 60(3): 546-562.

Kim, K. and J.P. Chavas. (2003). Technological Change and Risk Management: An Application to the Economics of Corn Production. *Agricultural Economics* 29: 125-42.

Koundouri, P., C. Nauges, and V. Tzouvelekas. (2006). Technology adoption under production uncertainty: Theory and application to irrigation technology. *American Journal of Agricultural Ecnomics* 88: 657-670.

Menezes, C., Geiss, C. and Tressler, J. (1980). Increasing Down Side Risk. *American Economic Review* 70 (3): 912 -932.