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How Does the Farmer Strike a Balance between Income and Risk across Inputs? An Application in Italian Field Crop Farms

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Abstract: The European Union's Farm-to-Fork strategy, aiming at increasing the environmental sustainability of farming, is oriented to limit farm inputs that could harm the environment. This restrictive policy affects farmers' productive choices and economic well-being. However, limited attention has been paid to how this could affect the economic risk farmers face. To do so, we examine how risk is affected by fertilisers, crop protection, irrigation water, and labour choices. This study relied on Antle's method of moments applied to the irrigated field crop farms of the Italian Farm Accountancy Data Network from 2008 to 2019. This paper fills the literature gap jointly using three aspects usually adopted separately. First, consider the three moments and the semi-variance to investigate the risks of farmers' strategies. Second, it accounts also for government payments to consider the relationship between these and risk. Finally, it adopts an estimation strategy that relies on the Generalised Method of Moments (GMM) for the first step and the Fixed Effects-Generalized Least Squared (FE-GLS) estimator for the second, considering time and individual fixed effects and considering interaction terms effects. According to our research, constraining fertilisers, crop protection, and irrigation water increases income variability, causing farming to be potentially riskier. However, restricting fertilisers and crop protection use decreases the downside risk. These results indicate that policy measures constraining input use, such as those foreseen in the EU, strongly influence the extent and type of risks farmers face. Therefore, policymakers should consider this evidence when designing environmental policies.

Keywords: risk management; Antle's method of moments; Farm-to-Fork; CAP

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1. Introduction

The European Farm-to-Fork Strategy (F2Fs) [1–6]) is designed to support sustainable food systems. It includes regulatory and non-regulatory initiatives that affect how farmers manage variable inputs such as pesticides and fertilisers because they could harm the environment. This strategy represents the pivot of the agricultural sector's contributions to support the European Green Deal. This study investigates how the farmers' input choices affect income and exposure to risk. Farmers have developed a variety of risk management strategies in order to reduce their risk exposure, including adapting the quantities of variable inputs such as fertilisers, crop protection chemicals, and irrigation [7–9]. Hence, policymakers should assess the articulated impact of F2Fs when it is targeted in input reduction.

Some of the literature has investigated how farmers' decisions about variable inputs affect their risk exposure [10,11]. However, these empirical shreds of evidence are inconclusive [11]. Different from previous studies, we do not focus on a specific input, such as irrigation water [12] or pesticides [11], but we consider four inputs at the same time that are key in producing field crops: irrigation water, plant protection chemicals, fertilisers, and labour.

This study is hinged on the fundamental works of Just and Pope (1976, 1978, 1979) [13–15] and Antle's moment-based approach for specifying the stochastic structure of the model [16–18]. This approach allows for testing how the management of different inputs affect farmers' incomes and risks. Though it is extensively used to assess risk exposure in agriculture, the Method of Moments, whose empirical application is based on observed secondary data, presents limitations [19,20]. We try to contribute to the ongoing debate and suggest an empirical procedure that partly overcomes some of the critiques raised in Just and Just (2011) [20] in the light of new evidence in the literature that highlights its robustness also in relation to the analysis based on quantile moments [21,22]. Notably, we apply a two-stage estimation procedure: in the first stage, we estimate a production function; meanwhile, in the second step, we estimate the relationship between risk and production factors.

We use a panel dataset of Italian cereal farmers covering the years from 2008 to 2019 from the Italian Farm Accountancy Data Network (FADN-RICA). Italy is an excellent case study for European agriculture due to its highly heterogeneous climatic, soil, socio-economic, and topographical features [23]. We aim to empirically assess how managing key variable inputs in the production of field crops affects risk exposure. Our findings inform the current debate on the design of agricultural policies that reduce the environmental footprint and enhance the environmental sustainability of the European farm sector. Some of these policies will affect the management of inputs and, in turn, farmers' risk exposure. We aim to shed light on this issue through this analysis. The extent to which farmers' decisions on variable input use affect their expected income and risk exposure could feed the policy debate on introducing measures that constrain chemical inputs and irrigation water use.

This study adopts, for the estimation of the first stage, the Generalised Method of Moments (GMM) [24], similar to Antle (2010) [17], in order to avoid specifying a likelihood function for production estimation. In the assessment of the second step, we draw back from Antle (1987) [17]. We exploit the data panel structure as in Bozzola and Finger (2020) [25], but, unlike these, we employ Fixed Effect Generalised Least Squares (FE-GLS) [26]. FE-GLS is an evolution of the method used in Antle and Goodger (1984) [27] that adopts the theoretical basis according to Just and Pope (1979) [15] and reduces the intragroup heteroskedasticity and serial correlation caused by prices, technology, and other unobservable elements that alter the covariance structure. This estimator, according to Ferdushi et al. (2020) and Griffiths and Anderson (1982) [28,29], uses unobservable time-invariant characteristics, thanks to the "within" estimator, allowing us to consider the correlation with the risk level and inputs at the same time. Simultaneously, FE-GLS reduces heteroskedasticity, serial correlation, and simultaneity bias.

The remaining part of the paper is organised as follows: Section 2 describes the theoretical basis for risk estimation and the econometric framework and summarises the data collected for this investigation. The results are described in Section 3, which also reports the robustness checks. Section 4 discussed the results focusing on the effect of the input on risk and expected income. Finally, Section 5 concludes by highlighting the political implications, limitations, and further development of our findings.

2. Methodology and Materials

This section examines how the ideas to disentangle the relationship between risk and inputs explained in the theoretical basis have been empirically applied. The first subsection introduces the theoretical framework that founded our analysis. What follows is the methodology to explain the adopted econometric framework. Finally, we describe and contextualise the materials utilised in this investigation.

2.1. Theoretical Basis

The effects of input choice in the welfare rely on the stochastic production function. Therefore, we can define the impact of different input applications on expected crop income and crop income risks as welfare effects. We account for uncertainty by analysing the moments of the profit distribution to determine how farmers' decisions about risk relate to inputs. This representation is founded on the Just and Pope framework [13–15], accounting for the critiques of Just and Just (2011) [20].

In particular, we adopt this formulation:

$$y = f(X) + \varepsilon \tag{1}$$

where y is output, $f(X)$ is the deterministic production function, X is a vector of inputs, and ε the error term. Considering $E(y) = f(X)$ as expected production, we have $V(y) = [y - E(y)]^2 = [y - f(X)]^2$.

The authors of [14,15] demonstrate that for $\frac{\partial E(y)}{\partial X} \gtreqless \frac{\partial V(y)}{\partial X}$, a change in $E(y)$ following a shift in X does not necessarily have the same sign as a switch in $V(y)$.

Using the example of Just and Pope "… agricultural inputs such as land, fertiliser, and chemical thinning practices seem to produce a positive contribution to variance of production in some cases. On the other hand, pesticides, irrigation, frost protection, disease-resistant seed varieties, and overcapitalisation all possibly have a negative effect on the variance of production attributable to weather, insects, and crop diseases. ([14]: page 69)".

Just and Pope (1978, 1979) [14,15] reformulate (1) including additive risk $h(X)$ that are included during the production process as:

$$y = f(X) + h(X)\varepsilon \text{ with } E(\varepsilon) = 0 \text{ and } V(\varepsilon) = \sigma^2 \tag{2}$$

According to Antle (1987,2010) [16,17], we use two steps to disentangle the terms of (2).

The production function $f(X)$ is estimate in the first step. The outcome allows deriving $h(X)\varepsilon$ as the difference $y - f(X) = h(X)\varepsilon$. In words, $h(X)\varepsilon$ are the residuals of the production function estimation from the first step.

To determine $h(X)$ from $h(X)\varepsilon$, we relied on the assumption that, in the asymptotic sense, $\varepsilon \sim N(0, \sigma^2)$, then an estimation relying on iid error can allow obtaining $h(X)$.

We suppose that farmers optimise their expected utility from farm income (π) considering risk, with an income production function relying on variable inputs d (fertilisers, plant protection chemicals, irrigation water, and labour) and control variables (x) such as decoupled direct payments (DDP), income from other gainfull activities (OGA), value of fixed assets, land, share of irrigated land on total, and share of rented land on total with the function $(y\ (\mathrm{x}, \mathrm{d}))$ defining the formula:

$$\underset{d}{\mathrm{Max}} E[U(y)] = h[E(y\ (x,d)),\ Var(y(x,d)),\ SVar^{-}(y\ \ (x,d)),\ Skew(y\ \ (x,d))] \tag{3}$$

Short-term decisions affect the stochastic production function varying the crop income through the setting of d. Consequently, the factors in d are strictly related with the risk exposure [30].

At this point, it is necessary to introduce the high moment of income. The *second* moment (variance) is defined as $Var(y\ (x,d)) = E(y - E(y\ \ (x,d)))^2$ while the negative semi-variance can be introduced with $SVar^{-}(y\ \ (x,d)) = E\{y\ (x,d) - E(y\ \ (x,d))\}^2 \forall\ P\ (x,d) < E(P\ (x,d))$.

According to Bozzola et al. (2018), Finger et al. (2018), and Bozzola et al. (2020) [31–33], the variance does not allow us to understand all the risk dimensions because it does not distinguish between downside risk and upside risk. In particular, the farmers are particularly averse to downside risk (i.e., unfavourable risky events). Following Antle (2010), [18], we introduce semi-variance analysis for this motivation. This assessment is particularly detrimental to risk analysis allowing us to analyse the risk in the lower income distribution tail.

The joint analysis was conducted with the assessment of the negative semi-variance and skewness of crop income distribution $Skew\ (y\ \ (\mathrm{x}, \mathrm{d})) = E(y\ - E(y\ \ (\mathrm{x}, \mathrm{d})))^3$ causing the risk adverse event management to be more explicable. Indeed, the skewness of the crop income increases (i.e., the coefficient is positive), holding both means and variance constant [10] and showing that the use of this input decreases the production results and increases the risk.

In a few words, through Equation (3), we can explicate the role of inputs on the distribution of expected crop income, its variance, negative semi-variance, and skewness causing it to be possible to assess the role of farm choices on risk management [25,33].

2.2. Econometric Framework

Antle's moment-based approach [16] is adopted to specify the stochastic structure of the model and test how different input use decisions affect crop income and its higher moments. To take into account the confounding factors that affect the estimation, in the model farm size, we introduce fixed assets, the share of rented and irrigated farmland, the level of decoupled direct payments, and the availability of income from other gainful activities. All the variables included in the empirical analysis are described in Appendix A, Table A1.

The availability of a panel dataset allows the application of estimation techniques controlling to a certain extent for unobserved heterogeneity or path dependency. Antle (1983, 1987) [16,17] suggests considering the following potential empirical issues.

An econometric strategy must be defined to identify the two steps highlighted in the theoretical framework: the production function estimation in the first step and risk function estimation in the second. The identification of these two steps has the necessity for different econometric strategies.

Regarding this approach, we need to take into account the critiques of Griliches ((1967) [34], pp. 277–278), who considers it "harder to make an adequate allowance for the simultaneity problem without constructing a complete production and input decision behaviour model" and Just and Just (2011) [20] who consider it impossible to identify the productive structure independently of the behavioural equations determined at time t. At the same time, we need to consider that $f(\cdot)$ and $h(\cdot)$ include all possible combinations of factors.

First, we assume the production and risk functions ($f(\cdot)$ and $h(\cdot)$) are equal in all considered farms. This assumption is challenging but can be partially relaxed by using a homogenous subset of field crops farms and individual intercepts η_i. Secondly, we consider exogenous and unobservable annual shocks by introducing both the time intercepts τ_T. To avoid η_i and τ_T two times, we adopted the "within" estimator only in the second step. This is expected to remove any general time trend affecting all farmers identically and time-invariant variables, which is an issue also addressed by Bozzola and Finger (2020) [25].

Because of these reasons, the Formula (2) assumes the following shape:

$$y_{i,t} = f(X)_{i,t} + [h(X)_{i,t}\varepsilon + \tau_T + \eta_i] \tag{4}$$

Finally, the stochastic component of function (4) can be found as: $[y_{i,t} - f(X)_{i,t}] = h(X)_{i,t}\varepsilon + \tau_T + \eta_i = \hat{u}_{it}$.

For the econometric point of view, we obtain production function $y_{i,t} = f(X)_{i,t}$, using the GMM estimator. This econometric tool overcomes the critique of Just and Just (2011) [20] regarding the impossibility that $\hat{u}_{it}$ follows the normal distribution. In fact, in GMM, it is not necessary to assume a specific probability density function, such as in a maximum likelihood estimator.

In the second step, the residual of the first moment of the profit distribution ($\hat{u}_{it}$) are then raised to power two and three to compute conditional higher moments (variance, semi-variance, and skewness) to analyse and disentagle risk components $\hat{u}_{it}$. After this tranformation, these values are utilised as dependent variables and regressed utlizing the same explanatory variables included in estimating the mean effect (first step or production function estimation), consistently with previous empirical work [25,35].

$$\hat{u}_{it}^2 = w(x_{it},\ d_{it};\delta) + \tau_T + \eta_i + \check{u}_{it} \tag{5}$$

$$\hat{u}_{it}^2 = w(x_{it},\ d_{it};\delta) + \tau_T + \eta_i + \check{u}_{it} \quad \text{if} \quad y < E(y_{it}) \tag{6}$$

$$\hat{u}_{it}^3 = s(x_{it},\ d_{it};\phi) + \tau_T + \eta_i + \tilde{u}_{it} \tag{7}$$

Empirically, in the second step, to ensure the relationship between risk and inputs is explicit, we must use an estimator that helps us differentiate the variable's effect in equations considering the presence of time-invariant variables and the linkage between inputs [25] (Note: In Bozzola and Finger, (2020) [25] the econometric strategy relied on the "within" estimator. The authors assume that the unobservable time-invariant characteristics, such as average quality of land, the managerial ability of the family running the farm, and other unobserved time-constant factors, control the current inputs. The use of FE-GLS can relax this assumption). The Fixed Effect Generalised Least Squares (FE-GLS) estimator is chosen because it reduces intragroup heteroskedasticity and serial correlation primarily provided by the heterogeneity in prices, technology, and other unobservable characteristics that can affect covariance structure [26]. This estimator allows the error covariance structure inside every group of observations to be fully unrestricted and is robust against any intragroup heteroskedasticity and serial correlation. However, it is necessary to adopt an identical structure related to heterogeneity factors across groups, otherwise FE-GLS estimation would be inefficient. For this motivation, we adopt a homogenous dataset characterised by uniformity in the heterogeneity of prices, technology, and other grouping characteristics.

This econometric tool is similar to GLS adopted by Antle and Goodger (1984) [27]. Unlike GLS, FE-GLS avoids the bias caused by the correlation between the standard error and input and recognises simultaneity [27,36]. Then, FE-GLS consider the correlation between the inputs and the output. Moreover FE-GLS, including the "within" estimator, eliminates τ_T and η_i terms obtaining the relation between risk and input in (5), (6), and (7) directly. Finally, FE-GLS address the correlation between individual time-invariant characteristics (such as soil fertility or location) and inputs.

2.3. Material

This paper relies on individual farm data from the Italian Farm Accountancy Data Network (FADN-RICA) [37]. Unobserved heterogeneity in prices, technology, and potentially other factors that can affect the correct specification of the estimation is considered using a specific crop type: "Specialised cereals (other than rice) oilseeds and protein crops" with FADN-RICA code "1510".

The introduction of irrigation as input raises an important question: the choice of the quantity of irrigation depends not only on the farmer's behaviour and needs of the crop but also on the availability of this resource. The farmers in areas where there is no possibility of irrigation are, therefore, not captured by this model. For this motivation, the farmers without irrigation utilised agricultural area (UAA) are not considered in this study.

After selecting the Italian FADN-RICA dataset using the parameters previously indicated, our case study comprises 6015 farm-level observations from 2008 to 2019 (the number of observations per year is reported in appendix—Table A2) (Note: We do not use 2020, even if it is available, because the risk was strongly affected by COVID-19's effects).

Table 1 shows the descriptive statistics. Note that the high variability characterises the income and input variables. In particular, it can be noted that the income has negative values caused by adverse events or mismanagement, including risk.

Due to this characteristic and the fact that the input factors can have a null value (i.e., they are not used), we opted for the standardisation of the values and not the use of the logarithmic transformation as in other studies concerning the production function. This procedure is also adopted to allow comparability with similar studies [11,12,25]. The high variability shows a remarkable fickleness in the management of the farm. Furthermore, the asymmetry and kurtosis analysis show how the distribution deviates from normality, with farmers favouring the low use of inputs.

Note that the direct payments are also characterised by variability, such as OGA and land, particularly in the case of fixed assets. Moreover, the negative value in the minimum figure is generated by depreciation. Finally, a good presence of farms irrigated both totally and partially and the variability in the share of land rent can be noted.

Table 1. Descriptive statistics (Data not standardised).

Type	Description	U.M.	Mean	Sd	Median	MAD	Min	Max	Skewness	Kurtosis
Dependent (y)	Income	EUR	26,300.77	62,485.42	11,360.47	16,101.33	−331,292.88	2,687,579.65	15.32	562.97
Regressors (d)	Fertilisers	EUR	8336.73	12,755.12	4171.24	4193.92	0.00	150,723.58	4.26	25.95
	Crop protection	EUR	4162.96	7180.14	1975.85	2123.81	0.00	122,502.74	5.82	52.01
	Labour	Hours	2756.64	1950.97	2200.00	1156.43	0.00	24,160.00	2.81	14.26
	Water	m^3	9154.89	34,966.66	0.00	0.00	0.00	894,308.94	9.58	138.23
Control variables (x)	DDP	EUR	16,348.05	24,925.82	8618.62	8293.57	0.00	501,923.92	5.62	56.48
	OGA	EUR	2756.44	14,629.79	0.00	0.00	0.00	300,478.59	9.13	108.50
	Fixed assets	EUR	847,354.54	4,698,733.21	346,857.45	429,556.07	−99.00	241,048,213.23	44.69	2229.20
	Land	Ha	42.80	58.76	25.07	22.42	0.06	654.10	4.34	26.83
	Share irrigated	%	0.50	0.40	0.52	0.71	0.00	1.00	−0.03	−1.62
	Share rented land	%	0.47	0.42	0.45	0.67	0.00	1.00	0.11	−1.67

3. Results

3.1. Empirical Results

A GMM estimator was adopted to estimate the relationship between crop income and decisions variable inputs (water, fertiliser, plant protection chemicals, and labour), controlling for other covariates. The results are reported in Table 2, column 1. After estimating the crop income equation (first moment), considering that the residuals are not normally distributed, we use the residuals of this regression to construct the dependent variables for the variance, negative semi-variance, and skewness equations (Formulas (5)–(7)). The results of these three regressions capture the risk and are indicated, respectively, in columns 2, 3, and 4 in Table 2. These findings demonstrate how inputs influence farmers' risk exposure differently.

Table 2. Estimation results for the income, variance, negative semi-variance, and skewness (equations.

Dependent (y)		UM.	(1) Expected (Income)	(2) Variance (Income)	(3) Semi-variance $^-$ (Income)	(4) Skewness (Income)
	Intercept		0.205 *** (0.066)			
Regressors (d)	Fertilisers	EUR	−0.009 (0.007)	−0.003 (0.007)	0.048 *** (0.003)	−1.791 *** (0.030)
	Crop protection	EUR	−0.044 *** (0.010)	−0.794 *** (0.008)	0.070 *** (0.006)	−2.297 *** (0.049)
	Labour	Hours	−0.014 (0.012)	−0.079 *** (0.017)	−0.003 (0.007)	−9.129 *** (0.093)
	Water	m^3	0.001 (0.003)	−0.066 *** (0.001)	−0.003 (0.002)	−0.202 *** (0.009)
Control variables (x)	DDP	EUR	0.147 *** (0.010)	−0.280 *** (0.022)	0.016 * (0.008)	−0.075 (0.099)
	OGA	EUR	0.036 * (0.036)	−0.110 *** (0.029)	−0.071 *** (0.012)	5.292 *** (0.160)
	Fixed assets	EUR	−0.001 (0.002)	0.002 (0.002)	0.000 (0.000)	−0.402 *** (0.071)
	Land	Ha	0.138 *** (0.009)	0.124 *** (0.037)	−0.037 *** (0.009)	−0.475 ** (0.178)
	Share irrigated	%	0.032 *** (0.009)	−0.011 (0.007)	−0.003 (0.004)	0.841 *** (0.040)
	Share rented land	%	−0.036 *** (0.008)	0.526 *** (0.022)	0.019* (0.009)	1.107 *** (0.159)
	R^2		0.389	0.053	0.653	0.055
	N. Observations		6015	6015	3289	6015

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05.

At a first glance, note that the model has a reasonable goodness-of-fit for the expected income and semi-variance but not for variance and skewness. These results are in line with other studies [11,12,25]. The farmers have reasonable control of the income and downside risk (negative semi-variance) but little for the upside risk (positive semi-variance) and crop failure (skewness) [18].

3.2. Robustness Checks

We have conducted robustness checks to evaluate the validity of the models.

In particular, for the first step, the models have been evaluated for the presence of multiple and spurious results caused by outliers [38]. To verify this effect, we have implemented 1000 cross-validation resamples. This operation consists of the data split into 1000 unique partitions and uses each with the model specification. After these resamples, we used a t-test to compare the cross-validation resamples with the models with the total sample. As a result, we found that all the coefficients do not statistically diverge, meaning that the solution is not spurious.

For the second step, we have compared the FE-GLS with pooled, "within" individual fixed effect, "within" time effect, and "within" individual and time effects for variance, semi-variance, and skewness models. In all the comparisons, we found that FE-GLS shows robustness in the estimation (the results for the robustness checks are reported in the appendix—Table A3 for the first steps and Tables A4–A6 for the second step).

4. Discussions

The results are resumed graphically in Table 3. Again, the effects of the variables investigated in the risk components are different.

Table 3. Graphical representation of results on income (column 1), variance (column 2), negative semi-variance (column 3), and skewness (column 4) equations.

Dependent (y)		**[1] Expected (Income)**	**[2] Variance (Income)**	**[3] Semi-Variance (Income)**	**[4] Skewness (Income)**
Regressors (d)	Fertilisers	◆	◆	▲	▼
	Crop protection	▼	▼	▲	▼
	Labour	▼	▼	◆	▼
	Water	◆	▼	◆	▼
Control variables (x)	DDP	▲	▼	▲	◆
	OGA	▲	▼	▼	▲
	Fixed assets	◆	◆	◆	▼
	Land	▲	▲	▼	▼
	Share irrigated	▲	◆	◆	▲
	Share rented land	▼	▲	▲	▲

Legend: ▲: Increase; ◆: Not Significance; ▼: Decrease.

Fertilisers have a controversial effect with no significant impact on expected and income variance (and consequently the risk as intended by Just and Pope (1978) [14]). According to Antle (2010) [18], it is necessary to investigate other moments, specifically semi-variance and skewness, to evaluate other aspects of risk. An increase in fertiliser expenditure improves the downside risk associated with negative semi-variance but decreases the probability of crop failure (i.e., the coefficient in the skewness model is negative and statistically significant). These effects can be explained by how farmers use fertilisers during production. A large amount of this input is employed before or during sowing (for example, in the cultivation of corn, the farmer cannot correct the amount of fertiliser during cultivation even after drought, frost, and floods that occur after sowing even if they can irremediably compromise production). These results diverge from Just and Pope (1978) [14] but align with Kumbhakar and Tsionas (2010) [39]. The difference with Just and Pope (1978) [14] was derived by using a particular dataset concerning potato farmers in Ecuador. Conversely, the result in Kumbhakar and Tsionas (2010) [39] is similar, albeit conducted in the Philippines, because the rice farming data are similar to those for our type of farms.

The outcomes for plant protection are in line with Just and Pope (1978, 1979) [14,15]. In particular, an incremental level of crop protection expense decreases income. At the same time, we can observe a reduction in the variation of income (i.e., decrease the risk) but only for upside risky subjects (i.e., increase negative semi-variance). Simultaneously, the recourse in crop protection decreases the probability of crop failure, as shown by the skewness regression's negative coefficient. The farmer uses pesticides only if they are strictly necessary, in the presence of weeds, pests, and disease or with a precautionary scope. In words, the use of pesticides can affect income, only decreasing it. The farmer recurs to this input with the sole aim of limiting further losses. These results align with the conclusion of Kumbhakar and Tsionas (2010) [39] for Spain, where the authors found that phytosanitary products are risk-reducing inputs, and for Bareille and Chakir (2021) [40] for France.

Irrigation water does not affect the income level but, as it is also intuitive, it reduces risk (i.e., reduces variance). Interestingly, the coefficient associated with the negative semi-variance is not statistically significant, meaning that irrigation water does not impact the downside risk. However, this suggests that this input decreases crop failure, given that the impact on the skewness is significant and negative. The motivation for these results can be found similarly in crop protection: irrigation water is used only in the case of an adverse event, such as lower-than-expected rainfall endangering crop production, and it is not employed preventively without connection with the real conditions of risk. This result highlighted the different behaviour of this factor in contrast with fertilisers, generally employed with a preventive scope. Note that, unlike crop protection, water does not influence the income level, i.e., it appears have income-neutral behaviour. When necessary for cultivation, water is used sparingly to reach an adequate production level and not go beyond the expected level of irrigated cultivation, with the only objective of avoiding water stress. These results partially diverge from the conclusions in Bozzola (2014) [12]. This could be because the analysis is carried out in all Italian farms at different times but also in the consideration of the particularly violent effects of extreme weather events in recent years [31,41].

The labour, as expected, decreases the income caused by the expenditure boost. Risk reduction is shown by decreasing variability and skewness. Labour is generally employed only with adverse events in order to contain shortcomings (Note: potentially, farmers can increase the use of factors that reduce risk and increase income. In general, however, this does not happen because the factors are strongly correlated with each other and an increase in one factor leads to the use of other factors, with negative effects on income and risk. For example, if we want to increase the number of inputs used such as fertilizer, water or pesticides, it is also necessary to increase the labour and capital necessary for the use of these factors. The farmers are trying to find the right balance in the optimal use of production factors to achieve maximum well-being). These results confirm what was obtained in Antle (2010) [18] and in Picazo-Tadeo and Wall §(2011) [42].

For the control variables, decoupled direct payments (DDP) increase the income and reduce the risks but only for upside risk (see the negative value for variance and positive for negative semi-variance). Payments increase income and are a relatively stable source of income. This result is in line with the previous analysis [43].

The income generated from other gainful activities (OGA), e.g., agritourism, can increase the level of Farm Net Income, decreasing this variability. As expected, the crop failure and the downside risk associated with these activities increase: the farms with OGA are riskier and can be read in the negative and significative coefficient for semi-variance estimation and positive for skewness. This effect is consistent with the theory that the diversification of sources of income reduces the risk but only for the less risky farmers [44].

The fixed capital only affects the risk of failure, reducing the skewness value and increasing it. This effect can be generated by the "sticky" feature of fixed assets. Indeed, farmers use the accumulation of fixed assets, along with assets in the form of livestock, agricultural plants, and machinery, as precautionary self-insurance savings to reduce risk; the change is related to the long-run effect [45–50].

Land improves the income level but with an increase in riskier behaviour that we see with the variance. However, a more in-depth analysis also investigating the semi-variance and the skewness shows that the increase in this factor increases the downside risk only for risky subjects, confirming the literature [45–50]. This can be in opposition to fixed assets but, considering that the recurse in rent land is frequent in crop fields, the factor is more flexible than fixed capital.

To evaluate the effect of the irrigated area in our investigation, it is necessary to compare with the amount of water used. Irrigated areas affect income positively but do not affect variability (variance) and downside risk (negative semi-variance). At the same time, irrigated areas can increase crop failure. These last results, similar to other studies, demonstrate that water areas have an unclear impact on risk [51]. This result seems counterintuitive but comparing the amount of the water effect can disentangle this effect. For example, if we have highly irrigated areas but do not use them, we increase the risk of failure, but if we use water to irrigate, we decrease crop failure [12].

Finally, we investigate the shared lending rents. The results confirm Szymańska et al. (2021) [52] on the negative impact on income because, as it is obvious, it affects expenses. The direct effect is the increase in variance and negative semi-variance, or downside risk. The skewness increase caused by the shared land confirms the negative effect on risk, particularly crop failure [52].

5. Conclusions

This study contributes to the existing literature from a methodological and empirical perspective. Regarding the first, it adds to the previous analyses by explicitly addressing time-invariant omitted variables bias through adopting the "within" time and individual effect estimator and the interaction terms using FE-GLS. The results confirm the theoretical framework proposed by Just and Pope (1979, 1978, 1979) [13–15] and show a strong correlation between inputs and the expected income with the consequence in risk management.

The empirical results are also policy relevant. The outcomes shed light on the effect of the reduction inputs policy, such as the European Farm-to-Fork strategy. According to our results, this policy, posing constraints to the use of some inputs, is expected to exacerbate the trade-off between environmental goals and risk management: on the one hand, it reduces the environmental impact; on the other hand, it reduces the number of tools available to the farmer to combat crop failure. The impact on risk differs for the input categories investigated in this paper. Fertilisers do not increase income but strongly affect the risk, particularly for downside risky agents. Crop protection can decrease the expected income and the probability of crop failure, especially for up-side risky subjects. A water use constraint has no impact on the income level but can indeed decrease the risk farmers face. Finally, an increase in employed labour is associated with a reduction in expected income and, simultaneously, with a decrease in risk exposure.

The support provided by the Common Agricultural Policy has also had a crucial impact on risk. According to the literature, an increase in the decoupled direct payments level is associated with a substantial decrease in risk with an increase in the income level. Similarly, policies supporting farm diversification towards other gainful activities can positively affect income levels and reduce risk. Likewise, policies encouraging agricultural diversification through other related activities can positively impact revenue, but the effect on risk is controversial. Finally, the assessment of the control variables shows an increase in the impact for subjects, particularly at risk (downside risk) for fixed assets and land; similarly, shared irrigated and rented land negatively affect the risky farmers.

This study demonstrates how complex the impact of policies affects input choices. In particular, these policies could affect the level and nature of the risks farmers are coping with. In addition, these findings imply that these policies should not be studied in isolation because other policy measures, noticeably those belonging to the Common Agricultural Policy, influence farmer's choices.

The analysis is not exempted from some limitations. The most relevant refers to potential endogeneity issues that will be explored and addressed in future research but considering the limitation derived by the critiques in Just and Just (2011) [20]. In addition, the models can be improved by considering other types of farms or different farmer characteristics, such as young versus no-young farmers. Another dimension that can be explored is how different CAP measures affect the risk, not only DDP. Finally, we can compare the estimation with a quantile moments approach [53].

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Appendix A

Table A1. Description of the variables.

Name	Variable Description	Full Description
Dependent (y)		
Income	Farm Net Income (FNI) (EUR)	Remuneration to fixed factors of production of the family (work, land, and capital) and remuneration to the entrepreneur's risks (loss/profit) in the accounting year.
Regressors (d)		
Fertilisers	Total fertiliser and soil improver expenditure (EUR)	Purchased fertilisers and soil improvers (excluding those used for forests). It includes purchased lime, compost, peat, and manure.
Crop protection	Total crop protection products expenditure (EUR)	Total crop protection product expenditure (EUR). It includes all materials used to protect crops and plants against pests, diseases, and stormy weather (insecticides, fungicides, herbicides, poisoned baits, bird scarers, anti-hail shelters, and frost protection).
Labour	Total labour input expressed in annual work unit hours	Total labour input of farm expressed in hours.
Water	Irrigation water (m^3)	Amount of irrigation water distributed.
Control variables (x)		
DDP	Decoupled Direct Payments (EUR)	Decoupled payments are budgetary payments paid to eligible recipients that are not linked to the current production of specific commodities or livestock numbers or the use of specific factors of production.

Table A1. *Cont.*

Name	Variable Description	Full Description
OGA	Other Gainful Activities (EUR)	Gainful activities of the farm comprise all activities other than farm work having an economic impact on the farm. It refers to: - Other gainful activities directly related to the farm where either the resources of the farm (e.g., area, buildings, machinery) or its products are used in the activity: o On the farm, such as tourism, handicraft, processing of farm products, or forestry; o Out of the farm, such as agricultural and non-agricultural contractual work; o Other gainful activities not directly related to the farm: o On the farm, such as non-farm work on the farm;o Out of the farm, such as working in a bank or teaching.
Fixed assets	Total value fixed assets (EUR)	Total value fixed assets (EUR) including land, buildings, forest capital machineries and equipment (deadstock), and breeding livestock.
Land	Total utilised agricultural area (UAA) (hectares)	Total utilised agricultural area of farm. Does not include areas used for mushrooms, land rented for less than one year on an occasional basis, woodland, and other farm areas (roads, ponds, non-farmed areas, etc.). It consists of land in owner-occupation, rented land, and land in sharecropping (remuneration linked to output from land made available). It includes agricultural land temporarily not under cultivation for agricultural reasons or withdrawn from production as part of agricultural policy measures.
Share irrigated land	Total UAA under irrigation/Total UAA (hectares/hectares)	UAA (excluding areas under glass) irrigated with fixed or mobile equipment during the accounting year. Irrigation may be by any means (including sprinklers and flooding).
Share rented land	Total UAA rented/Total UAA (hectares/hectares)	Land not belonging to the farm (that means not satisfying owner—occupation conditions), for which a fixed rent is paid in cash or kind.

Table A2. Number of observations per year.

Year	N° Farms
2008	652
2009	579
2010	540
2011	551
2012	541
2013	525
2014	442
2015	429
2016	461
2017	460
2018	401
2019	434
Total	6015

Table A3. Robustness check E (Income).

	Model	**Cross-Validation 1000 kfolds**	**T. Test (*p*.Value)**
Intercept	−0.205 (0.066)	−0.204 (0.000)	0.861
Fertilisers	−0.009 (0.007)	−0.008 (0.001)	0.324
Crop protection	−0.044 (0.010)	−0.044 (0.001)	0.355
Labour	−0.014 (0.012)	−0.012 (0.001)	0.327
Water	0.001 (0.003)	0.002 (0.000)	0.311
DDP	0.147 (0.010)	0.139 (0.000)	0.210
OGA	0.036 (0.036)	0.033 (0.001)	0.294
Fixed assets	−0.001 (0.002)	−0.001 (0.000)	0.323
Land	0.138 (0.009)	0.146 (0.001)	0.238
Share irrigated	0.032 (0.009)	0.032 (0.000)	0.278
Share rented land	−0.036 (0.008)	−0.035 (0.000)	0.435

Table A4. Robustness check variance (Income).

	FE-GLS	**Without FE**	**Individual FE**	**Time FE**	**Two Way FE**
Fertilisers	−0.003	−0.053	−0.654	−0.115	0.720
	(0.007)	(0.045)	(0.458)	(0.175)	(0.464)
Crop protection	−0.794 ***	−0.101	−0.943	−0.096	−0.895
	(0.008)	(0.175)	(0.648)	(0.228)	(0.643)
Labour	−0.079 ***	−0.116	−0.785 *	−0.092	−0.737 *
	(0.017)	(0.231)	(0.358)	(0.082)	(0.343)
Water	−0.066	−0.098	0.032	0.006	0.039
	(0.001)	(0.083)	(0.061)	(0.051)	(0.064)
DDP	−0.28	−0.004	0.361	0.043	0.261
	(0.022)	(0.048)	(0.331)	(0.067)	(0.282)
OGA	−0.11	0.053	0.054	0.035	0.089
	(0.029)	(0.073)	(0.148)	(0.069)	(0.155)
Fixed assets	0.002	0.029	0.001	0.000	0.000
	(0.002)	(0.067)	(0.004)	(0.003)	(0.003)
Land	0.124	0.000	0.407	0.260 *	0.515
	(0.037)	(0.003)	(0.431)	(0.132)	(0.413)
Share irrigated	−0.011	0.256	0.136	0.148	0.134
	(0.007)	(0.134)	(0.127)	(0.077)	(0.132)
Share rented land	0.526	0.157 *	0.011	0.016	0.147 *
	(0.022)	(0.077)	(0.067)	(0.022)	(0.074)
GLS	Yes	No	No	No	No
Time effect	Yes	No	No	Yes	Yes
Individual effect	Yes	No	Yes	No	Yes
R^2	0.053	0.019	0.019	0.004	0.019

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05.

Table A5. Robustness check semi-variance (Income).

	FE−GLS	Without FE	Individual FE	Time FE	Two Way FE
Fertilisers	0.048 ***	0.012	−0.009	0.012	−0.008
	(0.003)	(0.010)	(0.012)	(0.010)	(0.012)
Crop protection	0.07 ***	0.005	0.067 **	0.005	0.067 **
	(0.006)	(0.014)	(0.022)	(0.014)	(0.022)
Labour	−0.003	−0.007	−0.023	−0.007	−0.020
	(0.007)	(0.008)	(0.018)	(0.008)	(0.018)
Water	−0.003	0.005	0.005	0.005	0.005
	(0.002)	(0.004)	(0.003)	(0.004)	(0.003)
DDP	0.016 *	−0.026 **	−0.039	−0.026 **	−0.039
	(0.008)	(0.009)	(0.029)	(0.009)	(0.030)
OGA	−0.071 ***	0.021	−0.012	0.021	−0.012
	(0.012)	(0.012)	(0.014)	(0.012)	(0.014)
Fixed assets	0.000	0.000	0.000	−0.001	0.000
	(0.000)	(0.001)	(0.000)	(0.001)	(0.000)
Land	−0.037 ***	0.041 ***	0.055	0.041 ***	0.053
	(0.009)	(0.011)	(0.034)	(0.011)	(0.035)
Share irrigated	−0.003	0.006 *	0.006 *	0.006	0.006 *
	(0.004)	(0.003)	(0.003)	(0.003)	(0.003)
Share rented land	0.019*	0.006	0.006	0.006	0.007
	(0.009)	(0.003)	(0.016)	(0.003)	(0.016)
GLS	Yes	No	No	No	No
Time effect	Yes	No	No	Yes	Yes
Individual effect	Yes	No	Yes	No	Yes
R^2	0.653	0.125	0.046	0.125	0.045

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05.

Table A6. Robustness check skewness (Income).

	FE-GLS	Without FE	Individual FE	Time FE	Two Way FE
Fertilisers	−1.791 ***	−2.050	−8.490	−2.255	−9.371
	(0.030)	(2.327)	(6.230)	(2.324)	(6.316)
Crop protection	−2.297 ***	−1.623	−13.340	−1.353	−12.687
	(0.049)	(3.103)	(8.738)	(3.063)	(8.653)
Labour	−9.129 ***	−1.553	9.725 *	−1.476	−9.062 *
	(0.093)	(1.001)	(4.757)	(0.986)	(4.540)
Water	−0.202 ***	−0.059	0.876	0.059	0.960
	(0.009)	(0.499)	(0.709)	(0.531)	(0.744)
DDP	−0.075	0.413	4.407	0.288	3.101
	(0.099)	(0.956)	(4.475)	(0.869)	(3.789)
OGA	5.292 ***	0.190	0.741	0.262	1.213
	(0.160)	(0.847)	(1.976)	(0.872)	(2.071)
Fixed assets	−0.402 ***	0.006	0.030	0.011	0.015
	(0.071)	(0.036)	(0.065)	(0.040)	(0.051)
Land	−0.475 **	3.369	4.268	3.439 *	5.703
	(0.178)	(1.771)	(5.774)	(1.736)	(5.528)
Share irrigated	0.841 ***	1.909	1.587	1.799	1.563
	(0.040)	(1.025)	(1.721)	(1.021)	(1.793)
Share rented land	1.107 ***	−0.024	−0.153	0.058	1.646
	(0.159)	(0.247)	(0.839)	(0.288)	(0.942)
GLS	Yes	No	No	No	No
Time effect	Yes	No	No	Yes	Yes
Individual effect	Yes	No	Yes	No	Yes
R^2	0.055	0.003	0.018	0.003	0.018

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05.

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