Do Risk Preferences Really Matter? The Case of Input Use in Agriculture

Christophe Bontemps (TSE-R, Toulouse)
Douadia Bougherara (CEE-M, Montpellier)
Céline Nauges (TSE-R, Toulouse)

The role of risk and risk preferences in agriculture

- ✓ Extensive literature on risk in agriculture, including modelling of farmers' behaviour under both price and production risk; purchase of insurance contracts; estimation of crop yield distributions, of farmers' risk preferences etc.

- ✓ Farmers are found to be risk averse in most situations but by how much does risk aversion impact farmers' choices? How big is the impact?

- ✓ Two possible responses to cope with risk: contracting with an insurance company and using on-farm risk management tools (e.g. crop diversification; input use etc.)

- ✓ Here the focus is on production risk and input use as an on-farm risk management tool

Ex: the role of pesticides in managing production risk

Pesticides are used in agriculture for two main reasons (Feder, 1979):

- ✓ To increase the expected value of crop yields (*profit motive*)
- ✓ To protect crops and *to insure against the risk* of production variability

Profit motive or *economic rentability* driven by:

- The marginal productivity of pesticides
- The relative prices of output and pesticides

Insurance motive driven by:

- The risk-reducing role of pesticides (mitigation of production risk)
- Risk preferences of farmers - *risk* only impacts utility of risk-averse farmers

Main purpose & contribution of our paper

Under the assumption that farmers are risk averse and face production risk only, we assess (empirically) the relative importance of *profit* vs. *insurance* motives in driving farmers' decision on pesticide use.

Main outcomes of interest:

- **Quantity of pesticide used** driven by an *economic rentability motive vs.* quantity of pesticide used for *insurance purposes*

- **Economic value of the insurance component** (risk premium)

- **Impact of risk aversion on welfare** (certainty equivalent)

We consider situations that are representative of agricultural production in Europe.

Why does it matter? Link with environmental policies

Knowing whether economic rentability or insurance motive dominates will provide guidance for policies to manage pesticide use:

> A **tax on pesticide use** (as is done in Europe) may be more appropriate if the economic rentability motive dominates
>
> while
>
> **Subsidies to insurance premium** (as in the US) may be a better choice if the insurance motive dominates

Proposed methodology

- **Benchmark situation (built from existing empirical evidence)**
  - ✓ Representative production function (pesticides → crop output)
  - ✓ Representative utility function
  - ✓ Representative output/pesticide price ratio

- **Data:** simulated data built from real crop farm data from France

- **Outcomes**
  - ✓ Optimal pesticide use x^*, risk premium (RP*) and Certainty Equivalent (CE*) under risk aversion where CE is a monetary measure of welfare that accounts for the cost of risk in the case of risk aversion

  - ✓ Optimal pesticide use x_0^*, RP_0^* and CE_0^* under the assumption of risk neutrality

  - ✓ The comparison of (x^*, CE*) with (x_0^*, CE_0^*) provides an indication of the importance of the *risk* component or *insurance motive*

Main findings

The *risk (or insurance motive)* component has a relatively small impact on optimal pesticide use (x^*) and farmer's welfare (CE*).

In line with some of the findings from the literature:

- ✓ Weak or no link between pesticide use and degree of risk aversion: Webster (1977), Thornton (1984), Pannell (1990)
- ✓ Variance control (i.e. the risk component) explains only around 15% of pesticide use in Carpentier (1995)
- ✓ Crop response and payoff functions are usually flat around the optimum: Pannell, Malcolm and Kingwell (2000) and Pannell (2006)
- ✓ Insurance purchase drives small changes in acreage and chemical input use: Babcock and Hennessy (1996); Smith and Goodwin (1996); Goodwin et al (2004)

Problem formalisation – usual approach in agr. economics

Objective: to model farmer's decision on pesticide use (*x*)

- **Technology - Production function (Just-Pope form)**

$$y = f(x) + g(x)e$$

With *y* the output (crop), *x* the input (pesticides), and *e* the random term representing a random shock, assumed of mean 0.

Common assumptions for pesticides: $\underbrace{\partial f / \partial x}_{\text{(A)}} > 0 \text{ and } \underbrace{\partial g / \partial x}_{\text{(C)}} < 0$

(A): the marginal productivity of pesticides (in physical terms) – mean yield effect
(C): the risk-reducing role of pesticides – variance effect

An increase in pesticide use (*x*) increases the expected quantity of output produced (*y*) and reduces the variance of output (i.e., lowers production risk)

Problem formalisation – usual approach (cont'd)

- **Farmer's risk preferences – Expected utility model**

The representative farmer is assumed to choose *x* that maximises the expected utility of his profit:

$$Max_x E\left[U\left(\pi\right)\right] = E\left[U\left(p_y \underbrace{\left(f(x) + g(x)e\right)}_{y} - p_x x\right)\right]$$

With *U* the utility function representing risk preferences, p_y the price of output and p_x the price of input.

Fonction *U* is concave for risk-averse farmers, i.e. risk-averse farmers are willing to pay a positive amount of money to reduce output variance.

Problem formalisation – usual approach (cont’d)

The first-order condition (FOC) determining optimal pesticide use *x** is:

$$\underbrace{\frac{\partial f}{\partial x}}_{(\mathrm{A})} = \underbrace{\frac{p_x}{p_y}}_{(\mathrm{B})} - \underbrace{\frac{\partial g}{\partial x}}_{(\mathrm{C})} \underbrace{\frac{E\left[U'(\pi)e\right]}{E\left[U'(\pi)\right]}}_{(D)}$$

(A): The marginal productivity of pesticides (in physical terms)
(B): The relative prices of pesticides and output
(C): The risk-reducing role of pesticides
(D): Farmer’s risk preferences

If farmers are risk-neutral (D=0) or if pesticides do not impact variance (C=0), then the FOC reduces to:

$$\underbrace{\frac{\partial f}{\partial x}}_{(\mathrm{A})} = \underbrace{\frac{p_x}{p_y}}_{(\mathrm{B})}$$

Benchmark case: Production function - technology

$$y = f(x) + g(x)e = 15x^{0.3} + 30x^{-0.10}e$$

Input *x* is measured in monetary terms (EUR/ha) and can vary between 1 and 400

Output *y* is measured in quintal/ha [1 quintal = 0.1 tonne]

Input price p_x normalised to 1 and output price p_y set at at 11 EUR/quintal

Random shock *e* assumed to be normally distributed

To assess the role of uncertainty, we consider 1000 equally spaced random values *e* over the *N(0,1)* support

Benchmark case: Utility function – form of risk preferences

CRRA Utility function (with constant relative risk aversion, r_r)

- ✓ If relative risk aversion $r_r = 1$: $U(\pi) = \ln(\pi)$
- ✓ If $r_r \neq 1$: $U(\pi) = \{1/(1-r_r)\}\pi^{1-r_r}$

Following Anderson and Dillon (1992):

$r_r = 0.5$	hardly risk averse at all
$r_r = 1.0$	somewhat risk averse (normal)
$r_r = 2.0$	rather risk averse
$r_r = 3.0$	very risk averse
$r_r = 4.0$	extremely risk averse

Risk Premium (RP): $E[U(\pi)] = U[E(\pi) - RP]$

Certainty Equivalent (CE): $E(\pi) - RP$

Results: Impact of risk aversion on optimal input use and RP

Risk-averse farmers choose *x** that maximises the expected utility of their profit

	$r_r = 0$	$r_r = 1$	$r_r = 2$	$r_r = 3$
Optimal input use (EUR/ha)	264	275	306	337
Input used for self-insurance (%)	**0**	**4**	**14**	22
RP* (EUR/ha)	0	35	87	206
CE* (EUR/ha)	615	580	528	409
Change in welfare or CE (%)	**-**	**-6**	**-9**	-23

Notes: RP*: Risk Premium at the optimum; CE*: Certainty Equivalent at the optimum
Benchmark case: pesticides-crop price ratio = 1/11

Main result: For coefficients of relative risk aversion considered as normal or average (rr = 1), a risk-averse farmer spends an extra 4 EUR compared to a risk-neutral farmer to self-insure, which corresponds to 4% of total expenditure on pesticides. The risk premium is estimated at 35 EUR for an average risk-aversion level (rr = 1).

Results: Sensitivity to the price ratio

Price ratio		$r_r = 0$	$r_r = 1$	$r_r = 2$	$r_r = 3$
1 to 13	Input use (EUR)	336	**344**	**348**	356
	Insurance (%)	0.0	**2.3**	**3.4**	5.6
1 to 11	Input use (EUR)	264	**272**	**276**	284
(benchmark)	Insurance (%)	0.0	**2.9**	**4.3**	7.0
1 to 9	Input use (EUR)	200	**204**	**212**	216
	Insurance (%)	0.0	**2.0**	**5.7**	7.4
1 to 7	Input use (EUR)	140	**144**	**152**	156
	Insurance (%)	0.0	**2.8**	**7.9**	10.3

Also: Tests of sensitivity to the parameters of the production technology

More flexible form of risk preferences: Cumulative Prospect Theory

Main characteristics and differences with EUT:

(i) **Probability distortion**: an S-shaped probability weighting function which converts probabilities into decision weights is used to account for low probability events being commonly over-weighted and high probability events being usually under-weighted;

(ii) **Reference dependence**: individuals care about deviations from a reference point rather than the absolute initial or final wealth; values above the reference point represent gains and values below the reference point represent losses;

(iii) **Reflection effect**: a two-part utility function allows for differences in behaviour in the two outcome domains (gains versus losses).

(iv) **Loss aversion**: the slope may vary between the gain and loss domains. It is usually steeper for losses than for gains, meaning that the disutility of a loss is stronger than the utility of a similar gain.

We consider the value function described in Tversky and Kahneman (1992), also used in Babcock (2015):

$$v^{KT}(w) = \begin{cases} \left(\frac{1}{1-rr^{+}}\right)\left(w - w_{ref}\right)^{(1-rr^{+})} & \text{if } w \geq w_{ref} \\ -\left(\frac{1}{1-rr^{-}}\right)\lambda\left[\left(-w + w_{ref}\right)^{(1-rr^{-})}\right] & \text{if } w < w_{ref} \end{cases}$$

w_{ref} is the reference point; λ is a parameter measuring loss aversion

rr^{+} measures the concavity of the value function in the gain domain, and

rr^{-} measures the concavity of the value function in the loss domain

+ probability-weighting function, defined as in Tversky and Kahneman (1992)

$$\Gamma(p) = \begin{cases} \dfrac{p^{\gamma}}{\left[p^{\gamma} + (1-p)^{\gamma}\right]^{1/\gamma}} & \text{if } w \geq w_{ref} \\ \dfrac{p^{\delta}}{\left[p^{\delta} + (1-p)^{\delta}\right]^{1/\delta}} & \text{if } w < w_{ref} \end{cases}$$

Results from Cumulative Prospect Theory model

	Baseline (T-K, 1992)	No loss aversion	Linear value function	No probability distortion	Loss averse only
	rr+ = rr- = 0.12 lambda = 2.25 gamma = 0.61 delta = 0.69	rr+ = rr- = 0.12 lambda = 1 gamma = 0.61 delta = 0.69	rr+ = rr- = 0 lambda = 2.25 gamma = 0.61 delta = 0.69	rr+ = rr- = 0.12 lambda = 2.25 gamma = 1 delta = 1	rr+ = rr- = 0 lambda = 2.25 gamma = 1 delta = 1
Ref: 0					
x* (Δ, %)	272 (3%)	272 (3%)	269 (2%)	265 (0%)	264 (0%)
RP* (euros)	60	60	50	4	1
Ref: median profit					
x* (Δ, %)	275 (4%)	263 (0%)	275 (4%)	271 (3%)	272 (3%)
RP* (euros)	47	4	56	39	45

Note: Δ measures the quantity of input use that is induced by the aversion to risk. It is computed as $(x^* - x_0^*)/x_0^*$, with $x_0^* = 264$ being the optimal input use under risk neutrality.

Results from CPT model – more extreme parameter values

	Higher loss aversion[a]	**Higher probability distortion**[b]	**Stronger curvature only**	**Stronger curvature + other distortions**
	rr+ = rr- = 0.12 lambda = 3.50 gamma = 0.61 delta = 0.69	rr+ = rr- = 0.12 lambda = 2.25 gamma = 0.61 delta = 0.50	rr+ = rr- = 0.80 lambda = 1 gamma = 1 delta = 1	rr+ = rr- = 0.80 lambda = 2.25 gamma = 0.61 delta = 0.69
Ref: 0				
x* (Δ, %)	272 (3%)	272 (3%)	273 (3%)	301 (14%)
RP* (euros)	60	60	27	126
Ref: median profit				
x* (Δ, %)	279 (6%)	277 (5%)	265 (0%)	268 (2%)
RP* (euros)	62	51	13	13

Notes:

a: a higher *lambda* indicates a more pronounced aversion to loss

b: a lower *delta* indicates more distortion in probabilities for losses

Conclusion - Discussion

The *risk* component has a relatively small impact on optimal pesticide use (x^*) and farmer's welfare (CE*)

True under fairly general assumptions on production technology and utility functions

In line with some earlier findings from the literature

One possible explanation: profit and CE functions are usually flat around the optimum: Pannell, Malcolm and Kingwell (2000) and Pannell (2006)

Which recommendations in terms of public policies…

- ✓ If the *risk motive* component plays a negligible role then subsidies to insurance premia may not be very effective in inducing a change in pesticide usage

- ✓ Optimal input use is primarily driven by the *economic rentability* component (relative prices of input and output)

Hence price policies (i.e., a tax on pesticide) might be preferred but

- ▪ Pesticide usage usually found to be inelastic to its price so price would need to be increased significantly for the policy to induce large changes in pesticide usage

- ▪ High output prices incentivise farmers to produce more (mean yield effect) so any policy targeting pesticide usage may be difficult to implement in a context of high crop prices

Results from CPT model – Chavas' functional form

	a+ = a- = 0.5 b = 1 gamma = 0.8 delta = 0.8	a+ = a- = 0.5 b = 1 gamma = 0.61 delta = 0.69	a+ = a- = 1.5 b = 1 gamma = 0.8 delta = 0.8	a+ = a- = 1.5 b = 1 gamma = 0.61 delta = 0.69	a+ = a- = 2.5 b = 1 gamma = 0.8 delta = 0.8	a+ = a- = 2.5 b = 1 gamma = 0.61 delta = 0.69
Ref: 0						
x* (Δ, %)	274 (4%)	288 (9%)	308 (17%)	329 (25%)	338 (28%)	342 (30%)
RP* (euros)	35	94	106	226	252	412
Ref: median profit						
x* (Δ, %)	274 (4%)	288 (9%)	308 (17%)	329 (25%)	338 (28%)	342 (30%)
RP* (euros)	35	94	106	226	252	412

Extreme values for curvature of the value function.

Current knowledge from the literature

The estimation of the production function – two main approaches

1. Just and Pope (1978, 79) and Feder (1979): pesticides increase mean yield and decrease the variance of yield with production function written as

$$y = f(x) + g(x)e$$

where y is output (yield), x is pesticide use and e represents a random shock (e.g. bad weather)

2. Lichtenberg and Zilberman (1986): pesticides are specified as *damage control inputs* and not as productive inputs

→ First approach has been used much more frequently in the literature and will be used here

→ Estimates of yield elasticities to pesticides vary but most often in the range 0.1 to 0.4 for mean yield and -0.1 to -0.3 for the variance of yield

Current knowledge from the literature (cont'd)

Risk preferences and pesticide use

→ Farmers are found to be risk averse in most situations

- Risk aversion coefficients vary but relative risk aversion usually lies between 1 (low risk aversion) and 4 (high risk aversion)
- Recent evidence of loss aversion and probability distortion in farmers' population (Cumulative Prospect Theory); e.g., Bocquého et al. (2014)

→ No clear-cut evidence on the relationship between risk aversion and pesticide use in the empirical literature

- Weak or no link between risk aversion and pesticide use: Webster (1977), Thornton (1984), Pannell (1990), Le Cotty et al. (2017)
- Some link between risk aversion and pesticide use in Liu and Huang (2013) and Gong et al. (2016) who combined experimental and observational data

Current knowledge from the literature (cont'd)

Sensitivity of pesticide use to economic variables

→ Price (pesticide tax) often advocated as one of the most cost-effective instruments

- Leathers and Quiggin (1991): wealth effect of a pesticide tax whose sign depends on whether risk aversion increases or decreases with wealth
- Pesticide demand fairly inelastic to its price: most estimates lie between -0.7 and -0.02 (Skevas et al., 2013)
- Effect of a pesticide tax may be dampened by high crop prices (Femenia and Letort, 2016)

Current knowledge from the literature (cont'd)

Sensitivity of pesticide use to economic variables

→ Subsidies to crop insurance premia (common in the US, under talks in the EU)

- The purchase of crop insurance often induces a decrease in pesticide usage but the magnitude of the impact is generally found to be small

e.g. Quiggin, Karagiannis, and Stanton (1993); Goodwin, Vandeveer and Deal (2004) ; Smith and Goodwin (1996) and Goodwin and Smith (2003)

- When taking into account impacts of subsidies on crop allocation (extensive margin), total chemical input use may increase (Wu, 1999)

→ Agri-environmental schemes (voluntary contrats, common in Europe)

- Empirical evidence that program participation induced significant reductions in pesticide use in Germany (Pufahl and Weiss, 2009), UK, Italy and France (Arata and Sckokai, 2016)