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RISK AS A LIMIT OR AN OPPORTUNITY TO MITIGATE GHG EMISSIONS?

The case of fertilisation in agriculture

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In this paper, we investigate how risk and risk aversion influence the fertilisation behavior of farmers. We show analytically that a decreasing variance of yield along with nitrogen inputs encourages risk averse farmers to apply larger quantities of fertilizers compared with risk neutral behavior. Then, we use data concerning three departments in France (Deux-Sèvres, Seine-Maritime and Eure-et-Loir) to determine (i) crop yield response function to N fertilizers and (ii) risk aversion behavior of farmers on the basis of their actual fertilizers applications. We find that risk averse farmers represent 29,7% of farmers while risk seeking ones represent 35,5%. Risk aversion behavior is associated with an additional application of 29 kg/ha compared with risk neutral behavior which represents an average loss of 76 euros/ha. We show that the reduction of abatement linked to risk aversion behavior should appear only when crop yield variance is convex with respect to N fertilizers. Lastly, our results show that an insurance covering yield variability could be foreseen as an interesting tool to mitigate emissions.

Comments welcomed

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1. Introduction

Nitrogen pollution is a significant environmental issue around the world and in Europe (Galloway et al, 2008 ; European Commission, 2013). The carbon cycle usually receives more attention than the nitrogen cycle, due to the central role of CO_2 in global warming. However, the nitrogen cycle is also deeply disordered by human activities especially through fertilisation of agricultural soils. This disruption brings a range of impacts, from accelerating climate change to participating in water pollution and generates high external costs (Von Blottnitz et al, 2006). In the European Union, fertilisation from farm activities accounts for 38% of agricultural greenhouse gas (GHG) emissions and represents 4% of the overall European emissions (in 2014 according to the UNFCCC, 2016)[1]. France constitutes also a good example of the nitrogen over-application issue due to the importance of the agricultural sector in French economy and since air and water pollution by nitrogen has been highlighted by many studies (Dalmas, 2010).

In response to these environmental consequences, important regulations on fertilisation have been undertaken. In the forefront, the Nitrate Directive limits nitrogen application on specific areas and affects indirectly farming externalities, including GHG emission, but the ambitious national and international commitments to cut global emissions[2] strengthen the necessity to mitigate emissions in a cost-efficient way.

To tackle the pressing problem of climate mitigation it is generally argued that the most efficient instrument is emission pricing (Lamhauge and Cox, 2013; Ellerman et al., 2010). Many papers have investigated the potential impact of setting up this instrument in agriculture even though this sector has been set aside from European and national climate policies. To name a few, De Cara and Jayet (2011) evaluated the impact of a tax on fertilisation and induced reductions of greenhouse gases. Bourgeois et al. (2014) also simulated the impact of a tax on fertilizer application coupled with subsidies on perennial crops such as miscanthus. Likewise, Dequiedt and Moran (2015) assessed the impact on legume crops and the resulting impact on GHG emissions. These papers are all based on the assumption of profit maximization or cost minimization but little attention has been paid to other essential elements of the decision-making process of farmers. Among those elements, risk management appears as a determining dimension in the production choice of farmers (Chavas and Holt, 1990; Cook et al., 2013; Menapace et al., 2013) and could constitute a potential barrier to mitigate emissions. Indeed, in a survey conducted on the behavior of farmers, Dury (2011) reveals for

[1] In France, nitrogen fertilisation accounts for 44% of greenhouse emissions (GHG) from French agriculture and alone represents 8 % of national emissions in 2014 (UNFCCC, 2016)

[2] See for instance the European Council agreement in October 2014 aiming to reduce European greenhouse gas emissions by 40% by 2030 relative to 1990 levels

instance that less than 1% of farmers cite profit maximization as the sole decision criterion. 71% of them seek instead a "good" profit associated with minimal risk. Besides, Berentsen et al. (2012) show that the risks associated with organic dairy farms are more important than the risk of conventional agriculture (both on the size of the production and agricultural prices) and therefore limits the change of practices. Interested in the barriers associated with a fertilisation reduction program in the United States, Stuart et al. (2014) have shown that the yield loss associated with reduced fertilisation is considered as an important and immediate risk. For most of the interviewed farmers, applying an additional amount of fertilizer is perceived as a way to reduce exposure to production risks. Therefore, it is appropriate to study the impact of risk on the incentive effect of a emission price and also to consider the potential role of insurance as a tool to reduce emissions from fertilisation.

This paper contributes to the literature on GHG mitigation cost assessment in agriculture by providing some analytical and quantitative insights into the following three main questions:

- How risk aversion can explain all (or a part of) nitrogen over-application?
- To what extent risk aversion can limit the mitigation incentive created by a emission price on GHG emissions?
- If farmers use fertilizers as self-insurance, what would be the emissions reduction triggered by an insurance program to mitigate emissions?

For these purposes, we use an original data base, completed by InVivo-Agrosolution farming cooperative, which allows us obtaining a large sample of farmers'data located in three departments in France. We first use feasible generalized least square (FGLS) regression to determine the link between yield variability and nitrogen application at the plot level. In a second step, we use these results to derive risk aversion coefficient consistent with actual farmers' fertilizers spreading. Then, these coefficients are used to simulate the impact of emission price and also to simulate the impact of an insurance system on emissions.

The next section presents the literature on risk and fertilisation. Section 3 details the model of farmers' decision-making on nitrogen application. Data and econometric method are presented in Section 4. Section 5 presents the results. Discussion is given in section 6.

2. Literature review on risk and fertilisation

Can nitrogen be used by farmers to reduce their exposure to risk? The answer to this question depends on the link between inputs and yield variability (Lambert, 1990; Leather and Quiggin, 1991). Although this topic has been widely studied in the literature, there is no clear consensus on this link. First, an important stream of empirical studies concludes that fertilizers are a risk-increasing factor as they have variance-increasing effect on yield (Just and Pope, 1979; Rajsic et al., 2009; Montjardino et al., 2015). This statement depends on weather uncertainty, which implies high level of yield in good growing years and low in bad growing years. This uncertainty has two possible effects depending on the consideration of farmers risk aversion. On one hand, according to Babcock (1992), who takes into account solely the expected profit in the farmer objective function, farmers should be tempted to apply larger amount of nitrogen compared to the case where yield variability is not considered. Since farmers do not know what the growing conditions will be before nitrogen application, it is optimal for them to anticipate good conditions so that nitrogen will not limit potential profits in those years. On the other hand, other studies concludes that in reason of their risk aversion, farmers tend to spread less fertilizers so as to limit the probability of bad events (Montjardino et al., 2015; Broun, 2007; Finger, 2012). Second, an alternate stream concludes that fertilizers could conversely be a risk reducing factor. Because unobservable processes (such as leaching, denitrification or nitrogen up-take in previous crop in rotation) influence the availability of nitrogen in the soil this could results in reducing the variability of yields as nitrogen amount increases (Gandorfer et al., 2011 ; Comifer, 2011) and then could favor the over-application of fertilizers. This corresponds to studies focusing on risk perception of farmers, who consider nitrogen as a risk-decreasing input (SriRamaratnam, 1987; Stuart et al, 2014). Third, some studies argue that the link between fertilisation and variability can not be clearly established. Regev and al. (1997) show no conclusive evidence to assert if nitrogen is either risk-reducing or risk-increasing. Then, according to Antle (2010) empirical study on potato production, the conclusion on this link depends on utility framework implemented: a risk-value model based on partial moments implies that fertilizer is risk increasing, whereas an expected utility model based on full moments has the opposite implications. One explanation for these seemingly contradictory conclusions is the diverse climate and agricultural contexts of studies. Going forward, it seems necessary to assess the role of nitrogen at each geographical level to see whether it is a risk-reducing factor or a risk-increasing factor.

Some papers have addressed the question of the impact of insurance on chemical input use. Theoretically, two different effects have been identified (Bougherara, 2011). The first effect is linked to the above-discussed risk-reduction effect. As insurance increases income in bad states of nature, while decreasing income in good states of nature by charging a premium, it thereby cause farmer to act more like risk-neutral farmer (Sheriff, 2005). Hence, the impact on input use relies on the relationship between fertilizer and risk. If chemical inputs are risk-reducing then they will reduce the amount spread, with the opposite effect if they are risk increasing. The effect one is the moral hazard effect. It occurs when producers take actions to increase the probability and size of losses, and provide incentives for less intensive cultivation practices that result in reduction of inputs and average yields (Coble et al., 1993). Which effect dominates has been examined by empirical papers. In a study conducted on corn farmers, Horowitz and Lichtenberg (1993) conclude that insured farmers applied significantly more nitrogen per acre (+19%) than uninsured one, thus supporting the view that chemical inputs are a risk-increasing input. However these results were latter contradicted by Smith and Goodwin (1996) who confirm the view that moral hazard incentivizes insured farmers to use fewer chemical inputs.

As global warming is expected to cause an increase in the frequency of extreme climate events, insurance is mainly foreseen as a tool to favor adaptation to climate change (Smit and Skinner, 2002). However, as chemical input have been highlighted to play the role of a self-insurance when their risk-reducing ability have been elicited (see for instance Bougherara, 2011 for pesticides), insurance could also be considered as a possible tool to support the implementation of environmental measures[3]. This potential is for instance developed by Huang et al. (2001) who, in a study of US agriculture, analytically and empirically show that an insurance system can help to reduce the amounts of nitrogen applied by the farmer. So far, to our knowledge it has not been used as a tool to limit agricultural environmental externalities. Yet, an interesting example of the possible forthcoming role of instruments that support the adoption of environmental measures , by tackling uncertainty and risk, is provided by the 2015 framework convention between the Loire-Bretagne Water Agency and local farming cooperatives (Agence de l'Eau – Loire Bretagne, 2015). The objective of this convention is to favor the implication of farmers in improving the quality of water. Among the different incentives, the convention plans to establish the reimbursement of losses due to the implementation of innovation only in case of failure.

[3] In France, the current agricultural insurance system is characterized by public and private intervention that help to cover damages caused by frost, hail or drought. The public intervention is under the responsibility of the FNGRA (Le Fonds national de gestion des risques en agriculture) and aims to cover farmers against uninsurable risk. Insurable risks are covered by the private market, alongside government intervention: farmers receive a grant representing at most 65% of the insurance premium.

3. Modelling fertilisation application and risk

3.1. Economic decision model

We consider farmers who grow different crops (indexed by i) and who have to choose fertilizers amounts (x_i) on these different crops. As we assume that the problem is intra-annual, the land allocation among crops is already determined. It is assumed that the sole risk faced by farmers affects crop yields. At the time of N application, yields of the current crops are not known to the farmer. They are modeled as a random variable $\tilde{y}_i$, where $(\tilde{y}_i(x_i))$ follows a Gaussian distribution, with mean $E[y(x_i)]$ and variance $V[y_i(x_i)]$ are assumed to be known by the farmer. Absent any public regulation, the profit of one farmer is thus:

$$\tilde{\pi}(x_{i,..,n}) = \sum_{i}^{n} l_i[\tilde{y}_i(x_i)\, p_i - x_i w] \tag{1}$$

where w is the unit price of nitrogen fertilizer, p_i the crop price received by the farmer and l_i the field area. In order to integrate risk in the farmers' decision making, we assume that their preferences can be fully characterized by a von Neumann and Morgenstern (1947) utility function. Our analysis is based on expected utility-maximization. Then, the problem faced by any farmer is to choose input use intensity per crop that maximizes his overall expected utility. The optimal amount x_i^* per hectare is thus the result of the following problem:

$$\max_{x_{i,..,n}} \{E[u(\tilde{\pi}(x_{i,..,n}))]\} \tag{2}$$

where E denotes the expectation operator and $\tilde{\pi}$ the variable profit associated with crop production depending on fertilizer amount spread. Two possible utility functions are examined : (i) a constant absolute risk aversion (CARA) function (eq. 3) and (ii) a constant relative risk aversion (CRRA) (eq. 4). Both specifications have been commonly used in the literature examining expected utility based decisions (Markowitz 1952; Pope et al, 2011; Monjardino et al, 2015; Polomé et al., 2006). CARA function enables us to represent risk aversion behavior that remains constant with wealth; whereas CRRA allows us to represent Arrow's intuition implying that an individual's willingness to undertake a certain risky measure is greater when he or she is wealthier. CARA function is an exponential transformation of wealth:

$$u(\tilde{\pi}) = -e^{-\alpha\tilde{\pi}} \tag{3}$$

where α is the absolute risk aversion parameter ($\alpha > 0$ for a risk averse agent; $\alpha < 0$ for a risk loving agent). CRRA is a power function and is represented as follow:

$$u(\tilde{\pi}) = \frac{\tilde{\pi}^{(1-r)}}{1-r} \tag{4}$$

Where r is the relative risk aversion coefficient. Relative risk aversion and relative risk loving preferences are obtained respectively for $r > 0$ and $r < 0$. As yields are assumed to follow a Gaussian distribution, in both cases (CARA and CRRA), the expected utility can be written in function of the expected profit and the variance profit (V) (see appendix 8.1 and 8.2 for details) as follow:

$$\max_{x_{i,\dots,n}} \left\{ E\left[u\left(\widetilde{\pi}(x_{i,\dots,n})\right)\right] = a + b.E\left[\sum_{i}^{n} \tilde{\pi}_i(x_i)\right] - c.V\left[\sum_{i}^{n} \tilde{\pi}_i(x_i)\right] \right\} \tag{5}$$

With a=π_0 for CARA preferences and a=$u(2\pi_0) + u'(2\pi_0)\pi_0$ for CRRA preferences, π_0 being the initial wealth of a farmer. b=1 for CARA preferences and b=$u'(2\pi_0)$ for CRRA preferences. c=$\frac{-u''(2\pi_0)}{2} = \frac{r(2\pi_0)^{-1-r}}{2}$ for CRRA preferences and c=$\frac{\alpha}{2}$ for CARA preferences.

We found no covariance between the different yield functions[4]. Then, the solutions of the overall maximization program are equivalent to the solutions of individual field maximization program:

$$\max_{x_i} \{E[u(\tilde{\pi}_i(x_i))] = b.E[\tilde{\pi}_i(x_i)] - c.V[\tilde{\pi}_i(x_i)]\} \tag{6}$$

This form of equation allows us to represent in the objective function both expected income and profit variability, both of which are determined by nutrient input. The optimal input $x_i{}^*$ must satisfy the first order condition given by:

$$\frac{dE[u(\tilde{\pi}_i(x_i{}^*))]}{dx_i} = \frac{dE[\tilde{\pi}_i(x_i{}^*)]}{dx_i} - k\,\frac{dV[\tilde{\pi}_i(x_i{}^*)]}{dx_i} = 0 \tag{7}$$

[4] This finding is consistent for instance with Polomé et al. (2006) study on acreage allocation under risk where no covariance was found between crops after examination of panels of yields.

With k = $\frac{\alpha}{2}$ in for CARA preferences and k= $\frac{r}{4\pi_0}$ for CRRA preferences. The second order condition is written as:

$$\frac{d^2E[u(\tilde{\pi_\iota}(x_i))]}{dx_i{}^2} = \frac{d^2E[\tilde{\pi}(x_i)]}{dx_i{}^2} - k\ \frac{d^2V[\tilde{\pi_\iota}(x_i)]}{dx_i{}^2} < 0 \qquad (8)$$

From equation 7, we find according to the implicit function theorem (see appendix 8.7-a for demonstration):

$$\frac{\partial x_i^*}{\partial k} = \frac{dV[\tilde{\pi_\iota}(x_i^*)]}{dx_i} * \left(\frac{d^2E[\tilde{\pi}(x_i)]}{dx_i{}^2} - k\ \frac{d^2V[\tilde{\pi_\iota}(x_i)]}{dx_i{}^2}\right)^{-1} \qquad (9)$$

Proposition 1: Under CARA and CRRA utility functions, risk aversion increases the optimal amount of fertilizers when the variance of profit is decreasing with x_i, convex or linear[5].

This proposition illustrates the impact of attitude toward risk on optimal nitrogen application. It shows that nitrogen can be used to manage risk production and is in line with some studies mentioned in the literature review (Montjardino et al., 2015; Broun, 2007; Finger, 2012; Lambert, 1990). Hence, risk averse farmers apply more nitrogen than risk neutral ones when fertilizers are a risk-decreasing factor.

3.2. Policy instruments

1. Taxation of N_2O from fertilisation.

The solution to eq. 6 corresponds to a situation in which no policy instrument is in place on greenhouse gas emissions. In particular, the social cost of fertilisation is not internalized by the farmer. Consider now a situation where a price on GHG emission is introduced. The program becomes:

$$\max_{x_i}\{\mathrm{E}[u(\tilde{\pi_\iota}(x_i) - x_i f t l_i)]\} \qquad (10)$$

Where f represents the emission factor of fertilizers (eg. in tCO_2eq/kgN) and *t* denotes the level of the emission price (tax) in euros/tCO_2eq. The relation between the optimal fertilizer amount and the emissions tax is:

[5] Appendix 8.3 illustrates the different configurations of functions forms influencing optimal input $x_i{}^*$

$$\frac{\partial x_i^*}{\partial t} = fl_i * \left(\frac{d^2E[\tilde{\pi}(x_i)]}{dx_i^{\,2}} - k\,\frac{d^2V[\tilde{\pi}_i(x_i)]}{dx_i^{\,2}}\right)^{-1} \tag{11}$$

As the second order condition (eq. 8) implies the denominator to be negative then the emission price always generates emission reductions. We then focus on the impact of risk aversion on emission reductions triggered by emissions price (see appendix 8.4-b for demonstration):

$$\frac{\partial^2 x_i^*}{\partial t\,\partial k} = -fl_i\,\frac{d^2V[\tilde{\pi}_i(x_i)]}{dx_i^{\,2}} * \left(\frac{d^2E[\tilde{\pi}(x_i)]}{dx_i^{\,2}} - k\,\frac{d^2V[\tilde{\pi}_i(x_i)]}{dx_i^{\,2}}\right)^{-2} \tag{12}$$

Proposition 2: Under CARA and CRRA behaviors, when the variance is convex with respect to x_i then risk aversion reduces the marginal impact of emission price on fertilisation reductions.

This proposition illustrates the impact of attitude toward risk on the emissions price incentive to reduce GHG emissions. We observe that the determining factor is the form of the variance function. When the variance is linearly decreasing ($\frac{d^2V[\tilde{\pi}_i(x_i)]}{dx_i^{\,2}} = 0$), risk aversion bears no influence on emissions mitigation but when it is convex ($\frac{d^2V[\tilde{\pi}_i(x_i)]}{dx_i^{\,2}} > 0$) then GHG abatement are decreasing under risk aversion behavior. On the contrary, when the variance function is concave ($\frac{d^2V[\tilde{\pi}_i(x_i)]}{dx_i^{\,2}} < 0$) then risk aversion increases the abatement.

2. Insurance Program.

Proposition 1 indicates that risk averse farmers may use additional fertilizers as a self-insurance to minimize their exposure to risk. We examine the possibility to substitute it by an external insurance program aiming at reducing emission linked to risk aversion. First, farmers are free to subscribe to the insurance program by comparing their initial level of utility when they completely support risk to the utility associated with the insurance. Then, when they find that it is more interesting to participate in the insurance program, an indemnity is triggered only when the actual yield falls below a specific yield threshold noted τ (in % of the initial expected yield). When the realized yield is higher than this threshold, the farmer is not compensated. When loss occurs beyond this threshold the producer receives the yield shortfall valued at the crop price. In return, the farmer has to pay an insurance premium I in (euros/ha) whatever the amount of the realized yield. As we want to find the optimal nitrogen application amount, the expected utility maximization program under insurance participation can be written as:

$$\max_{\bar{x}_i}\{\mathrm{E}[u(\tilde{\pi}_i(\bar{x}_i) - I)]\} \quad (13)$$

s.t $x_i^* \geq \bar{x}_i > 0$

With $\bar{x}_i$ being the amount of nitrogen application under insurance. In a more detailed form eq.14 becomes :

$$\mathrm{E}[u(\tilde{\pi}_i(x\_ins) - I)] = \int_0^{\tau} g\left(\tilde{\pi}_i\big(\tilde{y}_i(x\_ins)\big)\right) u(\pi_i(\tau) - I)dy + \int_{\tau}^{+\infty} g\left(\tilde{\pi}_i\big(\tilde{y}_i(x\_ins)\big)\right) u(\pi_i(y) - I)dy \quad (14)$$

With $g(\tilde{y}_i)$ being the probability density function of a normal distribution. Participation in the insurance program occurs when $\mathrm{E}[u(\tilde{\pi}_i(x\_ins_i{}^*) - I)] > \mathrm{E}\big[u\big(\tilde{\pi}_i(x_i{}^*)\big)\big]$ and emissions reductions occur when the optimal $\bar{x}_i{}^*$ with insurance is lower than $x_{\mathrm{i}}{}^*$ maximizing the initial expected utility with no insurance. Appendix 8.5 illustrates 3 different cases of the impact of insurance on emission reductions.

4. Empirical Application

4.1. Data

The data used in this paper come from Epicles, a database compiled by InVivo-Agrosolution, a French farming cooperative. It comprises the fertilisation practices of farmers who are members of the cooperative, in particular the amount of nitrogen spread for each farmer, the amount prescribed by the cooperative, the resulting crop yield, the soil type and the preceding crop in the rotation. This information is available at the field level and is highly detailled in comparison to other data bases used in the literature[6].

We chose to restrict our attention to three departments (Deux-Sèvres, Seine-Maritime et Eure-et-Loir). Foremost this is because those departments are well represented in Epicles database and, also because, they represent a diversity of farming conditions. Deux-Sèvres department is mostly composed by livestock and cropping systems and is characterized by relative low yield, Seine-Maritime comprises also livestock and cropping systems, but with higher yields, and Eure-et-Loir which covers a part of the Beauce region, is mainly characterized by the presence of cropping farms with high yields and relatively low diversity in the crops composition. The Epicles database covers 22,5% of the Deux-Sèvres cereals land use, 10,7% of Seine-Maritime land use and 20,0 % of Eure-et-Loir land use.

[6] The European FADN (Farm accountancy Data Network) database, for instance, gathers data from representative farms of a given territory but not the data of all farms. Besides, it does not give information on the amount of fertilizers but the cost linked to fertilization.

We focus on 10 main crops : common wheat, oat, rape seed, durum wheat, fodder maize, grain maize, spring barley, winter barley, sunflower and triticale. We use data for four harvest campaigns (2010, 2011, 2012 and 2013) to assess the parameters of the yield and variance functions. We remove from the data set crop categories (characterized by a department location, a soil type, and a preceding crop type) whose number is inferior to 30. To isolate the effect of nitrogen on yield we do not examine plots having received any mineral element (K, S, G etc.) other than nitrogen. In addition, farmers who do not report their nitrogen application are also eliminated from the study. In some cases, the declaration is systematically the same as the amount advised by the cooperative or when the amount of nitrogen applied is 0. These cases are also left out. Finally, a total of 24 729 observations are used in the regressions (see table 1). The impact of a tax on GHG emissions and the implementation of an insurance program are assessed using the initial fertilisation levels of the 2013 campaign which represents 2 774 plots (appendix 8.6 gives a detailed overview of the different steps in the data base treatment).

Table 1 - Description of the sample used in the regression (step 2 of the data base treatment)

	Source	**Unit**	**Deux-Sèvres (79)**	**Seine-Maritime (76)**	**Eure-et-Loir (28)**	**Overall**
Number of observations	Epicles		16 007	4 691	4 031	24 729
Land Area (year 2013)	Epicles	ha	14 607	8 434	7 323	23 041
Number of Farms concerned	Epicles		1065	581	655	2 301
Average Chemical Fertilizer application for wheat (year : 2011)	Epicles	kg.ha-1	137	183	163	-
	Agreste Crop Survey (Agreste, 2014)	kg.ha-1	138	158	160	-
Average Yield for wheat (year : 2011)	Epicles	q/ha	68	85	79	-
	Agreste Crop Survey (Agreste, 2014)	q/ha	60	62	78	-

As Epicles reports only fertilisation and yield variables, economic parameters are taken from public databases. Prices are taken from the Eurostat database and correspond to the average price during the period 2007-2011. This average is supposed to represent the anticipated price by farmers on the basis of their value in the latter period. Fertilizer cost is based on a fertilizer price assumption of 1 €/kg (RICA and Agreste[7]). We suppose that fertilizer management cost relates to storage, transport and spreading is 2 €/kg (Agreste, 2011). To calculate π_0 in the CRRA hypothesis we include the CAP direct payment and fixed charges. Direct payment corresponds to the average subsidies found in the Agreste public data base and is specific to each department. The other public subsidies are considered negligible. Fixed charges are supposed to be 225 euros/ha following Agreste 2012. This cost represents a national average of instalment amortization, contract work and financing expenses.

4.2. Estimation methodology and functional forms

As we want to depict an exhaustive description of the possible links between fertilisation and yield, yields are regressed against fertilizer amounts for each crop category *i* characterized by a location within a department, a specific crop, a ground type and a specific preceding crop in the rotation. All in all, the 24 729 observations we have at our disposal before regression are classified into 213 crop categories. For each of these crop categories, inputs are allowed in the specifications to influence the mean but also the variability of crop yields. In the specification of the yield function, a quadratic functional form (eq. 15) was found to be the most adequate. We follow here Cerrato and Blackmer (1990) or Belanger et al. (2000). This functional form has the advantage of being easily implemented and can potentially takes into account the decrease of yield after achieving the maximum yield.

$$E[y_i(x_i)] = {\beta_1}_i + {\beta_2}_i x_i + {\beta_3}_i {x_i}^2 \quad (15)$$

Where β_1, β_2 and β_3 are parameters of the yield response function. If $\beta_2 + 2\beta_3 x_i < 0$, the marginal productivity of fertilizer is decreasing. Yield variance is determined by input use and is also specified by a quadratic function (eq. 2) for each crop.

$$V[y_i(x_i)] = {\rho_1}_i + {\rho_2}_i x_i + {\rho_3}_i {x_i}^2 \quad (16)$$

Where ρ_1 is the yield variation solely determined by weather and soil conditions. ρ_2 and ρ_3 quantify the influence of nitrogen on yield variation. Fertilizing is risk decreasing if $\rho_2 + 2\rho_3 x_i < 0$.

In order to estimate simultaneously the parameters of functions 15 and 16 feasible generalized least squares (FGLS) regression is applied following Finger and Schmid (2008) methodology[8].

[7] Data extracted for the year 2011 to 2014.

[8] The estimation is conducted with the MODEL procedure of the SAS statistical package (SAS INSTITUTE, 2012)

4.3. Estimation methodology for risk aversion

Risk aversion is estimated for each farmer g. As the data base treatment eliminates some fields per farm, we could not estimate robust aversion coefficient per farmer. Consequently, we used a pragmatic approach of calibration which consists in selecting the level of aversion k minimizing the distance between estimated fertilisation amounts x_i^* and observed fertilisation $x_{i_{obs}}$.

$$\min_{k_g} \left\{ \sum_i^n \left| x_{i_{obs}} - x_i^* \right| \right\} \tag{17}$$

In a more specified form, the minimization program can be also written as (see appendix 8.1 for a detailed demonstration):

$$\min_{k_f} \left\{ \sum_i^n \left| x_{i_{obs}} - \frac{k_f {p_i}^2 l_i \widehat{\rho_{2,\iota}} + w - \widehat{\beta_{2,\iota}} p_i}{(2\widehat{\beta_{3,\iota}} p_i - 2\widehat{\rho_{3,\iota}} k_j l_{j,i} {p_i}^2)} \right| \right\} \tag{18}$$

with $\widehat{\rho_{2,\iota}}$, $\widehat{\rho_{3,\iota}}$, $\widehat{\beta_{2,\iota}}$ and $\widehat{\beta_{3,\iota}}$ being the parameter estimates issued from the regression. This approach has the drawback of producing aversion coefficients which are not checked as significantly different from zero but has the advantage to depict a risk aversion distribution of farmers in the sample. Considering this limit, we also explore the impact of other risk aversion coefficients assessed in the economic literature on farmers. These are presented in the following table and will be uniformly implemented for all farmers for emissions tax and insurance simulations.

Table 2 – Aversion coefficient taken in the literature for sensitivity analysis

Scenarii	Aversion Coefficient	Type of aversion coefficient	Source
« CARA 1 »	Estimation	Absolute	Eq. 16
« CARA 2 »	Uniform* : 7,5.10-7	Absolute	Pope et al, 2011
« CARA 3 »	Uniform* : 0,0075	Absolute	Saha et al., 1994
« CARA 4 »	Uniform* : 0,04	Absolute	Brunette et al, 2015
« CRRA 2 »	Uniform* : 0,25	Relative	Lansink., 1999 “Value in the range [0,31-0,2]”
« CRRA 3 »	Uniform* : 1,12	Relative	Brunette et al, 2015
« CRRA 4 »	Uniform* : 5,4	Relative	Saha et al., 1994

* The same aversion coefficient for every farmer.

5. Results

5.1. Regression

We keep all of the estimates of the yield function (eq.15) and variance function (eq.16) associated with a p-value inferior to 5% and only in cases where heteroscedasticity is not detected[9]. Table presenting the exhaustive results of the parameter estimates per crop type is available upon request or through the link in the footnote[10]. Over the 213 different crop categories, 160 have been consistently estimated and 53 have not been estimated, either because of failure in the convergence of the model, simultaneous lack of significance in the parameter estimates or because of heteroscedasticity.

Table 3 presents a summary of the forms of the yield and variance functions derived from the parameter estimates. Over the 160 crop types whose functions have been successfully estimated, 97 of them follow a constant variance. For the others, the yield variance is influenced by nitrogen application. Within the latter category, the majority of crops have a linear decreasing variance function. Convex variance functions and concave variance functions come respectively second and third. From these results we observe that cases where there is risk-decreasing significance of fertilizer are relatively consistent and should not be neglected when assessing the emission tax impact.

[9] Using the White and Breusch-Pagan tests.

[10] The following link gives access to the table presenting the results of the regression : https://docs.google.com/spreadsheets/d/1qmaiz7boFxlZOJmesc7r9rDtYnIZ8hXJJMUpCzFLUSg/edit?usp=sharing

Table 3 – Forms of variance and yield functions detected from the regression

		Variance Function **(eq.16)**											
		Concave $\rho_2 > 0$ $\rho_3 < 0$		**Constant** $\rho_2 = 0$ $\rho_3 = 0$		**Convex** $\rho_3 > 0$		**Linear Increasing** $\rho_2 > 0$ $\rho_3 = 0$		**Linear Decreasing** $\rho_2 < 0$ $\rho_3 = 0$		**Total Types**	**Total Obs.**
		Types	**Obs.**	**Types**	**Obs.**	**Types**	**Obs.**	**Types**	**Obs.**	**Types**	**Obs.**		
Yield Function (eq.15)	**Concave** $\beta_3 < 0$	1	361	52	5 132	5[a,b]	1240[a,b]	2	505	28[a]	4 587[a]	88	11 825
	Constant $\beta_2 = 0$ $\beta_3 = 0$	1	121	27	2 756	2[a,b]	153[a,b]			12[a]	2 083[a]	42	5 113
	Convex $\beta_3 > 0$			1	294			1	54	5	371	7	719
	Linear Increasing $\beta_2 < 0$ $\beta_3 = 0$	1	147	17	1 824					5	396	23	2 367
	Total	**3**	**629**	**97**	**10 006**	**7**	**1 393**	**3**	**559**	**50**	**7 437**	**160**	**20 024**

Notes :

[a] Crop types where risk aversion implies additional nitrogen amounts application (see proposition 1)

[b] Crop types where risk aversion reduce the impact of emission price (see proposition 2)

5.2. Aversion

The validity of the different risk attitude hypotheses (see section 4.3) can be estimated by comparing the distance between actual and estimated nitrogen application per hectare (see the detailed results in appendix 8.7 for each scenario). In the CARA case, we observe that on average estimated nitrogen applications in 'CARA 1' scenario fit better actual observations than other scenarii : we find only a -6,9% difference on average per ha while other CARA scenario such as 'CARA 3' and 'CARA 4' broadly overestimate nitrogen application since the differences are respectively 93,2% and 473,4%; CARA 2 underestimates optimal applications by -11,7%. Regarding the CRRA case, we find that the best scenario is 'CRRA 2' since the difference is only -4,3% between estimated and actual observations. In addition, we decide to retain the 'CRRA 4' scenario, due to the good fit of nitrogen applications for risk averse farmers. Within this category, 'CRRA 4' provides the smallest difference of -20,5%.

Under the 'CARA 1' hypothesis, 29,7% of farmers are risk-averse (see table 4). This proportion is smaller than risk seeking farmers who represents 35,5% of the sample. Nevertheless the former set of farmers account for most of the emissions (49%) because, first, they are associated with a higher cultivated area and, second, they increase the amount of nitrogen application on crops presenting a decreasing variance with fertilisation (see proposition 1). When comparing the optimal amount of fertilizers under risk aversion behavior to risk neutral attitude we find that on average the surplus of fertilisation amount is 29,4 kgN/ha which represents an average expected profit loss of 75,8 euros per ha (see table 5). This surplus is particularly high on crop categories presenting a concave yield function with a linear decreasing risk, a convex variance function or on constant yield function with a linear decreasing variance. On these categories risk aversion is respectively associated with a surplus of nitrogen of 34.2 kgN/ha, 34,8 kgN/ha and 80,4 kgN/ha.

Table 4 – Representativity of risk attitude in term of farmers, land use and emissions (scenario CARA 1)

Risk atitudes	Farmers		Land Use		Emissions	
	Number	Share (%)	Land (ha)	Share (%)	tCO2eq	Share (%)
Risk Averse	204	29,7	5502	39	3 758	49,0
Risk Seeking	244	35,5	4908	34	1 973	25,7
Risk Neutral	73	10,6	1170	8	593	7,7
Undetermined	166	24,2	2670	19	1 354	17,6
Total	687	100	14250	100	7678	100

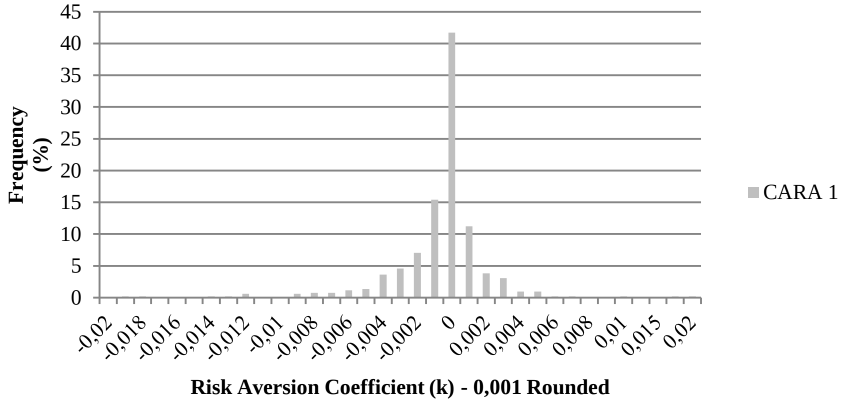


Figure 1 - Risk aversion distribution of farmers (including risk averse, risk seeking and risk neutral attitudes) - scenario CARA 1

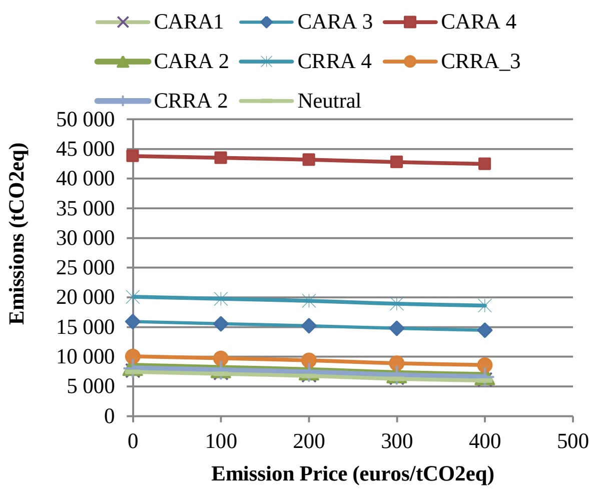
Table 5 - Impact of risk aversion on nitrogen application and expected profit (scenario "CARA 1")

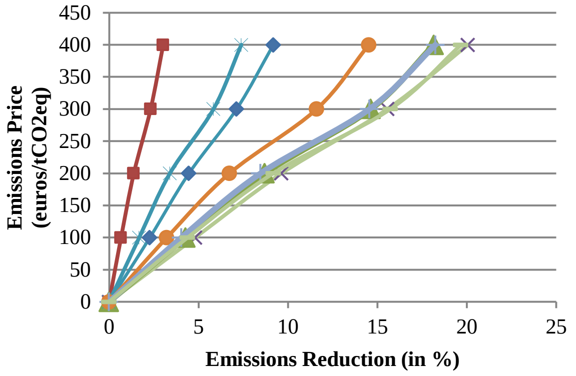
[a] Difference of profit between risk averse behavior and risk neutral behavior

Form of Expected Yield	Form of Variance function	**X***	**X* under risk neutral behavior**	**Nitrogen Application linked to risk aversion**	**Expected Profit**	**Expected Profit under risk neutral behavior**	**Loss linked to risk aversion[a]**
		kgN/ha	**kgN/ha**	**kgN/ha**	**euros/ha**	**euros/ha**	**euros/ha**
Concave	Constant	161	161,0	0,0	841	841	0,0
	Convexe	153	118,2	34,8	366	553,5	187,4
	LinInc	25	43,8	-18,3	691	752,4	61,5
	LinDecr	169	134,7	34,2	641	703,3	62,7
Constant	Constan LinDecr	80	0,0	80,4	577	818,4	241,1
Linear Inc.	Constant	109	109,1	0,0	1008	1007,9	0,1
	LinDecr	115	114,7	0,0	336	335,6	0,4
Overall		146	116,7	**29,4**	684	759,9	**75,8**

5.3. Impact of a price on N_2O emissions

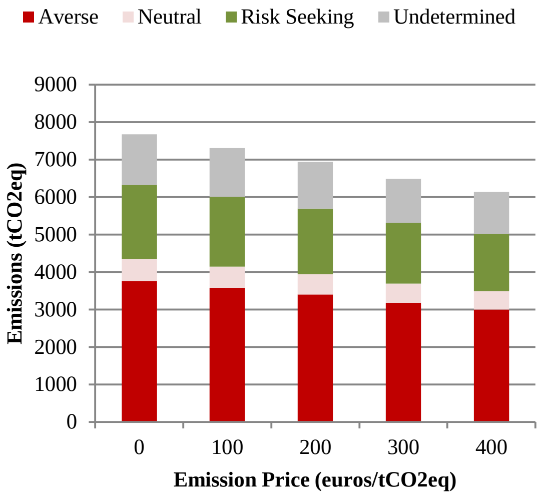
Results related to the impact of a price on GHG emissions are presented in figure 2. Figure 2-A shows the absolute emissions for all scenarii and figure 2-B the emissions reductions according to increasing tax on emissions. We observe that the price on emissions has to be quite high to trigger important emission reductions. Indeed, below 100 euros/tCO_2eq emission reduction are less than 5% in every scenarii. This relatively low impact is due to the low greenhouse gas intensity of fertilisation per hectare (around 0,05 to 0,65 tCO2eq/ha) which weakens the incentive created by the burden of emission tax. Notably, in every case, the emission price incentive is associated with emissions reductions but since risk aversion determines the initial amount of emissions the higher the risk aversion the weaker the abatement. As CARA 1 scenario integrates both risk averse and risk seeking behaviors a limited difference between trajectories exist with the 'Neutral' scenario. Additional emissions from risk averse farmers are compensated by lower emissions from risk seeking ones. Emissions reductions are associated with a slight decrease of yields mainly supported by the contribution of fertilisation reduction on rapeseed, common wheat and winter barley (figure 2-F). Focusing on emissions from risk averse individuals (figure 2-D), we observe that about 700 tCO_2eq (23% of emissions) are explained by risk aversion. This amount remains important as long as emission price increases, implying that, regardless of the emission price, aversion still explains a part of emissions. In figure 2-E, we observe the evolution of the economic burden of the emission price which represents 51 euros/ha for a emission price of 100 euros/tCO_2eq and which increases when emission price increases.

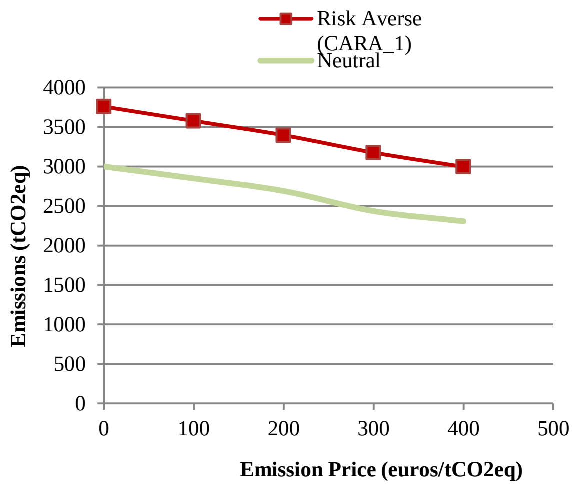




A. Evolution of emissions under different risk scenarii

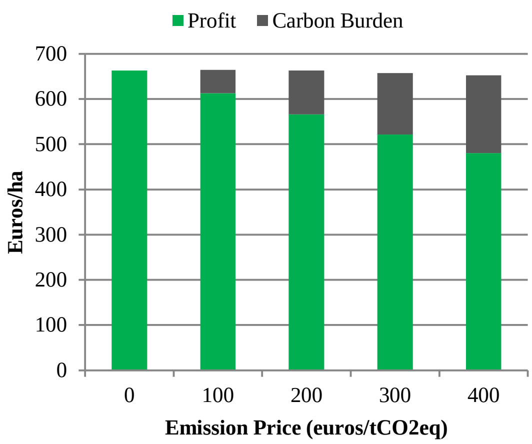
B. Marginal abatement cost curves under different risk scenarii

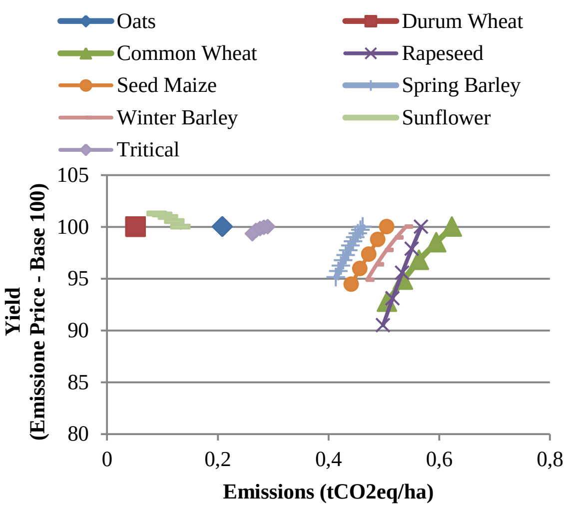




C. Evolution of emissions according to risk attitude (scenario CARA 1)

D. Impact of risk aversion of emissions (scenario CARA 1)





E. Economic Impact of Emissione Price (CARA 1)

F. Yield evolution according to emissions reduction (scenario CARA 1)

Figure 1 - Impact of a tax on emissions from fertilisation

5.4. Insurance

Table 6 presents the results of insurance according to different possibilities of trigger threshold τ and the different insurance premia in scenario CARA 1 (results on CRRA 4 scenario are exposed in appendix 8.9). The simulation for insurance is made only for risk averse farmers as CARA utility function is convex when the aversion coefficient is negative. In term of nitrogen application reduction, participant farmers are encouraged to act more like risk neutral individual. Emission reductions occur on crop types presenting a decreasing risk with nitrogen (see table 7). Consequently, nitrogen application is reduced to 12,9 to 37kN/ha which causes a reduction of 8,2% to 20,5% of risk averse individuals emissions. As expected, low insurance premiums and high trigger point τ involve higher participation to the insurance program. To achieve similar reductions on risk averse agents through emission price, tax has to achieve a range from 100 euros/tCO_2eq to 400 euros/tCO_2eq.

Table 6 - Impact of insurance on fertilizer application (in kgN/ha) and abatement (only on risk averse agents) – scenario CARA 1

				Insurance Trigger Threshold - τ (in percentage of the expected yield)		
				10%	50%	90%
Insurance Premium (euros/ha)	25	Abatement	%	11,5 %	15,2 %	20,5 %
		Fertilisation Reduction	kgN/ha	16,8	22,1	29,9
		Participants	%	100 %	100 %	100 %
		Participants making reductions	%	15%	37%	53%
		Expected profit	Euros/ha	727	738	799
	50	Abatement	%	11,5 %	15,2 %	20,5 %
		Fertilisation Reduction	kgN/ha	16,8	22,1	29,9
		Participants	%	100 %	100 %	100 %
		Participants making reductions	%	15 %	37 %	53 %
		Expected profit	Euros/ha	702	713	774
	400	Abatement	%	10,0 %	13,0 %	20,4 %
		Fertilisation Reduction	kgN/ha	14,6	19,0	29,7
		Participants	%	92 %	93 %	93 %
		Participants making reductions	%	12%	33%	53%
		Expected profit	Euros/ha	393	397	431
	600	Abatement	%	8,2 %	11,8 %	17,2 %
		Fertilisation Reduction	kgN/ha	12,0	17,2	25,1
		Participants	%	85 %	87 %	92 %
		Participants making reductions	%	10 %	30 %	47 %
		Expected profit	Euros/ha	260	255	279

Table 7 - Fertilisation reduction per type of crop (insurance premium 25 euros/ha and triggering threshold : 0,9)

		Fertilisation reduction (kgN/ha)
Form of expected Yield	**Variance function Form**	
Concave	**Constant**	0,0
	Convexe	-34,0
	Linear Increasing	0,0
	Linear Decreasing	-32,2
Constant	**Linear Decreasing**	-76,5
Linear Increasing	**Constant**	0,0
	Linear Increasing	-0,1

6. Discussion and conclusion

In this paper we investigate the role of risk aversion in nitrogen over-application, its potential impact on emission price incentive and the potential of an insurance system to mitigate GHG emissions from fertilisation. First, our results show that an important number of crop types present a risk decreasing relationship with nitrogen application. It generally results in additional fertilizers applied by risk averse individuals but does not represent a major obstacle to the impact of the emission price, as few yield variance have been revealed to be convex (see table 3). Our study further illustrates the value of insurance as an emission reduction tool. An interesting research opportunity to pursue would be to lead similar investigations to other mitigation measures.

We are in the framework of expected utility originally developed by von Neumann and Morgenstern (1947) which implies risk averse agents to favor, between two gains of equal expected income, the one with the lowest variability. This approach has some limitations highlighted, for instance, by Ingersoll (1987) who has given an example in which individuals prefer the situations in which variance is stronger. More recently, and in one case directly applied to agriculture, Tanaka, Camerer and Nguyen (2010) showed that the theory of expected utility does not fully represent the behavior of a panel of Vietnamese farmers. Some have found that prospect theory provides a more realistic representation of farmers surveyed (Kahneman and Tversky, 1979). The latter theory is echoed by Bocquého et al. (2014) who estimate the risk aversion of French farmers and have for main implication to make individuals more sensitive to losses as to gains and tend to make paying undue attention to unlikely extreme outcomes. Despite the aforementioned criticisms, however, expected utility theory, is relatively simple in its implementation and sufficient in explaining the contribution of additional doses of fertilizers compared to a situation where uncertainty is not taken into account. On this basis, its use is justified, but we take into account the other appropriate and divergent approaches in the literature.

Besides, we explore in this article risk aversion as a mean to explain the surplus of nitrogen application but in three scenarii (CARA 1, CARA 2, CRRA 2) we find that risk aversion does not fully explain all observed nitrogen amount (see appendix 8.7). This should attract our attention to additional reasons for over-application nitrogen found within other articles of the literature. For instance, these factors may include lack of trust in farm advisors or models (Stuart et al, 2014). The fact that we elicited here the links between fertilisation and yield variability for different crop types in 3 departments does not mean that crop yield will follow these relationships at each individual farm level. That lack of access to appropriate information or technological tools may inhibit the adoption of practices to increase nitrogen use efficiency. Moreover, recent private-sector developments in contracting have the potential to impact farming behavior as well. These contracts generally offer higher levels of profitability compared to commercial crops. Most seed contracts also have a competitive component: growers receive financial penalties or rewards based on how their production compares to other growers of the same variety (Dubois, 2006; Stuart et al, 2014). Consequently farmers concerned by contracts also act to achieve the optimal nitrogen to fit the best quality. All these elements, explain why a large share of farmers prioritizes yields above economic return (Stuart et al, 2013).

Moreover, our findings suggest that insurance, as it is made on a voluntary basis, would be preferable to a emission price. It is important to note however that, we only consider one option to mitigate emission. If other alternatives to mitigate emissions, like changing crop allocation, were represented in modelling, then we expect, from other results in the literature (De Cara and Jayet, 2011) that the abatement cost would be lower. Moreover, we implicitly assume that the insurance program is unaffected by the moral hazard effect. This effect is observed when farmers change their behavior when they know that a part of their risk is covered, thus potentially leading to some fraudulent, intentional losses. Among the conditions for the development of insurance, the insurer must be able to estimate accurately both expected frequency and severity of loss (Barnett et al., 1999). Current developments in insurance and farm advisement show that this latter point is bound to be improved. Pacifica insurance company initiated for instance in 2015 an insurance contract dedicated one grasslands implying surveillance by satellite to observe losses compared with a baseline built on an historical production data (Crédit Agricole Assurance – Airbus Défense & Space, 2015). Morevover, as farmers increasingly collect and report their economic gain and their production amount, used and shared with farm Cooperatives, this could constitute a lever to identify and control loss at the farm gate. Besides, if the implementation of insurance is conditioned by GHG mitigation, other techniques, involved in precision farming, can help to improve measurement like static chambers measuring gas fluxes between the soil ant the atmosphere (Collier et al., 2016) or organic emission assessment by drone teledetection (Gilliot et al, 2014).

Together, these findings highlight further avenues for research, which ought to be pursued in future works.

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8. Appendix

8.1. CARA (Constant absolute risk aversion)

Let consider one farmer having a certain initial profit π_0 and facing a risky wealth $\tilde{\pi}$. Under CARA attitude his utility function is defined as :

$$u(\tilde{\pi} + \pi_0) = -e^{-\alpha(\tilde{\pi}+\pi_0)}$$

With risky wealth $\tilde{\pi}$ corresponding to the sum of profit on its different crops:

$$\tilde{\pi} = \sum_{i=1}^{n} \tilde{\pi}_i$$

Consequently :

$$u(\tilde{\pi} + \pi_0) = -e^{-\alpha(\pi_0+\sum_{i=1}^{n}\tilde{\pi}_i)}$$

Since no covariance exists between crops, the yield distributions are independent. This assomption is consistent for instance with Polomé et al. (2006) study on acreage allocation under risk where no covariance was assumed between crop after examination of panels of yields. Then we can write:

$$u(\tilde{\pi}) = -e^{-\alpha\pi_0-\alpha\widetilde{\pi_1}-\alpha\widetilde{\pi_2}-\alpha\widetilde{\pi_3}-\ldots-\alpha\widetilde{\pi_n}}$$
$$u(\tilde{\pi}) = -e^{-\pi_0-\alpha\widetilde{\pi_1}}e^{-\alpha\widetilde{\pi_2}}e^{-\alpha\widetilde{\pi_3}} \times \ldots \times e^{-\alpha\widetilde{\pi_n}}$$

Profits between the different fields are independent. Consequently the optimum in one field is not influenced by the profit of another field. Besides, we know from the literature that the expected utility of CARA preferences can be represented by a mean-variance Markowitz form as follow (see for instance Cayatte, 2004 for demonstration):

$$E[u(\widetilde{\pi_i})] = E[\widetilde{\pi_i}] - \frac{\alpha}{2} V[\widetilde{\pi_i}]$$

Hypothese : $\widetilde{\pi_i} \rightarrow N\,(m,\,\sigma^2)$

$$E[u(\widetilde{\pi_i})] = E[\widetilde{\pi_i}] - \frac{\alpha}{2} V[\widetilde{\pi_i}]$$

Where expected profit follows:

$$E[\widetilde{\pi_i}] = l_i(E[\tilde{y}_i]P_i - x_iQ)$$

With :

l_i: area (ha)

y_i: yield (q.ha^{-1})

P_i: crop price (€.q^{-1})

x_i: fertilizer applied (kgN.ha^{-1})

Q: fertilizer price (€.kgN^{-1})

Expected yield is specified as quadratic:

$$E[y_i] = \beta_1 + \beta_2 x_i + \beta_3 {x_i}^2$$

Profit variance follows:

$$V[\tilde{\pi_i}] = V[l_i(\tilde{y}_i p_i - x_i w)]$$
$$= {l_i}^2 {P_i}^2 V[\tilde{y}_i]$$

Yield Variance is specified as quadratic as well:

$$V[y_i] = \rho_1 + \rho_2 x_i + \rho_3 {x_i}^2$$

The Expected Utility function can be written in the complete specified form as:

$$E[u(\tilde{\pi_i})] = l_i((\beta_1 + \beta_2 x_i + \beta_3 {x_i}^2)p_i - x_i w) - \frac{\alpha}{2} {l_i}^2 {p_i}^2 (\rho_1 + \rho_2 x_i + \rho_3 {x_i}^2)$$

The first order condition to find the optimal nitrogen application amount is:

$$\frac{dU_i}{dx_i} = 0$$

$$0 = l_i((\beta_2 + 2\beta_3 {x_i}^*)p_i - w) - \frac{\alpha}{2} {l_i}^2 {p_i}^2 (\rho_2 + 2\rho_3 {x_i}^*)$$

${x_i}^*$:

$$0 = l_i((\beta_2 + 2\beta_3 {x_i}^*)p_i - w) - \frac{\alpha}{2} {l_i}^2 {p_i}^2 (\rho_2 + 2\rho_3 {x_i}^*)$$

$$l_i((\beta_2 + 2\beta_3 {x_i}^*)p_i - w) = \frac{\alpha}{2} {l_i}^2 {p_i}^2 (\rho_2 + 2\rho_3 {x_i}^*)$$

$${x_i}^* = \frac{\frac{\alpha}{2} {p_i}^2 l_i \rho_2 + w - \beta_2 p_i}{(2\beta_3 p_i - 2\rho_3 \frac{\alpha}{2} l_i {p_i}^2)}$$

Consequently we observe that the optimal fertilizer amount is determined by the risk aversion coefficient. This finding is used in section 4.3 to determine risk aversion coefficients per farmer.

Let now study the impact of an emission price on the optimal amount of fertilizers:

- Expected utility with a tax on emissions:

$$U_i = l_i((\beta_1 + \beta_2 x_i + \beta_3 {x_i}^2)p_i - x_i w - x_i f t) - \frac{\alpha}{2}\ {l_i}^2 {p_i}^2 (\rho_1 + \rho_2 x_i + \rho_3 {x_i}^2)$$

  Where *t* is the emissions price and *f* the emission factor.

- The First order condition becomes:

$$\frac{dU_i}{dx_i} = l_i\big((\beta_2 + 2\beta_3 {x_i}^*)p_i - w - ft\big) - \frac{\alpha}{2}\ {l_i}^2 {p_i}^2 (\rho_2 + 2\rho_3 {x_i}^*) = 0$$

$${x_i}^* = \frac{\frac{\alpha}{2} {p_i}^2 l_i \rho_2 + w + ft - \beta_2 p_i}{(2\beta_3 P_i - 2\rho_3 \frac{\alpha}{2} l_i {P_i}^2)}$$

- The Second order condition being:

$$\frac{d{U_i}^2}{d^2 x_i} = 2 l_i \beta_3 p_i - \alpha {l_i}^2 {p_i}^2 \rho_3 < 0$$

- Impact of a emission price on fertilizer reduction:

$$\frac{d{x_i}^*}{dt} = \frac{f}{2\beta_3 p_i - 2\rho_3 \frac{\alpha}{2} l_i {p_i}^2} \iff \frac{d{x_i}^*}{dt} = \frac{l_i f}{\frac{d^2 E[\tilde{w}]}{d{x_i}^2} - k\,\frac{d^2 V[\widetilde{w_i}]}{d{x_i}^2}}$$

  If $\rho_3 \neq 0$ then the emission reduction will be influenced by the risk aversion coefficient.

8.2. CRRA (Constant relative risk aversion)

Let consider consider now the problem with a CRRA function :

$$u(\pi_0 + \tilde{\pi}) = \frac{(\pi_0 + \tilde{\pi})^{(1-r)}}{1-r}$$

With :

$u'(\tilde{\pi}+\pi_0) = (\pi_0 + \tilde{\pi})^{-r}$

$u''(\tilde{\pi} + \pi_0) = -r(\tilde{\pi} + \pi_0)^{-r-1}$

Where r is the relative risk aversion.

By definition the absolute risk aversion coefficient is :

$a = -\frac{u''(\tilde{\pi} + \pi_0)}{u'(\tilde{\pi} + \pi_0)}$

$a = \frac{r}{(\tilde{\pi} + \pi_0)}$

According to the Taylor series:

$u(2\pi_0 + \tilde{\varepsilon}) = u(2\pi_0) + \tilde{\varepsilon}u'(2\pi_0) + \frac{\tilde{\varepsilon}^2}{2}u''(2\pi_0)$

$E[u(2\pi_0 + \tilde{\varepsilon})] = u(2\pi_0) + u'(2\pi_0)E[\widetilde{\varepsilon}] + u''(2\pi_0)\ \frac{E[\tilde{\varepsilon}^2]}{2}$

With

$\tilde{\varepsilon} = \tilde{\pi} - \pi_0$

If we consider that $E[\tilde{\varepsilon}^2] \approx \mathrm{V}[\tilde{\varepsilon}]$, and no covariance then per field the first order condition is:

$$\frac{dU_i}{dx_i} = u'(2\pi_0)l_i\big((\beta_2 + 2\beta_3 x_i{}^*)p_i - w\big) + \frac{u''(2\pi_0)}{2}\ l_i{}^2 p_i{}^2(\rho_2 + 2\rho_3 x_i{}^*) = 0$$

Then $x_i{}^*$:

$$x_i{}^* = \frac{\frac{r}{4\pi_0}p_i{}^2 l_i \rho_2 + w - \beta_2 p_i}{(2\beta_3 p_i - \frac{r}{2\pi_0}l_i p_i{}^2 \rho_3)}$$

Impact of a price on emissions:

- The First order condition:

$$\frac{dU_i}{dx_i} = u'(2\pi_0)l_i\big((\beta_2 + 2\beta_3 x_i{}^*)p_i - w_i - ft\big) + \frac{u''(2\pi_0)}{2}\ l_i{}^2 p_i{}^2(\rho_2 + 2\rho_3 x_i{}^*) = 0$$

$$x_i{}^* = \frac{\frac{r}{4\pi_0}p_i{}^2 l_i \rho_2 + w + ft - \beta_2 p_i}{(2\beta_3 p_i - \frac{r}{2\pi_0}l_i p_i{}^2 \rho_3)}$$

- The Second order condition:

$$\frac{dU_i{}^2}{d^2 x_i} = 2l_i\beta_3 P_i - \frac{r}{2\pi_0}l_i{}^2 P_i{}^2 \rho_3 < 0$$

- Impact of a emission price on fertilizer reduction:

$$\frac{dx_i{}^*}{dC_p} = \frac{f}{2\beta_3 P_i\ - \rho_3 \frac{r}{2\pi_0} l_i P_i{}^2}$$

If $\rho_3 \neq 0$ then the emission reduction will be influenced by the risk aversion coefficient.

8.3. Illustration of rish aversion impact on fertilizer spreading

Legend :

$\frac{dE[\widetilde{\pi_i}(x_i)]}{dx_i}$

Optimal fertilizer amount for risk neutral farmers

$k\ \frac{dV[\widetilde{\pi_i}(x_i)]}{dx_i}$ with k>0

Optimal fertilizer amount for risk averse farmers (k>0)

$k\ \frac{dV[\widetilde{\pi_i}(x_i)]}{dx_i}$ with k<0

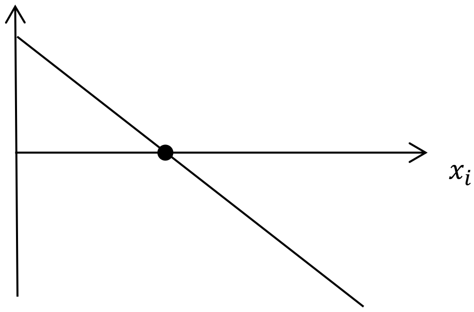
Optimal fertilizer amount for risk loving farmers (k<0)

Impact of risk aversion on fertilizer amount x_i

Profit function CONVAVE ($\frac{d^2E[\widetilde{\pi_\iota}(x_i)]}{dx_i^{\ 2}}$<0)

Constant

$$\frac{dV[\widetilde{\pi}_\iota(x_i)]}{dx_i} = 0$$

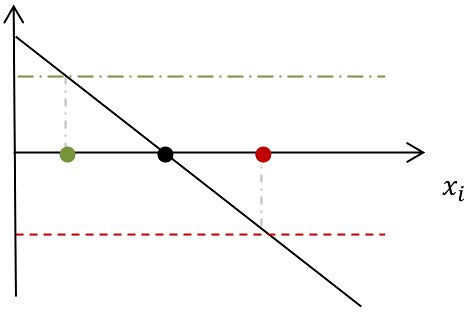


Risk aversion has no influence on optimal fertilizer amount

Linear Decreasing

$$\frac{dV[\widetilde{\pi}_\iota(x_i)]}{dx_i} < 0$$

$$\frac{d^2V[\widetilde{\pi}_\iota(x_i)]}{dx_i^{\ 2}} = 0$$

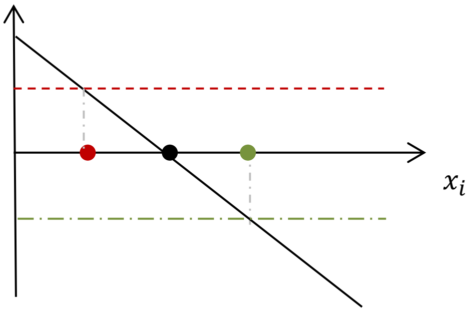


Risk aversion leads to an increase in fertilizer amount

Linear Increasing

$$\frac{dV[\widetilde{\pi}_\iota(x_i)]}{dx_i} > 0$$

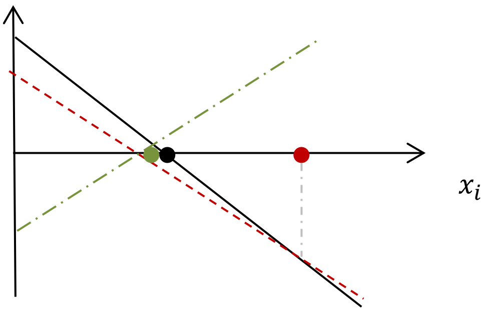
$$\frac{d^2V[\widetilde{\pi}_\iota(x_i)]}{dx_i^{\ 2}} = 0$$



Risk aversion leads to a decrease in fertilizer amount

Concave

$$\frac{d^2V[\widetilde{\pi}_\iota(x_i)]}{dx_i^{\ 2}} < 0$$

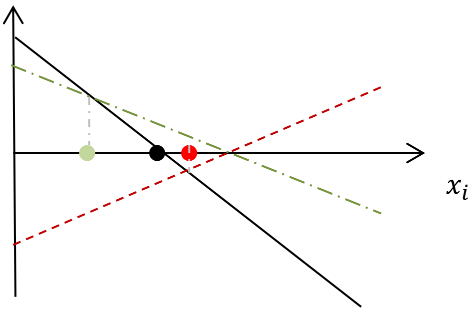


Risk aversion leads to an additional optimal fertilizer amount under 2 conditions :

- SOC has to be respected
- x leading to maximum variance < x leading to maximum expected profit

Convexe

$$\frac{d^2V[\widetilde{\pi}_\iota(x_i)]}{dx_i^{\ 2}} > 0$$



Risk aversion leads to an increase in fertilizer amount under the following condition :

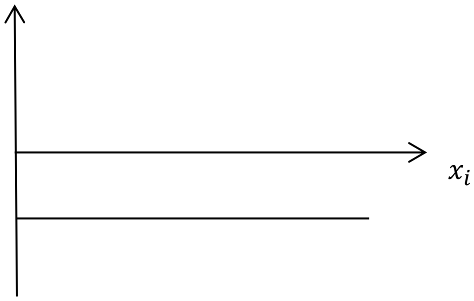
- x leading to minimum variance < x leading to maximum expected profit

Impact of risk aversion on fertilizer amount x_i

Profit function Linear Decreasing ($\frac{d^2E[\widetilde{\pi}_i(x_i)]}{dx_i^{\,2}}<0$)

Constant

$$\frac{dV[\widetilde{\pi}_i(x_i)]}{dx_i} = 0$$

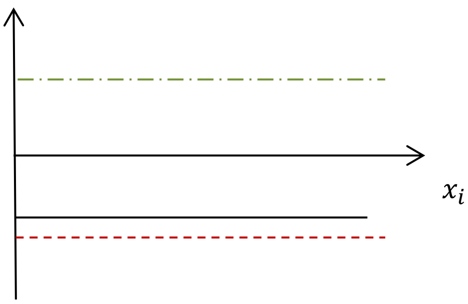


SOC not respected

Linear Decreasing

$$\frac{dV[\widetilde{\pi}_i(x_i)]}{dx_i} < 0$$

$$\frac{d^2V[\widetilde{\pi}_i(x_i)]}{dx_i^{\,2}} = 0$$

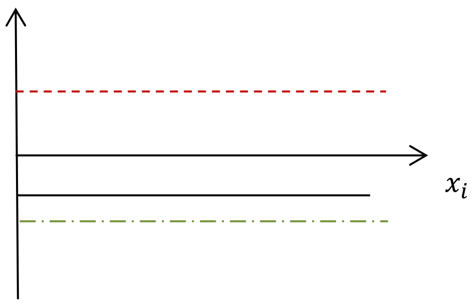


SOC not respected

Linear Increasing

$$\frac{dV[\widetilde{\pi}_i(x_i)]}{dx_i} > 0$$

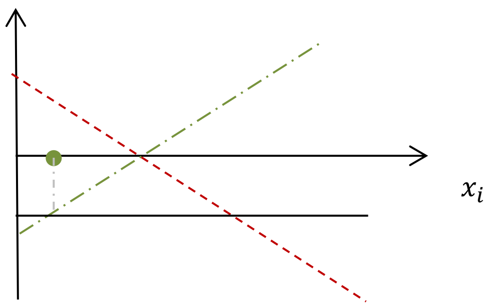
$$\frac{d^2V[\widetilde{\pi}_i(x_i)]}{dx_i^{\,2}} = 0$$



SOC not respected

Concave

$$\frac{d^2V[\widetilde{\pi}_i(x_i)]}{dx_i^{\,2}} < 0$$

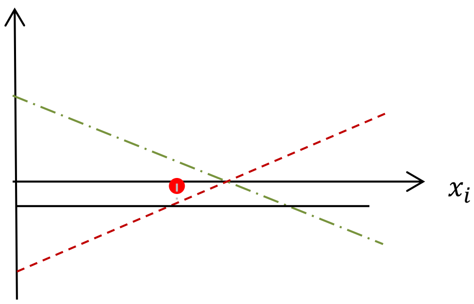


SOC is not respected for risk averse agents.

Risk loving preference leads to fertilisation.

Convexe

$$\frac{d^2V[\widetilde{\pi}_i(x_i)]}{dx_i^{\,2}} > 0$$



SOC is not respected for risk loving agents.

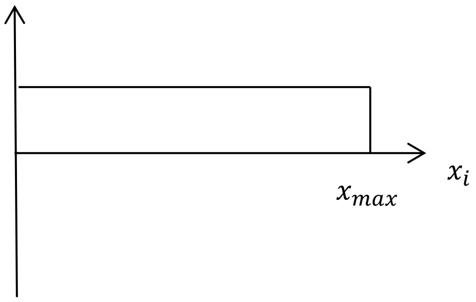
Risk avers preference leads to fertilisation.

Impact of risk aversion on fertilizer amount x_i

Profit function Linear Increasing ($\frac{d^2E[\widetilde{\pi_i}(x_i)]}{dx_i^{\,2}}$=0)

Constant

$$\frac{dV[\widetilde{\pi_i}(x_i)]}{dx_i} = 0$$

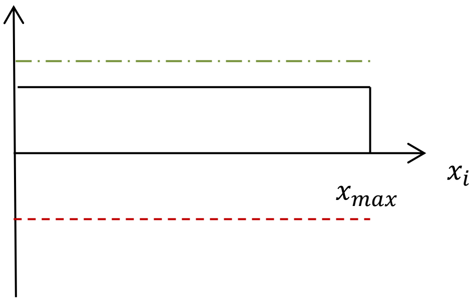


SOC not respected

Linear Decreasing

$$\frac{dV[\widetilde{\pi_i}(x_i)]}{dx_i} < 0$$

$$\frac{d^2V[\widetilde{\pi_i}(x_i)]}{dx_i^{\,2}} = 0$$

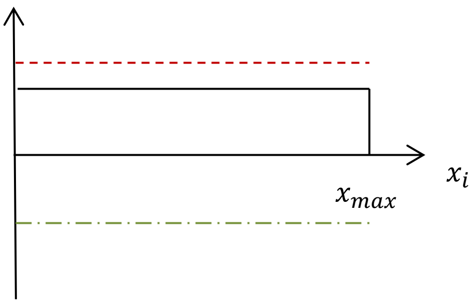


SOC not respected

Linear Increasing

$$\frac{dV[\widetilde{\pi_i}(x_i)]}{dx_i} > 0$$

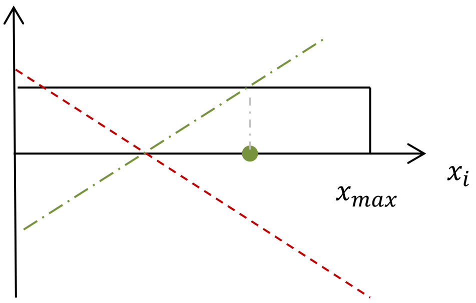
$$\frac{d^2V[\widetilde{\pi_i}(x_i)]}{dx_i^{\,2}} = 0$$



SOC not respected

Concave

$$\frac{d^2V[\widetilde{\pi_i}(x_i)]}{dx_i^{\,2}} < 0$$

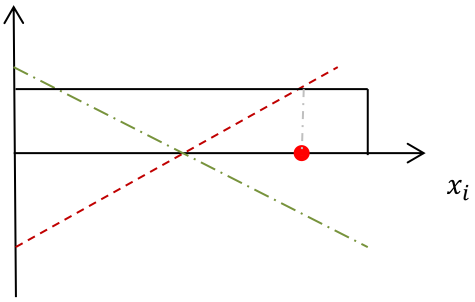


SOC is not respected for risk averse agents.

Risk loving preference leads to fertilisation.

Convexe

$$\frac{d^2V[\widetilde{\pi_i}(x_i)]}{dx_i^{\,2}} > 0$$



SOC is not respected for risk loving averse agents.

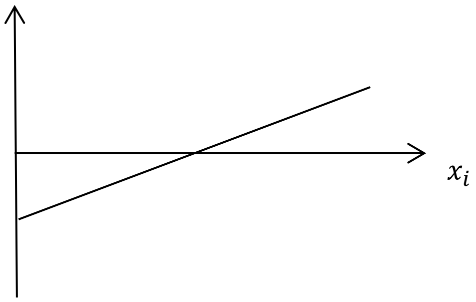
Risk avers preference leads to fertilisation.

Impact of risk aversion on fertilizer amount x_i

Profit function Convex ($\frac{d^2E[\widetilde{\pi_i}(x_i)]}{dx_i^{\,2}}$>0)

Constant

$$\frac{dV[\widetilde{\pi_\iota}(x_i)]}{dx_i} = 0$$

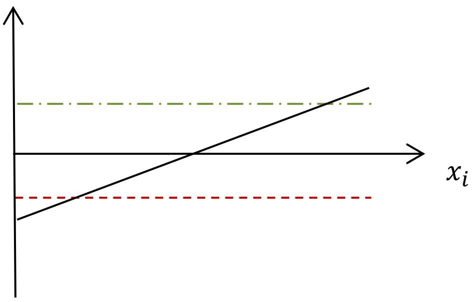


SOC not respected

Linear Decreasing

$$\frac{dV[\widetilde{\pi_\iota}(x_i)]}{dx_i} < 0$$

$$\frac{d^2V[\tilde{\pi}(x_i)]}{dx_i^{\,2}} = 0$$

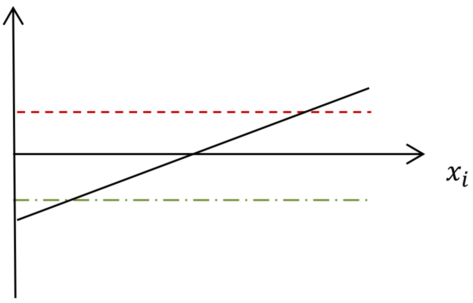


SOC not respected

Linear Increasing

$$\frac{dV[\widetilde{\pi_\iota}(x_i)]}{dx_i} > 0$$

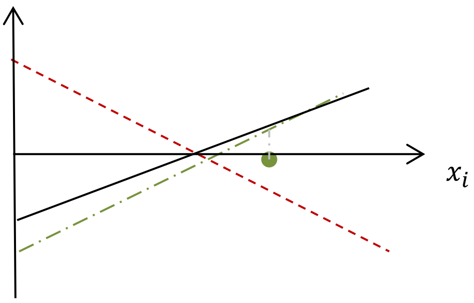
$$\frac{d^2V[\widetilde{\pi_\iota}(x_i)]}{dx_i^{\,2}} = 0$$



SOC not respected

Concave

$$\frac{d^2V[\widetilde{w_\iota}(x_i)]}{dx_i^{\,2}} < 0$$



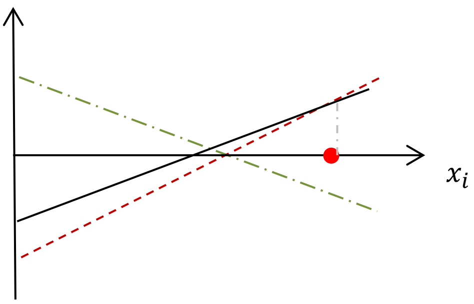
SOC is not respected for risk averse agents.

For risk loving preferences, the condition for solutions is:

$$\frac{d^2E[\widetilde{w}(x_i)]}{dx_i^{\,2}} < k\,\frac{d^2V[\widetilde{w_\iota}(x_i)]}{dx_i^{\,2}}$$

Convexe

$$\frac{d^2V[\widetilde{w_\iota}(x_i)]}{dx_i^{\,2}} > 0$$



SOC is not respected for risk loving agents.

For risk loving preferences, the condition for solutions is:

$$\frac{d^2E[\widetilde{w}(x_i)]}{dx_i^{\,2}} < k\,\frac{d^2V[\widetilde{w_\iota}(x_i)]}{dx_i^{\,2}}$$

8.4. Implicit function theorem

A. Impact of aversion on optimal fertilizer amount $x_i{}^*$

Let consider function (7):

$$f(x,k) = \frac{dE[\widetilde{\pi_\iota}(x_i{}^*)]}{dx_i} - k\ \frac{dV[\widetilde{\pi_\iota}(x_i{}^*)]}{dx_i} = 0$$

And a point $(x_i{}^*, k)$ which satisfies $f(x_i{}^*, k) = 0$ then according to the implicit function theorem :

$$\frac{\partial x_i^*}{\partial k} = -\frac{\frac{\partial f}{\partial k}}{\frac{\partial f}{\partial x_i^*}}$$

Or

$$\frac{\partial x_i^*}{\partial k} = \frac{\frac{dV[\widetilde{\pi_\iota}(x_i{}^*)]}{dx_i}}{\frac{d^2E[\widetilde{\pi_\iota}(x_i{}^*)]}{dx_i{}^2} - k\ \frac{d^2V[\widetilde{\pi_\iota}(x_i{}^*)]}{dx_i{}^2}}$$

B. Impact of aversion on emission tax incentive

Let consider function (7):

$$f(x,t) = \frac{dE[\widetilde{\pi_\iota}(x_i{}^*,t)]}{dx_i} - k\ \frac{dV[\widetilde{\pi_\iota}(x_i{}^*)]}{dx_i} = 0$$

And a point $(x_i{}^*, t)$ which satisfies $f(x_i{}^*, t) = 0$ then according to the implicit function theorem :

$$\frac{\partial x_i^*}{\partial t} = -\frac{\frac{\partial f}{\partial t}}{\frac{\partial f}{\partial x_i^*}}$$

Or

$$\frac{\partial x_i^*}{\partial t} = \frac{-\dfrac{\partial^2 E[\tilde{\pi}_i(x_i{}^*, t)]}{\partial t\, \partial x_i}}{\dfrac{\partial^2 E[\tilde{\pi}_i(x_i{}^*, t)]}{\partial x_i{}^2} - k\, \dfrac{\partial^2 V[\tilde{\pi}_i(x_i{}^*)]}{\partial x_i{}^2}}$$

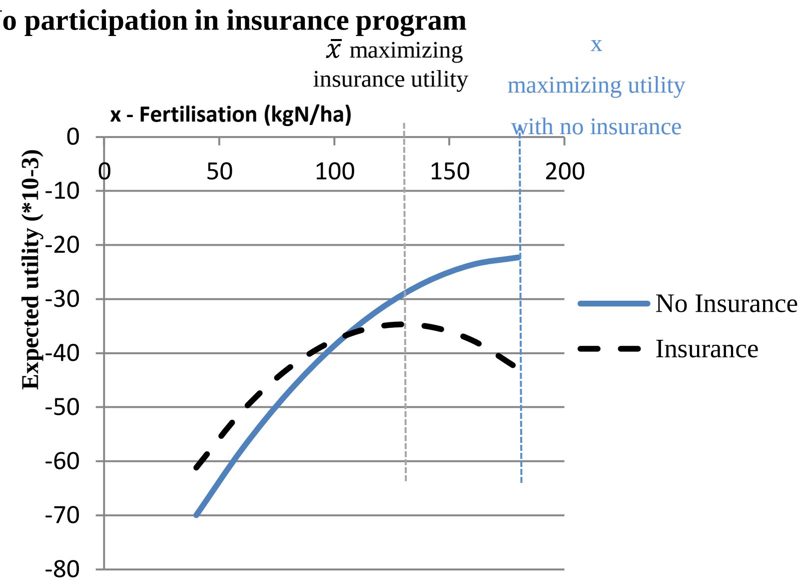
Or

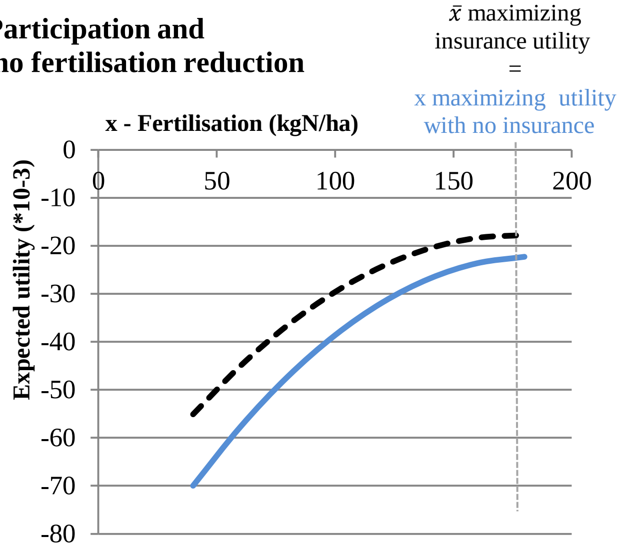
$$\frac{\partial x_i^*}{\partial t} = \frac{f l_i}{\dfrac{\partial^2 E[\tilde{\pi}_i(x_i{}^*, t)]}{\partial x_i{}^2} - k\, \dfrac{\partial^2 V[\tilde{\pi}_i(x_i{}^*)]}{\partial x_i{}^2}}$$

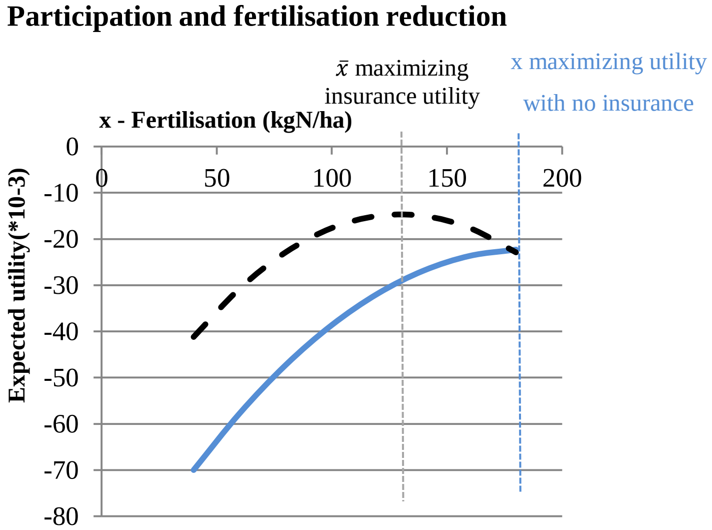
Then

$$\frac{\partial^2 x_i^*}{\partial t\, \partial k} = -f l_i\, \frac{d^2 V[\tilde{\pi}_i(x_i)]}{d x_i{}^2} * \left(\frac{d^2 E[\tilde{\pi}(x_i)]}{d x_i{}^2} - k\, \frac{d^2 V[\tilde{\pi}_i(x_i)]}{d x_i{}^2}\right)^{-2}$$

8.5. Illustration of the impact of insurance program on nitrogen amounts for one crop







8.6. Data base treatment

Step 1:
EPICLES
DATA BASE
(Period : 2010-2013)

6397 farms
(325 048 plots)

Principle : focusing on the main crop activities and deleting wrong nitrogen application declarations.

Removal of :

- plots corresponding to arboriculture and horticulture
- minor crops and grasslands
- wrong reporting (negative yield, farms with 0 fertilizers spread)
- crops having received K, P, G (so as to not biaise the regression)
- Removal of crops types representing less than 30 observations

Step 2:
REGRESSION
(Period : 2010-2013)

2301 farms
(24 729 plots)

Principle : obtaining a continuously balanced sample to estimation risk aversion coefficients.

Removal of :

- crops with no robust yield parameters
- plots corresponding to 2010 (for coherence between CARA and CRRA scenario as CRRA coefficient needs 2009 revenue)
- farms ending or starting activities during the period 2011-2013

Step 3:
AVERSION
ASSESSMENT
(Period : 2011-2013)

795 farms
(10 990 plots)

Principle : obtaining data to base simulations on 2013 year.

Removal of :

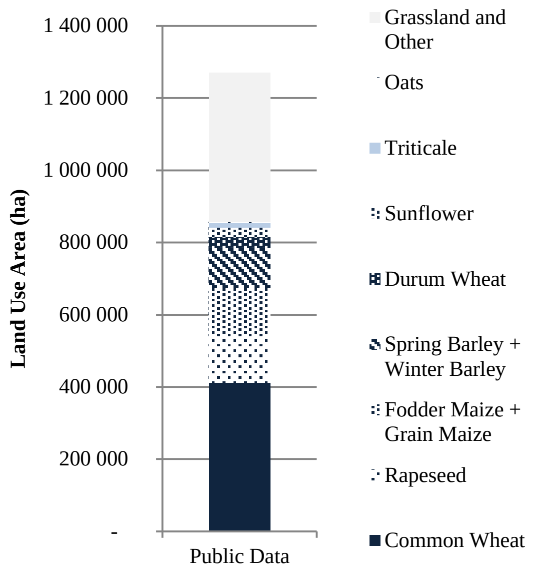
- crops corresponding to 2010-2012 period (simulations are made for 2013)
- crops where SOC is not respected (second derivative of utility >0)
- crops where x* is zero

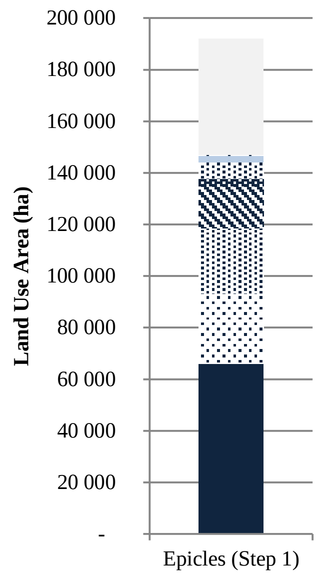
Step 4:
SIMULATIONS
(Period: 2013)

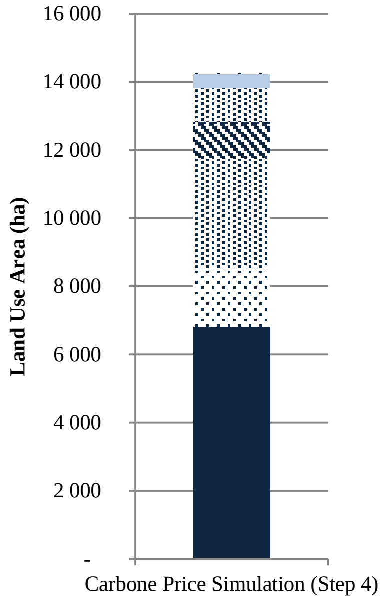
684 farms
(2774 plots)

- Emission Price
- Insurance : only for risk averse farmers (1053 plots - 204 farms)

Cropland Allocation in the three departments (year 2013)





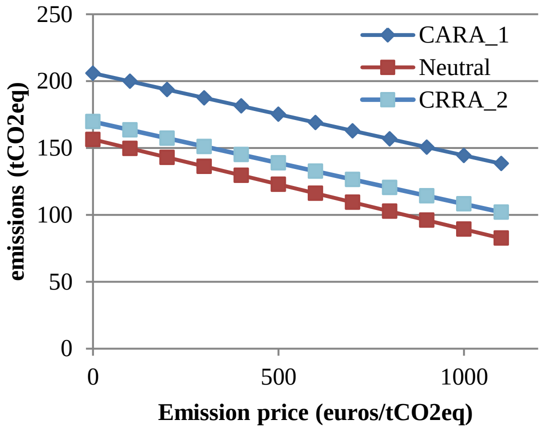


8.7. Accuracy of risk aversion scenario with observed emissions.

	Aversion Coefficient	**Type of aversion coefficient**	Risk Averse	Neutral	Risk Seeking	Undetermined	**All risk attitudes**
CARA 1	Distribution	Absolute	-7,0	-12,4	-6,9	1,3	**-6,9**
CARA 2	Uniform : 7,5.10-7	Absolute	-25,9	-12,4	10,3	1,3	**-11,7**
CARA 3	Uniform : 0,0075	Absolute	93,4	85,9	129,3	14,3	**93,2**
CARA 4	Uniform : 0,04	Absolute	528,3	459,5	565,3	15,3	**473,4**
CRRA 2	Uniform : 0,25	Relative	-25,7	-12,2	37,4	2,7	**-4,3**
CRRA 3	Uniform : 1,12	Relative	-24,9	-11,5	130,8	2,7	**20,6**
CRRA 4	Uniform : 5,4	Relative	-20,5	-5,5	589,9	5,8	**144,5**
Neutral	Uniform :0	Relative	-25,9	-12,4	10,3	1,3	**-11,7**

Average distance in % per ha between observed and estimated nitrogen application (The categorization of attitude toward risk is based on scenario CARA 1)

8.8. Impact of risk aversion on crops associated to convex variance functions



Emission reductions from risk averse farmers on crops having a convex variance function

	Slopes
	demissions / dEmissionprice
« CARA 1 »	-0,061
« CRRA 4 »	-0,062
« Neutral »	-0,067

Note : This figure is an illustration of proposition 2 which shows the impact of risk aversion on emissions reduction triggered by a tax on emissions. We focus here on crops having a convex variance function. We observe that the reduction rate is lower when considering risk aversion. Focusing on CARA 1 scenario, the reduction rate (-61 kgCO_2eq/dtax) is by 8% lower than the reduction rate (-67 kgCO_2eq/dtax) under Neutral behavior.

8.9. Insurance impact on emissions in the CRRA 4 scenario.

Emission Reduction for risk averse farmers in CRR4 4 scenario (in %)

		Insurance Trigger Threshold - τ (in percentage of the expected yield)		
		0,1	**0,5**	**0,9**
Insurance Premium (euros/ha)	**25**	- 3,4	- 5,0	-8,2
	50	- 3,3	- 5,0	- 8,2
	400	- 2,2	- 4,4	- 8,1
	600	- 2,1	- 3,9	- 8,0

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