Hail Insurance and Pesticide use in French agriculture: an empirical analysis of multiple risks management

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Abstract

This paper investigates the determinants of rapeseed hail insurance and pesticide use decisions using individual panel data set of French farms covering the period from 1993 to 2004. Economic theory suggests that insurance and prevention decisions are not independent due to risk reduction and/or moral hazard effects. Statistical tests show that the pesticide use and hail insurance demand are endogenous to each other. An econometric model involving two simultaneous equations with a mixed censored/continuous dependent variables is then estimated. Estimation results show that rapeseed insurance demand has a positive and significant effect on pesticide use and vice versa. Insurance demand is also positively influenced by the yield's coefficient of variation and the loss ratio, and negatively influenced by proxies for wealth (including CAP subsidies) and activity diversification.

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1 Introduction

In recent years, agricultural risk management has become a key issue of agricultural policy reforms. The context has indeed changed deeply. Price support policies[1], which provide farmers an economic safety net in addition to income support, tend to disappear under the pressure of world trade liberalization and environmental concerns, raising the issue of price risk management in a liberalized world (World Bank, 2005). At the same time, a substantial number of production risks due to climatic and phytosanitary hazards remain uninsurable without government support in favor of crop insurance (World Bank, 2005). Under free trade, production shocks are no longer compensated by rises in prices, a "natural hedge" of farmers' revenues that renders useless the need for crop insurance in autarky. The importance of climatic and phytosanitary risks as well as price volatility are thus calling for policy responses. The usual argument for risk policies in agriculture relies on the incompleteness of contingent claims markets that makes competitive markets inefficient in the short term. Such inefficiency provides a theoretical argument, in certain circumstances, for second-best Pareto improving government interventions that would mimic such absent contingent claims markets and restore the correct price incentives (Newbery and Stiglitz, 1981; Innes, 1990). In the long term, incomplete insurance and/or credit market lead to a too high, socially inefficient farm turnover, some viable agricultural firms being artificially unable to survive to temporary shocks (Kirwan, 2009).

Despite these well-founded theoretical justifications[2], the consensus is far too be reached about the true costs and benefits of government crop insurance programmes that take place in real world. Crop insurance markets are usually plagued by various kinds of market failures, making the distinction between welfare-enhancing and redistributive objectives particularly uneasy. Since in developed countries crop insurance programmes often involve substantial financial support from governments, this raises the issue of "disguised subsidies". In addition to being highly controversial in terms of their pure risk-sharing benefits, it is frequently pointed out that government risk management programmes (in particular crop insurance ones) may have adverse environmental consequences. In particular, they would incite farmers to produce more, on more degraded lands, by using higher levels of risk-increasing inputs such as fertilizers and selecting shorter crop rotations, the same crucial critics that were already addressed to the classical, price-support based, agricultural policies of the 70's-80's .

In the European Union, growing attention is also being paid to weather risks in agriculture in a context of profound reform of the Common Agricultural Policy (hereafter CAP). The European system differs from the U.S. one. Price risks used to be managed at the EU level through guaranteed prices while weather risks and crop insurance programmes, when they exist, are under the responsibility of Member States. Guaranteed prices have decreased due to CAP reforms and have been replaced by decoupled agricultural subsidies to support farm revenues, with an a priori ambiguous impact in terms of farmers' risk aversion (more risk due to less price protection but less risk aversion due to a wealth effect). This has lead Member States to assess the possibility of a crop insurance programme at the E.U. level. Enlarging the perimeter of mutualization for risks that are considered as systemic at the National scale has probably some economic sense, but the lessons from the costly U.S. experience certainly incite regulators to prudence.

This paper deals with multiple risks decision making in agriculture by investigating the determinants of rapeseed hail crop insurance and pesticides uses, using an individual panel data set of French farms covering the period from 1993 to 2004. We first propose a theoretical background, and then follow the reduced form approach and build an econometric model involving two simultaneous equations with a mixed censored/continuous dependent variables to account for potential endogeneity, which we estimate.

Related empirical literature.— The relation between production and insurance/hedging decisions is a central aspect of the welfare and redistributive impacts of crop insurance programmes. There is a large empirical literature on farmers' choices involving risk that intend to estimate how risk preference do indeed affect farmers' production and financial choices, and how these choices interact (Just, 2000; Just and Pope, 2003). Most papers concern the U.S. case, in part because several reforms of Federal risk management programmes have stimulated empirical research on this topic. Many papers focus on the relation between insurance and production choices, providing some empirical testing of the possible distorsive effects of risk management instruments (eventually magnified by public subsidies): Horowitz and Lichtenberg (1993) results suggest that crop insurance has encouraged pesticide and fertilizer input uses for corn producers in the U.S. Midwest. This contrasts with Smith and Baquet (1996), whose estimations show that

[1] through public storage in the European Union or Target Prices in the United States

[2] Such normative result must be qualified. Indeed, the welfare gains, eventually losses, from risk policies have been shown to be highly sensitive to changes in parameters, especially supply and demand elasticities (Newbery and Stiglitz (1981), Innes (1990)). More profound is the critics by Dixit, who considers that welfare gains coming from government interventions may be highly overestimated because classical models implicitly assume governments to be immune to the fundamental causes that make market collapse, such as moral hazard, adverse selection or imperfect observability

fertilizer and pesticide inputs for Kansas wheat producers tend to be negatively correlated with insurance purchases. Wu (1999) is the first to extend the analysis to acreage decisions as a risk diversification tool. In his estimation of the effect of crop insurance on crop acreage allocation and pesticide use in Central Nebraska Basins, he shows that crop insurance participation encourages producers to switch to crops in higher economic values. In a more recent paper, Goodwin et al. (2004) study the acreage effects of crop insurance using the samples of corn and soybeans production in the U.S. Corn Belt and wheat and barley production in Northern Great Plains. They estimate a simultaneous equation model to take into account a larger set of endogenous risk decisions of agricultural producers to simulate the possible effects of large premium changes. Their results suggest a relatively modest acreage responses to expanded insurance subsidies.

Some general conclusions can be drawn from the existing empirical literature. First, risk management choices are generally endogenous, suggesting possible substituability or complementarity between risk management instruments. Second, typical explanatory variables that may influence farmers' risk aversion such as yields' coefficients of variation, financial ratios (an imperfect measure of liquidity constraint), farmers' wealth, land ownership are most of the time statistically significant. This tends to support that risk do indeed matter in farmer's production decisions. Third, although statistically significant, some variables have in some cases a small quantitative effect (O'Donoghue et al., 2009), in other cases strong quantitative effects, suggesting prudence in drawing too general policy conclusions at the national scale. Fourth, most empirical studies[3], mainly based on U.S. data, did not lead to clear cut conclusions concerning the sign of the correlation between pesticide and insurance decisions[4], although the fact that both decisions are made *endogenously* are rarely challenged[5]. Since many producers' decisions involve risk considerations, it is difficult to build a theoretical model that would capture an exhaustive analysis of their interactions (Goodwin et al., 2004) and yield unambiguous results, even in a static model. The classical moral hazard framework does not include multiple sources of risks, adverse selection, price risk, which may be potential explanations of these contradictory results[6].

The current paper contributes to the existing literature in three ways. First, instead of relying on aggregated time-series or cross-section data as in most of previous studies, we use farm-level data. This is expected to provide us with a more precise description of individual decisions. Second, the current study uses panel data, which possess several advantages over conventional cross-sectional or time-series data sets, while exploiting genuinely observed regime transitions. At last, this paper contributes to the growing literature on the empirical analysis of risk management decisions in the case of France and other European countries (Koundouri et al., 2009; Mosnier et al., 2009).

This paper is organized as follows. In section 2 we present the empirical model followed by a description of the data and estimation results. We conclude in section 3 with a summary of our results and research perspective.

2 Empirical model

2.1 Econometric model

We now turn to the econometric model in order to examine hail insurance and pesticide use decisions. Our data set does not include insurance coverage itself but insurance expenses, for each crop. The usual way in the literature is to consider the demand for insurance as a binary variable identifying whether the farmer participates or not (Horowitz and Lichtenberg, 1993; Smith and Baquet, 1996; Wu, 1999). This is a limitation of these studies which focus on the decision of insurance purchase only and not take into account the level of coverage in the analysis. In spite of absent data, we choose to approximate the demand for insurance by the premium per unit area divided by the mean product per unit area, i.e. crop yield times crop price, calculated on the total years available. Such normalization by the mean product allows to eliminate the mechanical increase in premium coming from an increase in the value of the insured

[3]Another group of papers also deal with farmers' risk-taking decisions but differ in their econometric approach of the cited ones by building structural instead of reduced-form models. The advantage of such approach is to allow for simultaneous estimation of production technology parameters and risk preferences. Examples of papers fitting with this approach are Chavas and Holt (1996) and more recently and Koundouri et al. (2009) to evaluate the risk and wealth effects of agricultural policy changes towards decoupling in the European Union.

[4]Horowitz and Lichtenberg (1993) have found a positive correlation between crop insurance and chemical input use for corn producers in the U.S. Midwest. However, Smith and Goodwin (1996) demonstrated that fertilizer and chemical use for Kansas wheat producers tended to be negatively correlated with insurance purchases. Wu (1999) and Goodwin, et al. (2004) suggest no clear relationship between crop insurance demand and input use.

[5]Using Hausman-Wu test, Goodwin et al. (2004), Smith and Baquet (1996) and Wu (1999) have found that insurance, crop mix, and chemical use decisions are not exogenous and should be estimated using a simultaneous equations approach.

[6]Theory suggests that the demand for risk-reducing inputs should be lower for those who buy insurance than for those who do not buy because of a standard moral hazard effect. This moral hazard argument has been the cornerstone of empirical studies and discussions on the subject in the USA.

output in the case of a linear transaction cost function.

Our approach follows the empirical literature on crop insurance and production decisions, such as pesticide use (Horowitz and Lichtenberg, 1993; Smith and Baquet, 1996), cultivation practices (Goodwin et al., 2004) and cropping patterns (Wu, 1999). We thus fit into the simultaneous equation approach framework. To investigate the determinants of crop insurance demand under endogenous input use decision, we estimate our model using individual farm panel data covering the period from 1993 to 2004 instead of the usual cross sectional dataset. Our dataset allows us to capture individual farmers effects and also to follow the evolution of farmers' choices over a long period of time. Panel data, by taking into account the inter-individual differences and intra-individual dynamics have several advantages over cross-sectional or time-series data. In our case the two most important advantages are to have more accurate inference of model parameters and to control the impact of farmer's individual heterogeneity.

Following the empirical literature, we consider that the farmers' crop insurance and pesticide input use decisions are made jointly. Our econometric model thus corresponds to two simultaneous equations with a mixed censored/continuous dependant variables and panel data. The simultaneous equation system can be written as follows

$$\begin{aligned} I_{it}^* &= X_{1it}'\beta_1 + P_{it}\gamma_1 + w_{1it}, && (1) \\ P_{it} &= X_{2it}'\beta_2 + I_{it}^*\gamma_2 + w_{2it}, && (2) \end{aligned}$$

and the observed counterpart is:

$$I_{it} = \begin{cases} I_{it}^* & \text{if } I_{it}^* > 0, \\ 0 & \text{otherwise.} \end{cases}$$

where I_{it}^* is the latent variable for the farmer's i insurance demand at time t, I_{it} is the observed demand insurance for the farmer i, P_{it} is the pesticide input demand of farm i at time t, X_{1it}' and X_{2it}' are vectors of explanatory variables, $\beta_1, \gamma_1, \gamma_2, \beta_2$ are parameters to be estimated, w_{1it} and w_{2it} are error terms, $i = 1, ..., N$ indexes the farmers and $t = 1, ..., T$ indexes time period of observation. The error term w_{mit} $(m = 1, 2)$ is decomposed as

$$w_{mit} = \mu_{mi} + \varepsilon_{mit}, \qquad m = 1, 2, \quad i = 1, ...N, \quad t = 1, ...T, \tag{3}$$

where μ_{mi} is the individual effect for the farm i and the variable of decision m and ε_{mit} is an i.i.d. error term for equation m.

We make the following distributional assumptions:

$$\mu_{mi} \hookrightarrow N(0, \sigma_{\mu_m}^2), \;\; \varepsilon_{mit} \hookrightarrow N(0, \sigma_{\varepsilon_m}^2), \;\; E(\mu_{mi}\varepsilon_{mit}) = 0, \;\; \text{for all } \; m = 1, 2, ..., M$$

with

$$E(\mu_{mi}\mu_{kj}) = \begin{cases} \sigma_{\mu_{mk}} & \text{if} \quad i = j, \\ 0 & \text{otherwise,} \end{cases}$$

$$E(\varepsilon_{mit}\varepsilon_{kjs}) = \begin{cases} \sigma_{\varepsilon_{mk}} & \text{if} \quad i = j \quad \text{and} \quad t = s, \\ 0 & \text{otherwise,} \end{cases}$$

for all $m, k = 1, 2, \quad i, j = 1, ...N, \quad$ and $\quad t, s = 1, ...T$.

The model (1-2) has a mixed structure since it includes both a latent variable and its dichotomous realization. Procedures for estimating simultaneous equation models in which one or more equation contains limited dependent variable have been developed by Amemiya (1974), Amemiya (1979) and Nelson and Olson (1978). Nelson and Olson (1978) propose a simple two stage estimation procedure where endogenous variables are replaced by predicted values obtained at first stage by regression upon an instrument set. This two-step procedure has the advantage to give consistent estimates of the coefficients of the model, however Amemiya (1979) shows that this two-step procedure misrepresents the true variances of parameters. Bootstrapping methods were proposed in the literature to estimate consistently the parameters of the matrix of variance covariance.

Following the literature, we estimate our model by a two-stage procedure (Maddala, 1983)[7]. In order to obtain consistent estimates of the parameters of the variance-covariance matrices we use bootstrap methods proposed by Efron (1979) and Efron (1987). The bootstrapping approach consists in drawing with replacement a large number of pseudo-samples of size N (which correspond to the number of observations in the observed data). For each sample

[7] Our model corresponds to the model 2 in Maddala (1983).

the two-step procedure is applied in order to generate a distribution of consistently estimated parameters. Such an approach provides consistent variance-covariance parameter estimates that are robust to heteroscedasticity.

Since our sample consists of panel data, we have to choose between a random effect and a fixed effect specification. We assume a random effect model because the fixed effect specification suffers from the incidental parameters problem[8]. In the case of Tobit model, Greene (2004) shows that the incidental parameters problem causes a downward bias in the estimated standard deviations in the Tobit model specification. Such problem might lead to erroneous conclusions concerning the statistical significance of the variables used in the regressions.

The first step of the two-stage procedure consists in estimating the reduced form of the system (1-2) which can be written as follows:

$$I_{it}^* = X_{it}'\Pi_1 + \xi_{1it}, \quad (4)$$

$$P_{it} = X_{it}'\Pi_2 + \xi_{2it}, \quad (5)$$

where X_{it}' includes all the exogenous variables in X_{1it}' and X_{2it}'. This first step of the procedure provides us with estimates of the parameters Π_1, Π_2 as well as the matrix of variance covariance of individual effects and iid error terms. In our case, we estimate the equation in (4) by a random effect Tobit model and the equation in (5) by ML-RE model. In the second step, we estimate the equation (1) by RE-Tobit after substituting $\widehat{P_{it}}$ for P_{it} and the equation (2) by RE-ML after substituting $\widehat{I_{it}^*}$ for I_{it}^*. This two stage procedure gives consistent estimates of the model coefficients (Maddala, 1983), but the estimates of variance of the coefficients may be inconsistent because predicted values of the endogenous variables are used in the second stage of the estimation procedure.

Marginal effects.— Computation of elasticity measures requires calculation of marginal effects from the RE-Tobit model[9]. Given the censored nature of insurance demand equation different marginal effects can be computed for each explanatory variable. For each explanatory variable x_j, we have calculated at the mean of the sample, the three elasticities[10]:

1. Conditional elasticity: which measure for each explanatory variable the elasticity of the expected insurance demand given that the farmer holds an insurance contract.

$$Ela_{conditional} = \frac{\partial \ln E(I|I>,x=\bar{x})}{\partial \ln x_j} = \beta_j \frac{x_j}{E(I|I>,x=\bar{x})} \quad (6)$$

2. Probability elasticity: which measure for each explanatory variable the elasticity of the probability that a farmer holds an insurance contract.

$$Ela_{proba} = \frac{\partial \ln Pr(I>0|x=\bar{x})}{\partial \ln x_j} = \frac{\partial Pr(I>0|x=\bar{x})}{\partial x_j} \frac{x_j}{Pr(I>0)} \quad (7)$$

3. Unconditional elasticity: which measure for each explanatory variable the elasticity of the expected insurance demand

$$Ela_{unconditional} = \frac{\partial \ln E(I|x=\bar{x})}{\partial \ln x_j} = \beta_j \times Pr(I>0|x=\bar{x}) \frac{x_j}{E(I|x=\bar{x})} \quad (8)$$

As we have

$$E(I|x=\bar{x}) = Pr[I>0|x=\bar{x}] \times E[I|I>0,x=\bar{x}], \quad (9)$$

we can easily show that for each explanatory variable, the total elasticity is the sum of the probability elasticity and the conditional elasticity:

$$Ela_{unconditional} = Ela_{conditional} + Ela_{proba} \quad (10)$$

[8]The incidental parameters problem of the maximum likelihood estimator in the presence of fixed effects (MLE/FE) was first analyzed by Neyman and Scott (1948) in the context of the linear regression model.

[9]As proposed by Wooldridge (2002) the marginal effects were estimated by making the normalization of the individual-specific effects such as $E(\mu) = 0$.

[10]see Greene (2008).

2.2 Data description

The study is conducted on a sample of French farmers from the *Departement* of Meuse. Our data are provided by the Management Centre (*Centre de Gestion de la Meuse*). Our sample is an unbalanced panel observed between 1993 and 2004. One interesting feature of our database is that it contains detailed information for each crop on major inputs: fertilizers (N, P, K), pesticide inputs (herbicides, fungicides, insecticides, and growth regulators) and insurance.

As shown in table 1, approximately 88% of farmers in our sample hold a hail insurance contract. This proportion remained almost constant over the observation period 1993-2004, varying between a minimum of 81.90% in 1993 and a maximum of 91.25% in 2002.

Table 1: Farms who hold a hail insurance contract

Year	**Total number of farmers**	**% of farmers who hold hail insurance contract**
1993	442	81.90%
1994	432	83.56%
1995	450	85.33%
1996	451	85.36%
1997	483	87.78%
1998	489	88.34%
1999	487	90.14%
2000	481	89.39%
2001	459	89.10%
2002	446	91.25%
2003	392	89.79%
2004	161	89.44%
Total	5173	87.55%

Summary statistics presented in table 2 show that on average the farmers who hold a rapeseed hail insurance contract had less CAP subsidies than farmers without hail insurance contract. They are also more specialized in rapeseed production and have less animal production revenues (related to their total revenues).

2.2.1 Choice of explanatory variables

According to the literature, the demand for crop insurance and risk-reducing input could be influenced by farms' characteristics such as farm's diversification, wealth, and liquidity constraints. We hereafter construct some proxies for these variables as explanatory variables of insurance demand.

Diversification.— The degree of farm's diversification is expected to have a negative effect on insurance demand and pesticide use since it can be considered as a substitute to insurance as a risk management instrument. We consider two forms of farm diversification: *crop diversification* which refers to the classical rotation choice, and *activity diversification* which refers to the relative shares of crop activities taken as a whole with other sources of farms' revenues, i.e. livestock in our sample. Several index provide consistent measures of the degree of diversification, namely the Herfindahl index and Theil index of entropy. With two activities only, relative shares in the farm's total output constitute a simpler measure of diversification. Computation of these index revealed that they are indeed highly correlated. We thus choose to restrict to a single measure. Since we have only three crops and two activities (crop and livestock), we define crop diversification as the share of rapeseed in the total crop product (*scol_produit*) and activity diversification as the share of livestock in the total farm product (*sanim_produit*). Note that since livestock activity is assumed exogenous, the activity diversification index can also be interpreted as a wealth effect.

Wealth.— If farmers display decreasing absolute risk aversion, then wealthier farmers may perceive less of a need to insure. There is not any real consensus in the literature in building a proxy for wealth in similar studies (farms' net present values, size index such as land area). The following proxies for farmers' wealth are included.
Non-crop revenues. As livestock activities provide returns that are independent to crop ones, we can interpret the activity diversification index as a proxy for wealth in addition to a diversification one.
Farm size. Many studies in the literature include a measure of farm size as a proxy for wealth. It also captures

Table 2: Summary statistics

Variable	Definition	Insurance=0 Mean (std. dev.)	Insurance=1 Mean (std. dev.)
primassph_col	premium per unit area / mean yield	0	0.008
		(0)	(0.005)
col_pacph	CAP subsidies per ha	4.734	4.672
		(0.917)	(0.788)
sanim_produit	share of animal revenue	0.564	0.455
		(0.226)	(0.259)
scol_produit	share of rapeseed production	0.246	0.287
		(0.099)	(0.099)
loss_ratio	sum of indemnities / sum of premium	0.259	0.791
		(0.74)	(1.409)
ratio_liq	debts / assets	0.158	0.183
		(0.131)	(0.138)
ind_ferm	=1 if land renting	0.991	0.995
		(0.096)	(0.073)
puthf	percent of family labor	0.933	0.906
		(0.132)	(0.158)
cvrdt_col	CV of rapeseed yield	0.399	0.275
		(0.457)	(0.278)
col_laglnprix	log rapeseed lagged price	-3.166	-2.447
		(4.455)	(3.309)
sau	Total farm area	16593.073	19764.295
		(7645.564)	(9979.700)

the effect of economies of scale on the demand for insurance. We thus include the agricultural area (SAU[11]) as an explanatory variable.
CAP income support. Agricultural income support policies are also a major part of farmers' revenues, and can therefore be a strong component of the farmers' wealth effect. Hence CAP subsidies are also included as a proxy of farmers' wealth (*col_pacph*) as an explanatory variable.

Financial characteristics.— Financial characteristics of the farm such as debt and liquidity constraints are strongly expected to affect insurance and input choices through their impact on farmers' risk aversion. More liquidity constrained farmers would insure more ceteris paribus. We have built the three following ratios in order to capture such liquidity constraint: the total debt ratio, the land debt ratio and the liquidity ratio (*ratio_liq*). These three ratios are expected to have a positive effect on insurance and input uses. For the same liquidity constraint reason, farmers who rent land are expected to buy more insurance and use more pesticides because they are more leveraged (Wu, 1999). We thus include a rent index (*ind_ferm*).

Loss ratio.— The demand for insurance is expected to depend on the expected return from insurance (usually negative), which includes premiums and expected indemnities. To capture such factor, we use individual farmers' loss ratios (*loss_ratio*), a variable that is equal to the total indemnities divided by total insurance premiums for the available years. Since our panel is unbalanced, differences due to catastrophic events that arise some years can be a source of bias between farmers (Goodwin, 1993). However, excluding these years from our analysis would also create some bias and weaken the analysis so we kept all available years in our sample. Heterogeneity in loss ratios can be due to by asymmetric information if farmers are more informed that insurers about the distribution of their yield risk. Goodwin (1993), Just et al. (1999) and more recently Goodwin et al. (2004) provided empirical evidence of the importance of such factor on the incentive to insure in the U.S. agricultural context.

[11] Surface Agricole Utile in French.

Yield variation.— In order to catch the effect of crop risk on insurance and pesticides, we include as it is usually the case in the literature[12], the individual coefficient of variation of yield (*cvrdt_col*). Intuitively, a high coefficient of variation reflects a higher crop risk exposure, thus an incentive to get insured.

Labor composition.— Total labor includes hired labor and family labor. The composition of the total labor could give us an idea of the nature of farm management. We build an index, $puthf$, which is equal to the share of family labor in the total farm labor (Wu, 1999).

2.3 Estimation results

Are insurance demand and pesticide use endogenous? The Durbin-Wu-Hausman test.— To test the simultaneous equation specification adopted in our model, the Durbin-Wu-Hausman[13] test was performed to test the hypothesis that: (1) crop insurance decisions are exogenous to pesticide use and (2) pesticide use is exogenous to crop insurance decisions. Results of these tests are presented in table 3 and show that the exogeneity hypothesis is rejected for the variable pesticide input in the insurance demand equation and for the insurance demand in the pesticide input equation. These results suggest that there exist some unobservable factors that might influence both crop insurance demand and pesticide use. We therefore need to control for correlation between those unobservables and crop insurance demand and pesticide use which provides a strong reason for our simultaneous equation model.

Table 3: Durbin-Wu-Hausman test results

Null Hypothesis	DWH statistic	DF	Test result
crop insurance demand is exogenous to pesticide use	14.05	7	Rejected at 5% level of confidence
pesticide use is exogenous to crop insurance demand	19.43	9	Rejected at 2% level of confidence

Model estimation.— We estimate a simultaneous equation model of crop insurance demand and pesticide use for rapeseed using the two-stage procedure proposed by Nelson and Olson (1978) with a bootstrapping method to estimate consistent parameters of the variance-covariance matrices. Estimations are made on rapeseed only because this crop exhibits the higher coefficients of variation than wheat and barley.

The estimation results are presented in Table 4. Table 4 displays the insurance model as a function of our explanatory variables and the pesticide choice equation. As can be seen by inspecting the results the significant variances of individual random effects confirms the advantage of using panel data and modeling individual effects. We conclude that the classical regression model with one single constant term is inappropriate and that there exist in the data individual heterogeneity captured by individual random effects. The elasticities $Ela_{unconditional}$,$Ela_{conditional}$ and Ela_{proba} (equations 6-8) are computed at the means of all variables and are presented in Table 5. The significant variables in Table 4 also have significant marginal effects (elasticities) in Table 5.

Concerning the parameters estimates, a first important result is that the quantity of pesticides (*col_qphytophhat*) used by farmers increases with the demand for insurance (*primassph_col*). Moreover, the demand for insurance increases with pesticides. As we have noted earlier, the empirical literature provided no consensus on the sign and magnitude of the effects of insurance on pesticide use. Horowitz and Lichtenberg (1993) results suggest that crop insurance has encouraged the chemical input use for corn producers in the U.S. Midwest. However, Smith and Goodwin (1996) demonstrated that fertilizer and chemical use for Kansas wheat producers tended to be negatively correlated with insurance purchases. Wu (1999)) has focused on the effect of crop insurance on crop patterns and chemical use in Central Nebraska Basins. The results show that crop insurance participation encourages producers to switch the crops in higher economic values. Thus, the expected relationship between insurance participation and input use is unclear. The results of Goodwin, et al. (2004) suggest a relatively modest acreage responses to the increases in crop insurance participation.

Our estimation results concerning the effects of diversification on insurance demand are in line with our expectations. The variable *scol_produit*, which measure the share of rapeseed in total crop production has a positive and

[12] See for example Goodwin et al. (2004).

[13] The "Durbin-Wu-Hausman" (DWH) test is numerically equivalent to the standard "Hausman test" obtained using in which both forms of the model must be estimated. Under the null hypothesis, it is distributed Chi-squared with m degrees of freedom, where m is the number of regressors specified as endogenous in the original instrumental variables regression.

significant effect on insurance demand. This means that farmers that planted more rapeseed are less diversified and need more crop insurance protection. In the same way, the variable *sanim_produit* which measure the share of livestock activities in the farm revenue has a negative and significant effect on insurance demand. This confirm the fact that activity diversification reduce risk aversion and so insurance demand of farmers. Wu (1999) and O'Donoghue et al. (2009) find a statistically significant negative effect of crop diversification on crop insurance demand. Concerning activity diversification, Goodwin (1993) does not find a statistical negative relationship between the extent of diversification into livestock and the tendency to insure. Results concerning diversification must be interpreted with caution. Indeed, a negative correlation can be explained by a substitution effect between risk management tools, but a positive correlation, if arises, can be explained by heterogeneity in farmers' risk aversion: ceteris paribus, more risk averse farmers would diversify more, buy more insurance and use more risk-reducing inputs. Therefore, which of these effects dominates is likely to depend on the particular application and data set.

As expected, the CAP subsidies *col_pacph* have a negative and significant effect on the insurance demand, which can be interpreted as a wealth effect. The effect of direct payments on farmers' risk preferences has been recently estimated by Koundouri et al. (2009) using a structural model to estimate simultaneously risk preferences and technology parameters. Direct payments were shown to substantially decrease farmers' degrees of risk aversion.

Estimation results show that a higher yield coefficient of variation of rapeseed (*cvrdt_col*) appears to be positively and significantly correlated with greater demand for insurance. Such a positive relationship is conform to the intuition. However, the coefficient of variation is in part endogenous due to input uses (in particular pesticides) and crop diversification. For example, more risk averse farmers could insure more against hail risk while using more pesticides to reduce pest risk, and so exhibit a lower coefficient of variation of yield, calling for cautious interpretation.

The parameter estimate on the composition of total labor ($puthf$=family labor /professional labor) has a negative sign but is statistically insignificant at 10%. As expected, land ownership also affect farmers' insurance decisions ind_ferm. Farmers who rent land tend to exhibit a higher demand for insurance.

Another interesting but not surprising result is that higher loss ratio is significantly and positively correlated with greater demand for insurance. As discussed in Goodwin et al. (2004), the fact that both higher loss ratios and higher yield coefficients of variation are positively correlated with insurance demand suggest that the cost of insurance as well as size of the risk reduction do indeed matter in farmers' insurance decision. Finally, the parameter estimates of the liquidity ratio *ratio_liq* has the expected sign but is not significant.

Marginal effects.— We now compute elasticities to get some insight about the magnitudes of the relations between variables. The results are presented in Table 5. First, we note that this magnitude is quite small concerning the relation between insurance and pesticides: the probability to buy insurance increases by 0.026% when pesticide use increases by one percent. Unconditional elasticity, which sums up the probability to buy insurance with insurance demand when positive, is equal to 0.056 %. Such figures should be interpreted cautiously since they may be the result of several effects, some of them acting in opposite directions: the moral hazard effect, which predicts a negative relationship between insurance demand and pesticide use, and the risk reduction effect, which predicts a positive one. In the present region study, it seems however reasonable to think that the moral hazard effect is not very important in practice because of the presence of insurers' auditing concerning input uses. Moreover, the fact that the insured risk displays low geographical correlation at the departement level, the perceived probability of being audited by farmers may be sufficiently high to deter the moral hazard incentive. The positive, although quite modest, elasticity value of pesticide use and provides some support to the risk reduction effect of insurance.

Heterogeneity in farmers' risk aversion can also explain such positive correlation but is unobservable. In this case, a low value for elasticity could be explained by unobservable heterogeneity in pesticide productivity. Indeed, pesticides not only reduce risk but also increase expected yields. The latter motive may be predominant in farmers' pesticide use decisions, explaining low values of elasticities.

These elasticity results shed some light on the complex interaction between insurance and pesticide choices at the farm level. Although the estimated figures seem to be small, they may be the result of countervailing incentives and/or unobservable heterogeneity. Therefore making predictions about the consequences of crop insurance reforms in France on pesticide use should take these limits into consideration. During the period 1993-2004, available private insurance contracts protected against hail risk only. Other production risks such as drought were managed through the public fund FNGCA. Expanding the number of risks insured by private insurance contracts would give farmers more freedom to choose their combination of risk management tools at the farm level. This may increase the magnitude of the relation between insurance demand and pesticides.

We now discuss the other factors affecting insurance demand. Classifying them with respect to the value of the probability elasticity and unconditional elasticity in decreasing order, we get 1. the rent index, 2. the yield's coefficient

Table 4: Rapeseed insurance demand and Rapeseed pesticide use

	primassph_col
col_qphytophhat	0.00344***
	(5.34)
col_pacph	-0.000211*
	(-2.04)
sanim_produit	-0.00312***
	(-4.13)
scol_produit	0.00218*
	(2.32)
loss_ratio	0.000664**
	(2.96)
ratio_liq	-0.000857
	(-0.93)
ind_ferm	0.00360***
	(3.67)
puthf	-0.000660
	(-1.31)
cvrdt_col	0.00838***
	(6.49)
_cons	-0.00348
	(-1.74)
sigma_u	0.00811***
	(12.08)
sigma_e	0.00317***
	(22.85)
$(N \times T)$	5127

t statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

	col_qphytoph
primassph_colhat	4.850*
	(2.00)
col_laglnprix	0.0105***
	(5.27)
sau	0.00000445***
	(5.03)
ann3	-0.296***
	(-15.74)
ann4	-0.129***
	(-7.99)
ann5	0.0220
	(1.25)
ann6	-0.0638***
	(-4.07)
ann11	0.108***
	(4.55)
_cons	1.575***
	(66.19)
$(N \times T)$	5127

t statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

of variation, 3. CAP subsidies per ha, 4. activity diversification and 5. the loss ratio.

The values of elasticities for the yield's coefficient of variation (*cvrdt_col*, 0.117 and 0.255) confirms the role of farmers' heterogeneity in risk exposure on insurance demand. The other explanatory variables have interesting consequences for agricultural policy. First, CAP subsidies (*col_pacph*) have a negative but quite small impact on the probability to insure (-0.088), but a rather high one on total insurance demand (-0.192). This suggests that the wealth effect due to farmers' income support plays a non-negligible role in reducing the consequences of income shocks due to weather events. If such income support decreases due to forthcoming CAP reforms, farmers of our sample would be more disposed to increase their demand for risk-management tools such as insurance against weather events. Estimated elasticities for activity diversification (*sanim_produit*) have the same order of magnitude than these for CAP subsidies (-0.074 and -0.161), suggesting that income diversification is also a substantial substitute for crop insurance in our region study.

Estimated elasticities for loss ratios (*loss_ratio*), considered as a proxy for the cost of insurance, are rather small (0.023 and 0.049 respectively). This suggests that a crop insurance policy based on premium subsidies should not lead to strong changes in insurance demand against hail risk. These results are in line with previous studies in the United States. In this country, only large levels of premium subsidies allowed to increase the rate of penetration of insurance at the national scale. Moreover, in many cases expected indemnities are higher than premiums, rendering insurance contracts valuable even for risk-neutral producers. The situation is quite different in France, where hail insurance is a "mature" market, with a large rate of penetration rate and decades of existence without any government subsidy (the average loss ratio of our sample is 0.791). Hence it is not so surprising that the impact of a change in the cost of insurance has modest effects on insurance demand. Intuitively, such impact could be more substantial for multiple peril crop insurance contracts, introduced through a public-private partnership in France in 2005, since they provide coverage against an extended set of risks, some of them displaying strong spatial correlation, hence higher premiums. From a theoretical perspective, literature shows that a risk-averse individual[14] always buys insurance against a low

[14]In fact, any individual having preferences that display the second-order stochastic dominance property.

probability-high loss event if he buys insurance for any other risk having the same expected loss. This suggests that crop insurance contracts extended to low frequency risks (typically drought) would always be bought by farmers who already have a hail insurance contract under identical transaction costs. However several factors are susceptible to curb insurance demand for this extended set of risks. First, these risks may not only differ in their distribution but also in their transaction costs. Insurance premiums are more difficult to calculate for less frequency risks, and spatial correlation as well as ambiguity may imply premium overloading by insurers. Second, there is substantial empirical evidence that shows individuals are reluctant to buy insurance against low probability events, or even do not consider at all risks under a certain probability threshold. At last, the insurance decision requires processing information and learning, so emerging insurance contracts may require a time lag for adaptation.

Table 5: Marginal effects: elasticities at the sample mean

x_j	$\frac{\partial \ln E(I\|x=\bar{x})}{\partial \ln x_j}$	$\frac{\partial \ln E(I\|I>0,x=\bar{x})}{\partial \ln x_j}$	$\frac{\partial \ln P(I>0\|x=\bar{x})}{\partial \ln x_j}$
col_qphytophhat	0.056**	0.030**	0.026**
	(2.36)	(2.35)	(2.36)
col_pacph	-0.192***	-0.104***	-0.088***
	(-5.77)	(-5.76)	(-5.67)
sanim_produit	-0.161***	-0.087***	-0.074***
	(-4.40)	(-4.43)	(-4.32)
scol_produit	-0.023	-0.012	-0.010
	(-0.84)	(-0.84)	(-0.84)
loss_ratio	0.049***	0.026***	0.023***
	(3.75)	(3.76)	(3.71)
ratio_liq	0.004	0.002	0.002
	(0.35)	(0.35)	(0.35)
ind_ferm	0.305**	0.164**	0.140**
	(2.29)	(2.29)	(2.29)
puthf	-0.079	-0.043	-0.037
	(-1.49)	(-1.49)	(-1.49)
cvrdt_col	0.255***	0.138***	0.117***
	(13.34)	(13.75)	(11.81)

t statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

3 Conclusion and discussion

This paper investigates the determinants of hail insurance and pesticide use decisions using an individual panel dataset of French farms covering the period 1993-2004. Statistical tests show that the pesticide use and insurance demand are endogenous to each other. An econometric model involving two simultaneous equations with a mixed censored/continuous dependent variables is then estimated.

The results of our estimation are twofold. First, it is confirmed that insurance demand has a positive effect on pesticide use and vice versa, providing empirical support for the interdependence of technical choices and insurance decisions. However, it is also shown that the magnitude of this relation, measured by elasticities, is quite small. Several explanations are proposed for this result: the presence of countervailing incentive effects of insurance (risk reduction and moral hazard), the ambiguous role of risk-decreasing inputs on the variance of yield, or the preponderance of the expected profit motive versus the risk-reducing one in pesticide use decisions by farmers. From an environmental policy perspective, this suggests that reforms aiming at facilitating the access to insurance against an expanded set of risks or reducing the cost of insurance may have positive but modest effects on pesticides use. With monoperil hail insurance contracts, moral hazard temptations concerning the use of pesticides may be more easy to control than for multiperil crop insurance contracts, for two reasons. The first one is that estimating the relative impact of pest and climate shocks on the final yield may be more difficult when multiple climate shocks enters the insurance contract. Another problem associated with multiple peril insurance contracts is that increasing the number of covered peril could possibly increase correlation across individual claims, thus lower the probability of audit.

Second, the analysis of the explanatory factors of insurance demand confirm theoretical predictions and have interesting consequences for agricultural policy analysis. CAP subsidies have been shown to have a statistically significative and negative influence on insurance demand, and in turn on pesticide use. This is in line with the assumption that farmers' preferences are characterized by decreasing absolute risk aversion, confirming results of several other studies in France and abroad. From an agricultural policy perspective, this suggests that decrease in CAP subsidies would increase the farmers' propensities to pay for risk management instruments, underlying the need for an integrated approach between income support and risk management policies in this sector. Activity diversification has also a statistically significant and negative influence on insurance demand, which confirms the assumption that whole-farm diversification is a substitute to insurance and risk-reducing inputs. More surprising is the fact that crop diversification is not statistically significant. This suggests that diversification is more an issue at the whole-farm level than at the crop acreage level. This points out interesting questions in terms of environmental policy in the agricultural sector. Indeed, our results suggest that encouraging crop rotations against monoculture would have no statistically significant impact on the intensity of pesticide use per hectare. Crop rotations thus may be chosen for other reasons than risk. They can be more profitable in expectation due to positive external effects between crops that follow each other, or be the result of other constraints such as soil qualities, which are not included in our data set. Our results show that farmers with riskier yields tend to buy more insurance, which is in line with theoretical predictions. The loss ratio, has a significant effect but of small magnitude on insurance demand, suggesting a low price elasticity of demand for insurance. Crop insurance premium subsidies could thus have small impacts on insurance demand. However, it should be noted that the insurance contracts that are analyzed in the present study are not the same than those that are actually subsidized in France, which cover multiple risks. Finally, we have shown that financial ratios are not statistically significant, which is also surprising.

Future challenges.— The results of this study could be enhanced and continued in several ways.

First, we do not consider price risk in our analysis. This is clearly a shortcut since theory suggests that production and insurance decisions are distorted when prices risk is introduced. Moreover, the CAP reforms of the 90's and beginning of 2000's significantly decreased price floors for major crops in the European Union, leading to a potential increase of real or perceived price risk for farmers. However, futures and forward markets were also available in France during the period covered by our sample, allowing farmers to transfer price risks to financial markets and so significantly reduce the importance of price risk. Unfortunately, farmers' positions on futures and forward markets are not available in our database, preventing us to include price hedging decisions in our analysis.

Second, our data concerning phytosanitary products are aggregate expenses, which include a set of specific inputs targeted to different sources of risks (moisture, etc.). It is possible that some producers are more exposed to some specific risks that are more costly to self-insure than others. We have assumed a continuous relation between the quantity of pesticides used (measured by the expenses) and the magnitude of loss reduction. In reality, the timing of application may be also determinant, so equal applied quantities with different fractioning can lead to different results in terms of loss reduction, but these actions are not observable. Phytosanitary (as well as fertilizer) decisions have in fact a dynamic nature, which can include observation and learning by the producer. Such ingredients would suggest a more subtle theoretical framework but is out of the scope of this paper.

Third, it would be interesting to build a structural model that would allow joint estimation of technology and preferences. This requires to deepen the theoretical analysis of the joint demand for insurance and pesticides with two independent risks. This would allow us to confirm our results concerning the shape of farmers' preferences as well as making useful comparisons with results obtained elsewhere, in particular Mosnier et al. (2009) in the French case.

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