The adoption of innovative cropping systems under price and production risks: a dynamic model of crop rotation choice

Aude Ridier, Karim Chaib, Caroline Roussy

Working Papers SMART - LERECO

The adoption of innovative cropping systems under price and production risks: a dynamic model of crop rotation choice

Aude RIDIER, Karim CHAIB, Caroline ROUSSY

Working Paper SMART – LERECO N°12-07

October 2012

UMR INRA-Agrocampus Ouest **SMART** (Structures et Marchés Agricoles, Ressources et Territoires)
UR INRA **LERECO** (Laboratoires d'Etudes et de Recherches en Economie)

Les Working Papers SMART-LERECO ont pour vocation de diffuser les recherches conduites au sein des unités SMART et LERECO dans une forme préliminaire permettant la discussion et avant publication définitive. Selon les cas, il s'agit de travaux qui ont été acceptés ou ont déjà fait l'objet d'une présentation lors d'une conférence scientifique nationale ou internationale, qui ont été soumis pour publication dans une revue académique à comité de lecture, ou encore qui constituent un chapitre d'ouvrage académique. Bien que non revus par les pairs, chaque working paper a fait l'objet d'une relecture interne par un des scientifiques de SMART ou du LERECO et par l'un des deux éditeurs de la série. Les Working Papers SMART-LERECO n'engagent cependant que leurs auteurs.

The SMART-LERECO Working Papers are meant to promote discussion by disseminating the research of the SMART and LERECO members in a preliminary form and before their final publication. They may be papers which have been accepted or already presented in a national or international scientific conference, articles which have been submitted to a peer-reviewed academic journal, or chapters of an academic book. While not peer-reviewed, each of them has been read over by one of the scientists of SMART or LERECO and by one of the two editors of the series. However, the views expressed in the SMART-LERECO Working Papers are solely those of their authors.

The adoption of innovative cropping systems under price and production risks: a dynamic model of crop rotation choice

Aude RIDIER

Agrocampus Ouest, UMR1302 SMART, F-35000 Rennes, France

INRA, UMR1302 SMART, F-35000 Rennes, France

Karim CHAIB

EI Purpan, Université de Toulouse, F-31000 Toulouse, France

Caroline ROUSSY

INRA, UMR1248 AGIR, F-31000 Castanet-Tolosan, France

Acknowledgements

The authors are grateful to the MIC MAC French ANR Systerra project for the funding of this research. They also want to thank the extension services of the Midi-Pyrénées MAESTRIA project and the farmers who participated in the experiments.

Auteur pour la correspondance / Corresponding author

Aude RIDIER
INRA, UMR SMART
4 allée Adolphe Bobierre, CS 61103
35011 Rennes cedex, France
Email: aude.ridier@agrocampus-ouest.fr
Téléphone / Phone: +33 (0)2 23 48 56 92
Fax: +33 (0)2 23 48 53 80

The adoption of innovative cropping systems under price and production risks: a dynamic model of crop rotation choice

Abstract

We investigate the role played by both production and market risks on farmers' decision to adopt long rotations considered as innovative cropping systems. We build a multi-period dynamic farm model which arbitrates each year between conventional and innovative rotations. With discrete stochastic programming, the production risk is accounted for as an intra-year risk, yearly farming operations being declined according to a decision tree where probabilities are assigned. The simulations for a sample of 13 farmers who are currently experimenting this innovation in south-western France, show that substantive sunk costs act as incentives to remain in the long rotation when the farmer is supported for his engagement. They also show that both a high risk aversion and a highly positive market trend tend to slow down the conversion towards innovative systems.

Keywords: innovative cropping systems, dynamic model, crop rotation decision, risk, subjective probabilities

JEL classifications: C61, D0, Q12, Q55

Adoption de systèmes de culture innovants en situation de risque de production et de marché : un modèle dynamique de choix de rotation

Résumé

Cet article analyse le rôle du risque de production et de marché sur la décision d'agriculteurs d'adopter des rotations longues considérées comme des systèmes de culture innovants. Nous proposons un modèle multi-périodique dynamique qui met en concurrence chaque année des rotations classiques avec des rotations innovantes. La programmation stochastique discrète permet de prendre en compte le risque de production intra-annuel, les opérations culturales pouvant être ajustées au fil de l'année suivant un arbre de décision. Les simulations pour un échantillon de 13 agriculteurs qui expérimentent ces nouvelles rotations dans le sud-ouest de la France montrent que des coûts irrécupérables liés à l'adoption de l'innovation incitent à rester dans la rotation longue quand celle-ci bénéficie d'un soutien public. Elles montrent aussi qu'une aversion au risque élevée et une tendance positive sur les prix ralentissent la conversion vers des systèmes innovants.

Mots-clefs : systèmes de culture innovants, modèle dynamique, décision de rotation, risque, probabilités subjectives

Classifications JEL : C61, D0, Q12, Q55

The adoption of innovative cropping systems under price and production risks: a dynamic model of crop rotation choice

1. Introduction

French agronomic research teams, jointly with farm extension services and groups of farmers, seek to build up and spread among crop farmers new cropping systems enabling to decrease the polluting pressure at farm level (to diminish water, nitrogen and pesticide consumption). In many areas, farmers feel ready to change their practices, because they face more often decreasing soil fertility or disease-resistance problems due to intensive use of chemical inputs. Innovative Cropping Systems (ICSs) consisting in long rotations (up to seven years) enable to introduce intermediary crops with low level of inputs (legumes or nitrogen-catching crops), while farming practices are slightly rearranged (replacing chemical treatments by mechanical operations or delaying the sowing date for instance). Different cropping systems of that sort have been built up inside two research and development projects in the Midi-Pyrénées region, south-western France. They aim at diminishing the average input usage over the coming years thanks to long rotation strategies. These ICSs are tested ‘in the field’ by several volunteer farmers participating in those projects.

The adoption of ICSs inside the existing crop acreage is perceived by farmers as risk increasing because of the uncertainty about the expected yield of the new practices ‘in the field’ in the presence of climatic risk. This yield risk perception is also due to the lack of knowledge and experience on the new crop systems. Also, the current instability characterizing the grain market price trends could have a negative impact on the adoption of innovations and on investment in general[1].

In this paper, we propose to study the adoption of a long rotation as an alternative to the conventional wheat-sunflower short rotation (without irrigation in both cases), in a context of production and market risk. Agronomists have used an integrated method of prototyping in order to install such cropping systems in interaction with real farms, following in this way the approach suggested by Vereijken (1997) and implemented in other extension networks in France[2]. We analyze the innovation adoption within the expected utility framework. We model

[1] Even if crop diversification can mitigate market risk when price distributions of the different crops are negatively correlated, the current trend of increasing and unstable prices seems favorable to very short term acreage adaptation, together with the keeping of specialized crop acreage in the most profitable crops.

[2] Such networks are called ‘systèmes de culture innovants’.

farmer's adjustment behaviour when facing both production and market risks during the multiyear rotation, accounting for both intra-year and inter-year risks.

The modelling of farm rotation choices is still subject to intensive research (see for instance Hennessy, 2007 or Carpentier *et al.*, 2011). The issue of farm acreage decision and farm rotation revision under risk is also connected with the literature on the adoption of innovations. Some approaches of farm innovation are based on historical experimental data which enable to assess the level of risk linked to different cropping systems and to compare them according to the distribution of risks (Stanger *et al.*, 2008, Chavas *et al.*, 2009, Acs *et al.*, 2009). These static approaches require an access to historical data about the innovative systems. This is not possible in our case-study since we consider the very starting point of the innovation experience with no real past data.

Bio-economic modelling approaches can overcome the absence of historical data. In the approach proposed by Blazy *et al.* (2010), a banana farm model is built which simulates both the biophysical and technico-economic processes of resource management under different scenarios of adoption of innovations concerning pest reduction. The model combines a cropping system and a farming system which calculates the performance of the output of the cropping system at farm level. This mechanistic farm model enables to test the impact of different technical innovations but it does not allow to consider the issue of adoption in an economic or risk-management perspective. Doole and Pannell (2008) propose to test the value of incorporating pasture inside land-use rotations using an integrated bio-economic model combining a deterministic simulation model of plant and seed growth with an economic optimization tool (compressed annealing). Other dynamic approaches enable to account for revising decisions during the innovation process and focus on the role of information in such decisions using Bayesian learning rules (Abadi Ghadim and Pannell, 1999) or option value approaches (Isik *et al.*, 2001).

In order to conduct an *ex-ante* study of the adoption of ICSs, with few historical data, we propose to build a Discrete Stochastic Programming (DSP) model (Trebeck and Hardaker, 2001; Apland and Hauer, 1993) which maximizes the expected utility. We assume that, in order to adopt the ICSs in an uncertain context, the farmer needs technical flexibility. Technical flexibility means, for the farmer, the possibility to revise his technical decisions when the economic or climatic context is changing. In order to assess this flexibility, we build a sequential decision model. The decision variable is the annual acreage, considering the preceding crop. The sequence of intra-year technical operations is entirely depicted, each year, through a decision tree. A level of risk is associated to the different branches corresponding to different sequences of technical operations. Also, a list of possible rotations over several years is identified, considering the innovative rotation as the initial goal, and identifying the different possible revisions along the years. Giving up a rotation and therefore its objective, *i.e.*, revising the initial rotation, implies sunk costs for the farmer since investments (machineries, knowledge) have been made to enter the innovation process (Barenklau and Knapp, 2007; Marra *et al.*, 2003; Chavas, 1994).

The decision to revise the acreage is influenced by both perceived production risks and anticipated price risk. Subjective probability judgments are directly assessed with a sample of farmers using a visual impact method to evaluate the level of production risk perceived (Hardaker *et al.*, 2004). The specification of price anticipations is an assumption made in the model; it is not directly estimated. Risk preferences are obtained through a direct elicitation method.

In the next section of the paper, we expose the dynamic model and the main assumptions on farmers' beliefs and preferences. In the third section, we briefly explain how we obtained the farm data and the farmers' behavioural parameters used to test the model. These data come from three kinds of sources: regional reference data on production costs, experts' interviews to detail the intra-year farm operations and their possible revisions and field experiments to assess farmers' perceptions and preferences[3]. In the fourth section, we present the results of several simulations performed with the model, testing the adoption of ICSs under a set of incentives, and analyzing the role played by the degree of risk aversion and different market price trends.

2 The model of crop rotation choice

The decision variable is the crop sown in year *t* considering the preceding crop chosen in year *t*–1. The crop chosen in year *t* is characterized by a technical pattern, *i.e.*, a set of technical operations carried out all along the year. Different sets are possible, depending on the frequency and intensity of pest treatments and nitrogen applications. Different rotations and rotation lengths are also possible for farmers. The objective of the model is to maximize the present value of the farm gross margin's expected utility on the planning horizon which lasts seven years.

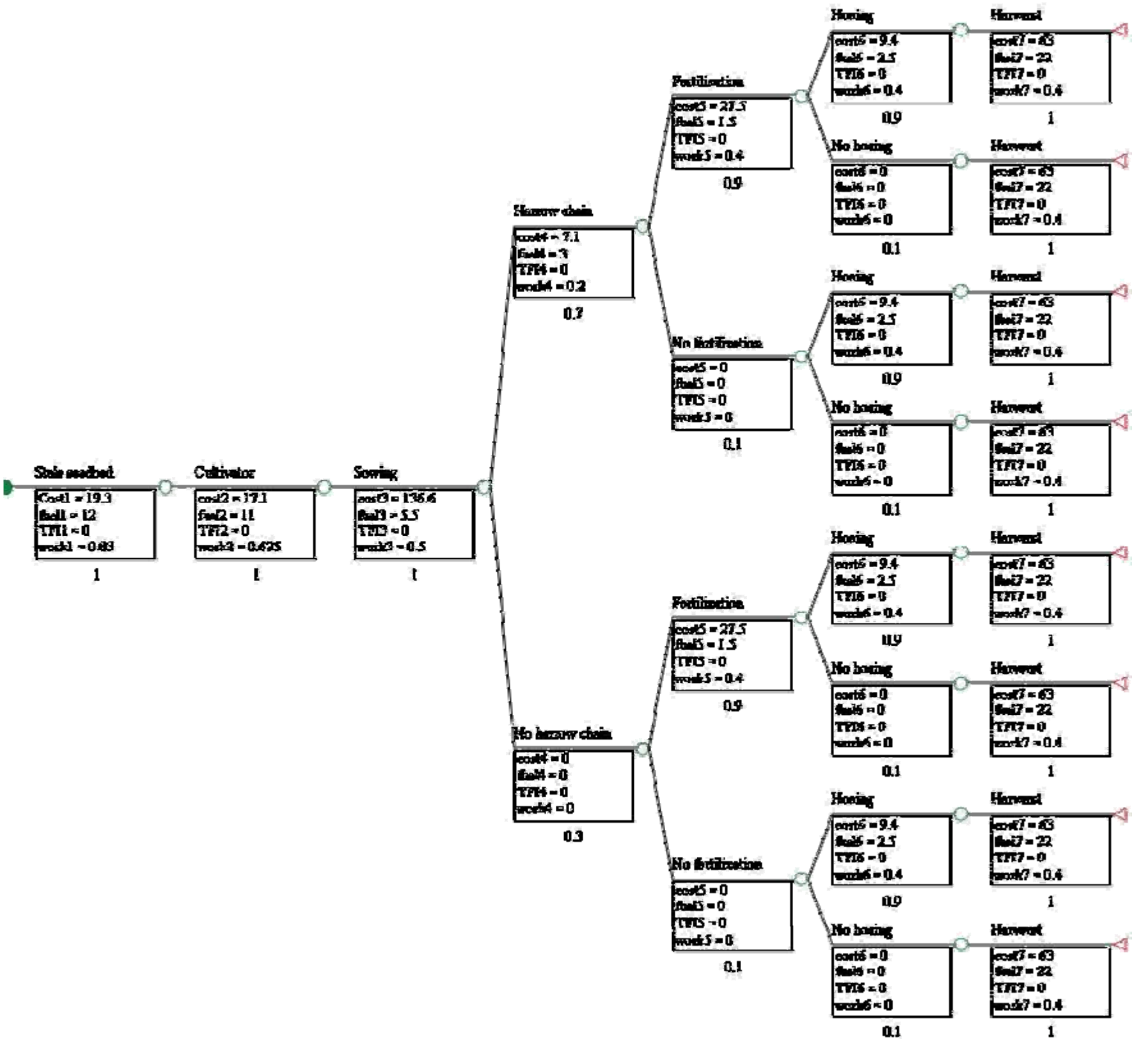
2.1 Decision variables

The innovative crop system studied here is a seven-year crop rotation. A multi-period model of inter-temporal choice is built up. Each year (denoted *t* in the following), land use decisions are revisable inside a set of possible rotations, considering the preceding crop and its possible impact on crop yield and the crop price situation anticipated for the coming seven years. Each year, the farmer accounts for both anticipations on yields and prices to take his decision of crop acreage for the coming seven year planning horizon, and each year his decisions are revisable: the model is recursive and thus dynamic. Only a succession of seven crops belonging to the initial 'innovative' rotation is considered as really innovative. If the rotation

[3] The detailed experimental protocol is not presented here as it is out of the scope of this paper.

is modified meanwhile it is not considered as innovative since the ‘rotation-effect’ is skipped. Several degrees of innovation will be considered: a succession of two to six crops belonging to the initial rotation will be considered as not totally innovative but as ‘partially’ innovative.

Figure 1: Example of a decision tree computing seven farming operation during a single period *t* of the planning horizon (conventional soft wheat)



Note: cost1: variable cost of operation ‘1’; fuel: quantity of fuel consumed (in liters); TFI: Treatment Frequency Index; work: number of hours worked. The number appearing below the square is the probability associated with the operation.

Each year, a set of technical operations is also chosen[4]. The various series of intra-annual technical operations are detailed through a decision tree, each branch corresponding to a set of decisions or a state of nature with an associated probability. This probability is the

[4] It is possible to change the frequency and dose of pest and nitrogen applications at different steps of the year. These technical operations take place according to a decision rule based on observations and agronomical criteria (climactic forecasts, plant health, etc.).

combination of the probabilities associated to the different operations. Also, different indicators can be calculated: production cost, labour and fuel consumption and an index of frequency of treatments[5]. The decision tree gives a distribution for those variables (Figure 1).

In the model, t is a period of the planning horizon which lasts seven periods. As mentioned before, the decision variable is the crop acreage and it depends only on t. Each t is divided into sub-periods corresponding to the different technical operations.

Among the set of possible crops some are 'conventional' and other belong to 'innovative' cropping systems (long rotations). Crop succession is controlled by the model: a set of possible preceding crops K' is associated to each crop K[6].

The optimization model determines a seven-year rotation considering the (K,K') sets. This choice depends on the distribution of costs of the intra-year operations, on the distribution of the resulting yields and on price anticipations. The choice is revised each year inside this dynamic model.

2.2 The objective function

The objective function of the recursive multi-period model is the maximization of the utility of the net present value of total farm wealth (W_t) over the planning horizon beginning on t. W_t is the actual sum, from t to t+6, of annual incomes $Z_{s,t}$ with ρ being the discount rate of the project:

$$W_t = \sum_{s=t}^{t+6} \frac{Z_{s,t}}{\rho^{s-t}} \tag{1}$$

Utility is defined as an Arrow-Pratt constant absolute risk aversion (CARA) function, r_a being the constant absolute risk aversion coefficient:

$$U(W_t) = 1 - e^{-r_a \cdot W_t} \tag{2}$$

[5] The model generates the following outputs: the expected utility of the present value of the cumulated gross margin of the rotation chosen, the level of consumption of pest protection products, and the level of labour consumption per hectare.
[6] This set has been identified based on opinions of experts (extension services, researchers). Rotations that are impossible in agronomical terms, such as sunflower after sunflower, are prohibited.

2.3 The stochastic parameters of the model

In this discrete stochastic programming (DSP) model, stochastic variables are the cost, the yield and the price from which the gross margin distribution per crop *k*, $Z_s(k)$, is calculated:.

$$Z_s(k) = \sum_{k \in K, k' \in K} \left[X_{t,s}(k, k') \left(\tilde{Y}a_t(k, k') \tilde{P}a_t(k) - \tilde{C}a_t(k, k') \right) \right] \tag{3}$$

where $X_{t,s}(k,k')$ is the area of crop *k* in period *s*, during the horizon which begins on *t* and considering the preceding crop *k'*, i.e., the crop in the previous period; $\tilde{Y}a_t(k, k')$ is the yield of crop *k* anticipated in year *t*: it is the same for all the periods *s* of the planning horizon and only depends on the preceding crop *k'*; $\tilde{P}a_t(k)$ is the price of crop *k* anticipated in year *t* which, as for yield anticipations, is the same for all the *s* periods of the planning horizon; and $\tilde{C}a_t(k, k')$ is the cost of crop *k* anticipated in year *t* and depends on the preceding crop *k'*.

The perceived yield $\tilde{Y}a_t(k, k')$ of crop *k* with preceding crop *k'* is stochastic. The yield distribution was elicited in the field with farmers already involved in innovative rotations, using the visual impact method developed in Hardaker *et al.* (2004). Direct interviews enabled to measure the probability judgments of the different crop yields involved in 'conventional' versus "innovative" rotations. We made sure that each farmer took the impact of the preceding crop in the rotation into account when evaluating the yield. This survey enabled to take, *ex ante*, the perceived riskiness of both innovative and conventional rotations into account.

Price anticipation: we assume that the farmer anticipates crop prices at the beginning of each year and for the coming seven years. These anticipations are made according to a normal law in which the mean price is the price observed the year before and the standard deviation is calculated from empirical data observed quarterly between 2008 and 2010:

$$\tilde{P}a_t(k) \sim Normal(\overline{p_t}(k); \sigma(k)) \tag{4}$$

where $\overline{p_t}(k)$ is the average price and $\sigma(k)$ is the variance of the price distribution for crop *k*.

In the model, we simulate stochastic prices considering that the average price follows an arbitrary trend with respect to which a sensitivity analysis is performed:

$$\overline{p_t}(k) = (1 + trend)^t p_0(k) \tag{5}$$

where $trend$ is a percentage of the mean price increase or decrease and $p_0(k)$ is the average price observed between 2008 and 2010.

The cost per crop $\tilde{C}a_t$ is stochastic is defined as follows:

$$\widetilde{Ca}_t(k,k^{'}) = \widetilde{Ca}_{op}(k) + Invest_{|k \in K_i} + SunkCost_{|k \notin K_i \cap k' \in K_i} - PR_{|k \in K_i \cap k' \in K_i} \tag{6}$$

where K_i is a subset of K and denotes the set of ‘innovative’ crops. The definition of $\tilde{C}a_t$ includes several components. The first component is $\tilde{C}a_{op}$, the distribution of cost calculated for the succession of technical operations corresponding to the decision tree. It is independent of the time period but it indirectly depends on *t* because it takes into account the preceding crop. Since innovative practices involve substantial effort in terms of technical skills, learning and equipment, the second and the third components represent an extra cost of investment incurred when an ‘innovative’ crop is chosen (denoted *Invest*) and a sunk cost (denoted *SunkCost*) when switching from innovative back to conventional cropping system. This sunk cost is both a barrier to entry and to leave innovative cropping systems. Finally, to compensate for these costs, an incentive premium (PR) is given to each hectare of ‘innovative’ crop when it follows another ‘innovative’ crop. In our case-study of experimenting farmers, the technical support given by the expert network and the knowledge provided by extension services can be considered as an implicit financial support, represented here by the premium.

3 Data

The model was applied to a sample of 13 cash crop farms of south-western France. These farms have recently started to experiment innovative cropping systems on about 10% of their total agricultural area. Data concerning production costs per operation have been collected. An evaluation of individual risk perception (perceived yield variability) and risk aversion has also been carried out. We do not provide details on this methodology but we present the main outputs of these experiments which will then be introduced as parameters in the model.

3.1 The decision tree

A decision tree was built for each crop. The different branches describe the different possible management operations for each crop during a production cycle namely, one year. Each node corresponds to a revisable operation for which several options have been reported by both experts and farmers when they conceived the new cropping system all together. For each crop, a sequence of management operations has been described; some are certain, others are risky because their outcome depends on the state of nature (Figure 1). Interviews enabled to measure the farmers' probability judgment regarding the risk probability associated with each operation on a Likert scale. Also, several indicators of costs, labour needs and frequency of pest treatments[7] have been calculated for each operation. Finally the decision tree details, for each crop, the distribution of costs and other indicators. This distribution is farmer-specific and depends on the perceptions of each farmer.

3.2 Production costs

The production costs consist of machinery costs (including fuel consumption, mending and depreciation costs) and input costs. Input costs are extracted from the French technological network on innovative cropping systems[8]. Machinery costs and labour needs per operation depend on the type of equipment. According to the type of equipment, costs are calculated thanks to the database of the French Office for Coordination of Agricultural Machinery (BCMA) and to the reference costs documented in the national inventory of farming practices (La France Agricole, 2009). The remaining data are collected from local extension services

[7] Those indicators are calculated on the basis of existing regional references according to several types of soils and climates.
[8] http://www.systemesdecultureinnovants.org/

and in a specialized technical institute[9]. The Treatment Frequency Index (TFI) is also calculated for each crop. It accounts for the number of homologated dose of pest treatment per hectare over a year[10] (Table 1).

3.3 Evaluation of the yield risk perceived

Farmer's probability judgments concerning the crop yield variability in the 'conventional' and in the 'innovative' technology are assessed following the visual impact method proposed in Hardaker *et al.* (2004). This subjective elicitation of yield distribution is carried out as follows: several intervals of yield variability are proposed to the probability assessor between a minimum value and a maximum value, and he is asked to allocate tokens to each yield interval. At the beginning of the procedure, the assessor is provided with 25 tokens. However, he does not have to use all the tokens and he can also ask for more. The probability of each interval is the ratio of the number of tokens allocated to this interval on the total number of tokens used. In addition to this, the assessor is asked to evaluate his own degree of confidence in his prediction.

Among the different farmers, several types of perceptions are identified because all famers do not balance 'negative' and 'positive' events the same way (some are optimistic, others are pessimistic). According to the First Order Stochastic Dominance (FOSD) criteria, 'conventional' cropping systems (CCSs) are the most often preferred with respect to the 'innovative' ones; this means that, according to an increasing utility function, CCSs are preferred. In some cases, neither the First Order nor the Second Order Stochastic Dominance criteria is sufficient (Figure 2). In this case, the farmer's choice will be influenced by other constraints than risk (agronomical constraints from the rotation or labour constraints for instance). We propose to focus on this particular case in the following[11].

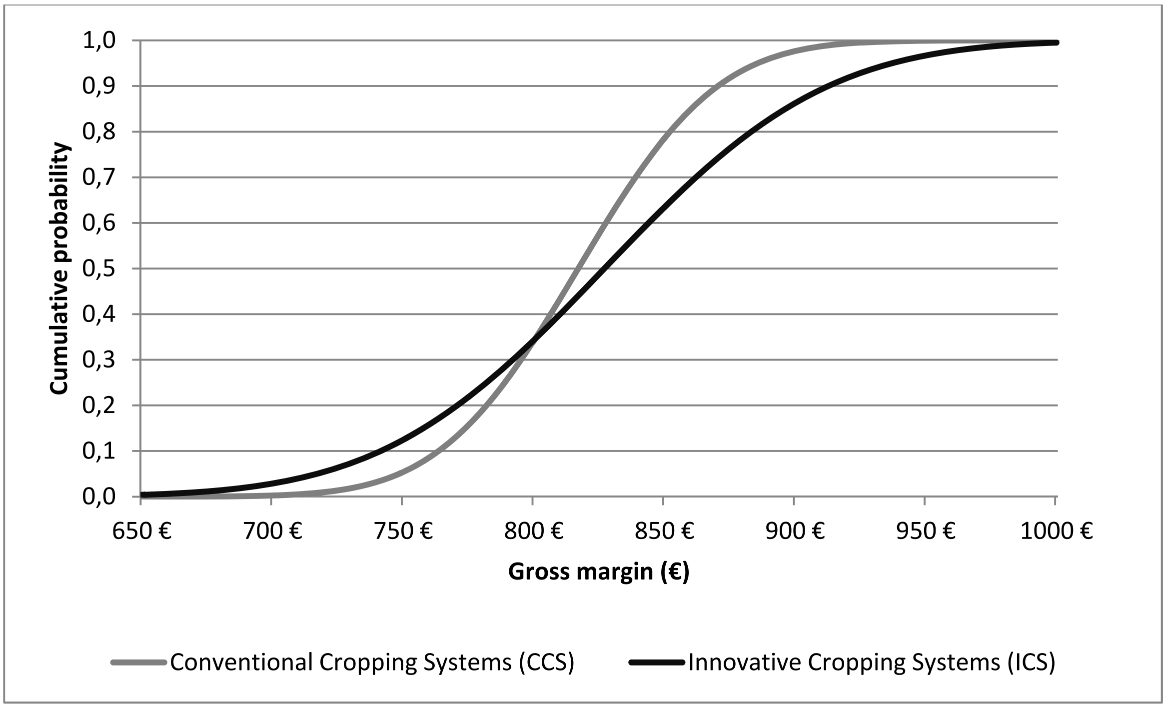
A gap remains between the *a priori* gross margin calculated under certainty and the perceived risky gross margin (Table 1).

[9] CETIOM: technical institute for oilseed crops
[10] TFI = (dose applied × area treated in hectares) / (homologated dose × area in hectares)
[11] In order to make such a situation visible, Figure 2 depicts two cumulative distributions in a stylized way. In reality, because the methodology consists in revealing discrete probabilities, the distributions and curves are not so smooth.

Table 1: Descriptive statistics on certain versus perceived risky yields, costs, prices and variable input consumption per hectare for the short rotation (wheat-sunflower) and the long 'innovative' rotation: averages for the 13 surveyed farmers

	Short rotation		**Long innovative rotation**						
Crops	Soft wheat	Sunflower	Sunflower	Soft wheat	Sorghum	Soft wheat	Peas	Rapeseed	Soft wheat
Year	[1,3,5,7]	[2,4,6]	1	2	3	4	5	6	7
Index of Treatment Frequency	4.1	2.6	1.3	3.0	0.0	3.0	4.9	5.5	3.0
Labour (hour/ha)	4.1	3.1	3.0	3.4	3.2	3.4	7.6	8.0	3.4
Certain cost (€/ha)	584	428	311	501	281	501	613	688	501
Perceived cost (€/ha)	510	415	284	366	279	366	596	688	366
Certain yield (ton/ha)	6.2	2.5	2.4	6.0	7.6	6.0	3.4	2.5	6.0
Perceived yield (ton/ha)	7.0	2.9	2.4	6.6	7.5	6.6	3.5	2.9	6.6
Market price (€/ton)	205	375	375	205	150	205	260	600	205
Certain gross margin (€/ha)	687	509	589	729	859	729	271	812	729
Perceived gross margin (€/ha)	925	673	616	987	846	987	314	1052	987
Cumulated certain gross margin (€/ha)	4275					4718			
Cumulated perceived gross margin (€/ha)	5719					5789			
Perceived standard deviation of the gross margin (€/ha)	292					468			

Figure 2: Comparison of the stylized cumulative distribution functions for both cropping systems



3.4 Risk aversion

The risk aversion has been elicited through a field experiment which involved the 13 surveyed crop farmers based on lottery games, similar to the one used by Holt and Laury (2002), Tanaka *et al.* (2010) and Bocquého *et al*. (2011)[12]. We implemented the experimental procedure proposed by Holt and Laury (2002), namely a multiple price list, which allows to elicit attitudes towards risk, and modified it to recover farmers' risk preferences in both the gain and loss domains. As pointed out in other studies, this approach is consistent with subjective probabilities. It derives from our estimations that the relative risk aversion coefficient r_a ranges from 0.69 to 0.85, denoting a high level of relative risk aversion among the surveyed farmers.

[12] The protocol is divided into two independent tests. The first one consists of four series of lotteries. In a series, at each row (14 rows per series) the farmer has to choose between two lotteries A and B. He can switch from A to B at any row of the series. The probabilities defining the two lotteries are unchanged, while the amount of gains or losses varies across the rows. The second test is built according to the same principle with four series of lotteries being proposed to the farmer. However, in this second test, the outcomes are unchanged while probabilities vary across rows. In order to validate the protocol, one of the lotteries is randomly played so that each farmer may win between 3 and 135 €.

4 Simulation results

In this section, we report several scenario simulations obtained with the model described in section 2 and the data obtained through the field surveys presented in section 3. We test the impact of several parameters on the adoption of innovative cropping systems. In 'baseline', the reference scenario, the value of the investment cost, the sunk costs and the premium are set to zero. In 'scenario 1', the impact of sunk costs on adoption is tested, considering a given level of investment attached to innovative crops and a given level of incentive premium mitigating this investment cost. In 'scenario 2', the impact of the level of risk aversion on adoption is investigated, and then, in 'scenario 3', the role of different market price trends is tested (Table 2).

Table 2: Description of the simulated scenarios

	Baseline	Scenario 1	Scenario 2	Scenario 3
ρ (discount rate of the project, in %)	3	3	3	3
r_a (relative risk aversion coefficient)	0.7	0.7	**0.2 to 1.7**	0.7
Price change (%/year)	+5	+5	+5	**+1 to +9**
Investment cost (€/ha)	**0**	90	90	90
Sunk cost (% of investment cost)	**0**	**0 to 90**	50	50
Incentive premium PR (€/ha)	**0**	120	120	120

In order to better estimate the level of incentive required for the adoption of the ICSs we first measured this financial effort by using the probability distributions and the coefficient of risk aversion elicited during the farm survey. This effort is measured by an adoption premium (*AP*) which corresponds to the monetary increase in gross margin per hectare required to leave the farmers indifferent between 'conventional' and 'innovative' systems:

$$EU(GM_{CCS}) = EU(GM_{ICS} + AP) \tag{7}$$

with *EU* being the expected utility, *U* a CRRA utility function similar to the one presented in equation (2), *GM* the mean gross margin per hectare and per year, and *AP* the adoption premium per hectare and per year.

A coefficient of relative risk aversion of 0.7 is applied. The complexity of constraints weighting in a farmer's decisions (agronomical and labour constraints mainly) is indirectly accounted for through the preference elicitation. For the type of risk perceptions associated with both cropping systems (CCS and ICS) presented in Figure 2 we calculate an adoption premium of €43 per hectare.

As a consequence, when assigning values to the different parameters of our model under different scenarios, we tried to approach this value as close as possible. As we can see in Table 2, the differential proposed between the cost of investments (90€/ha) and the level of the incentive premium (120€/ha) amounts to 30€/ha. This value is somehow close to the 43€ calculated for the adoption premium.

The farm type on which the simulations were performed has an average size of 100 hectares and it is specialized in cash crops, with no other possible farming activities.

We analyze the results with two respects. First, we monitor how the crop acreage changes during the 7-year planning horizon. Second, we assess the share of area entering to and exiting from innovative techniques during the 7-year planning horizon. Three types of land use corresponding to three levels of adoption are reported:

- a total adoption of the 7-year rotation (denoted Entire ICS);
- a rotation longer than three years (but less than six years) occurring at any moment within the 7-year horizon will be considered as a partial adoption of the innovation (denoted PARTIAL);
- a continuous cropping of a single type of crop or of a two-year rotation (whatever the crops among the seven possible ones) is considered as a conservative choice, that is a continuation of the 'conventional' system (denoted TRADI).

4.1 Baseline

In the baseline scenario, we set the value of investment cost, sunk costs and premium at zero. In this situation, since innovative crops are perceived as riskier by most farmers, it is not surprising to obtain a low share of the farm area under partial adoption (4.5 hectares), almost no adoption of the entire ICS (0.3 ha), and the major part of the farm acreage (95.2 ha) under 'conventional' short term rotation.

4.2 Influence of sunk costs on adoption: results of 'scenario 1'

As appears in equation (6), innovative practices involve substantial effort in terms of technical skills, learning and farm equipment. Unfortunately, this effort, composed of quantifiable and unquantifiable costs (similar to transaction costs), and which represents a barrier to adoption, has not been totally quantified in this study. However, we consider that these costs are implicitly revealed in the farmer's risk attitude. To compensate for this effort, we attribute a positive value to the premium *PR* given to each hectare under an 'innovative' crop succeeding another 'innovative' crop. The balance between investment cost and the premium *PR* is an estimation of the adoption premium mentioned earlier.

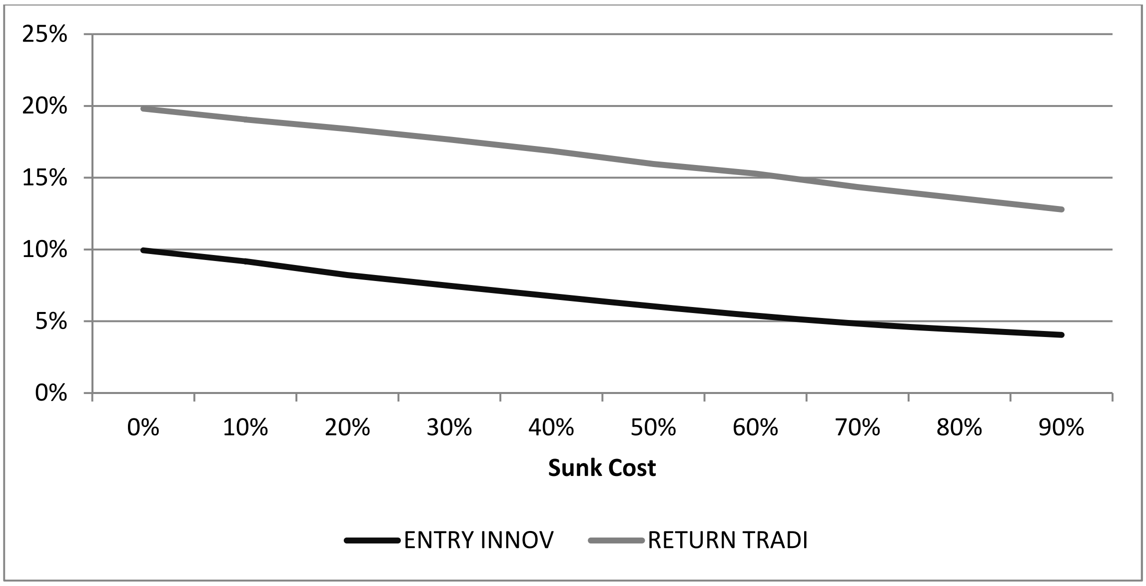
After having performed a sensitivity analysis, we propose to set the value of the investment cost at 120€/ha and the level of crop premium *PR* at 90 €/ha. In these conditions, we tested the impact of sunk costs: when ending the innovative rotation, a share of the investment costs is not recovered. Such sunk costs were set as a percentage of the investment costs (Table 2).

In the absence of sunk costs, but with a compensatory premium *PR* for each hectare converted to the 'innovative' system, the farmer is encouraged to temporally switch to non-'innovative' crops that are more profitable (especially when prices vary). This behaviour is however not realistic because of the sunk costs due to the investment in innovative systems. Thus, we performed simulations with varying sunk costs in order to test which level can prevent the farmer from switching too easily from 'innovative' to 'conventional' system (Figure 3).

As expected, Figure 3 shows that the greater the sunk costs the more stable the decision to engage into 'innovative' systems through time; both the share of area entering into 'innovative' systems (ENTRY INNOV') and the share of area interrupting 'innovative' management (RETURN TRADI) are lower under high sunk costs. On the other hand, sunk costs make farmers more reluctant to engage into costly innovative practices and decrease the average share of area engaged in rotations longer than three years (Figure 4).

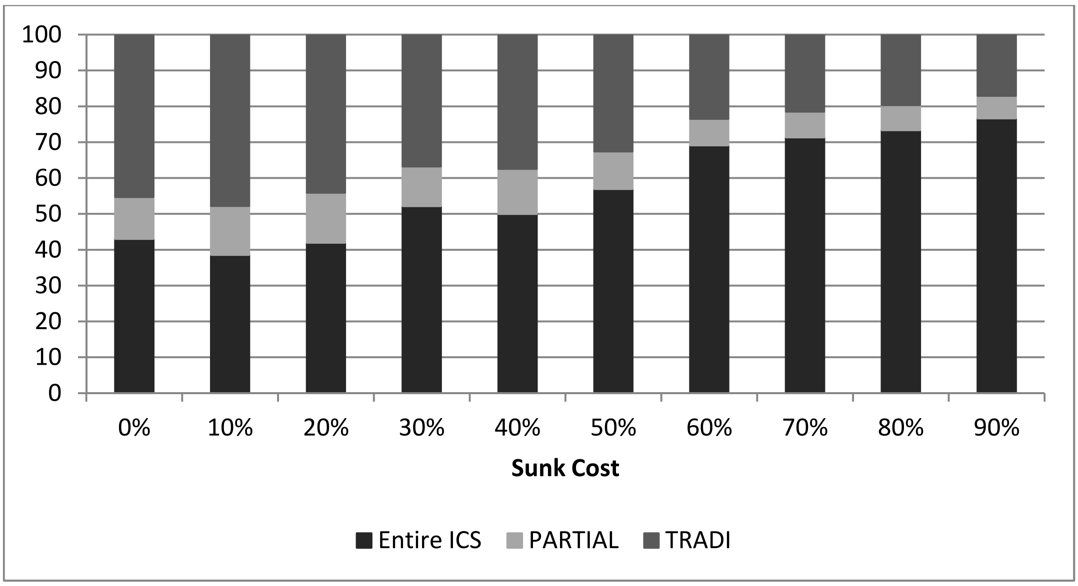
When the sunk costs represent 50% of the investment cost, the level of adoption of the entire ICS is about 50%, which is substantial. This level is achieved with a high level of both investment and sunk costs and if a compensatory premium is provided, disconnected from investment.

Figure 3: Share of the farm area switching between 'conventional' and 'innovative' systems with respect to the level of sunk costs



Note: 'ENTRY INNOV' stands for the share of area converted into innovative system and 'RETURN TRADI' stands for the share of area where the innovative system is abandoned.

Figure 4: Share of the farm area under null, partial or total adoption of 'innovative' rotation with respect to the level of sunk costs

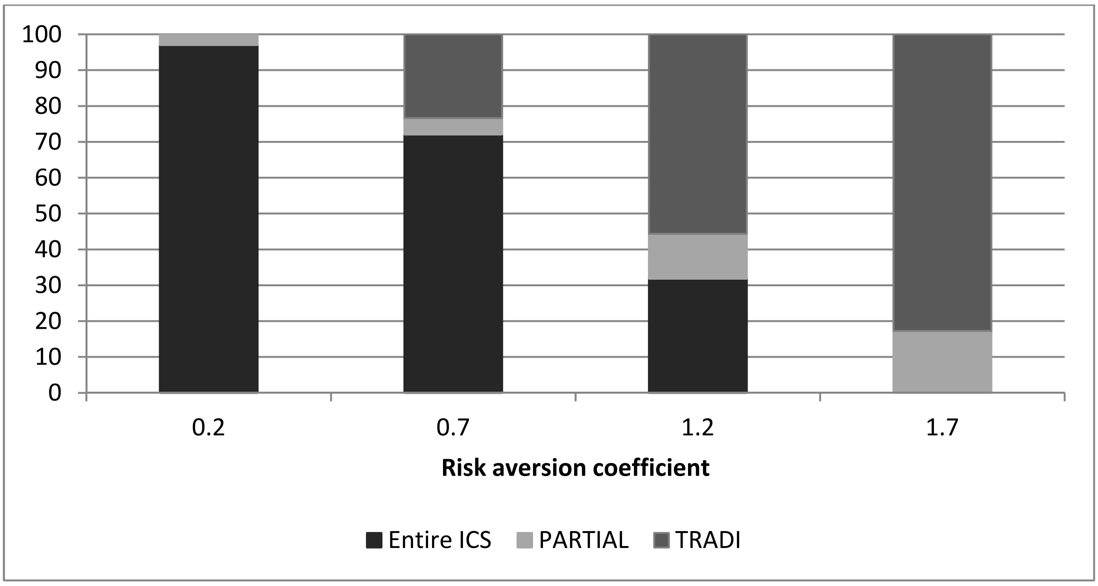


4.3 Influence of risk aversion on adoption: results of 'scenario 2'

The coefficient of relative risk aversion that was identified through the field survey among farmers is rather high, around 0.8 on average. Since innovative systems are perceived as riskier than conventional ones, it is clear that, with a CARA utility function as used in the model, innovative systems are not favoured.

Here we propose to vary the risk aversion coefficient, from a low level of 0.2 to a high level of 1.2. It is clear in our simulations that low levels of risk aversion (coefficient below 0.7) tend to favour longer rotations unless they are perceived as riskier (Figure 5).

Figure 5: Share of the farm area under null, partial or total adoption of 'innovative' rotation, with respect to the level of risk aversion



4.4 Influence of the market price trend on adoption: results of 'scenario 3'

In the former scenarios, we assumed that the farmer anticipates a 5% steady trend of rising prices. Here we simulate other steady trends (Figure 6). The simulations show that the more the prices increase, the more the farmer chooses most profitable crops, whether 'innovative' or not. The results also show a more frequent abandonment of the long rotation (Figure 7): when the price trend increases, the farmer tends to switch more frequently between 'innovative' and 'conventional' systems.

When we simulate a negative price trend, the crop acreage decisions change in the opposite way: highly negative price trends tend to favour 'innovative' crops, which benefit from the compensative premium *PR*.

Figure 6: Share of the farm area under partial or total adoption of innovative rotation, with respect to the level of the price trend

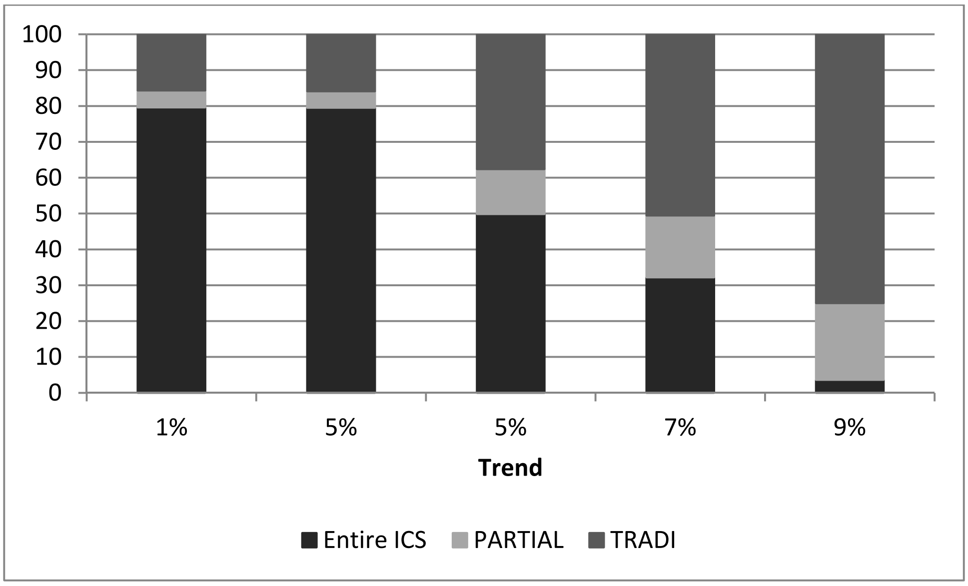
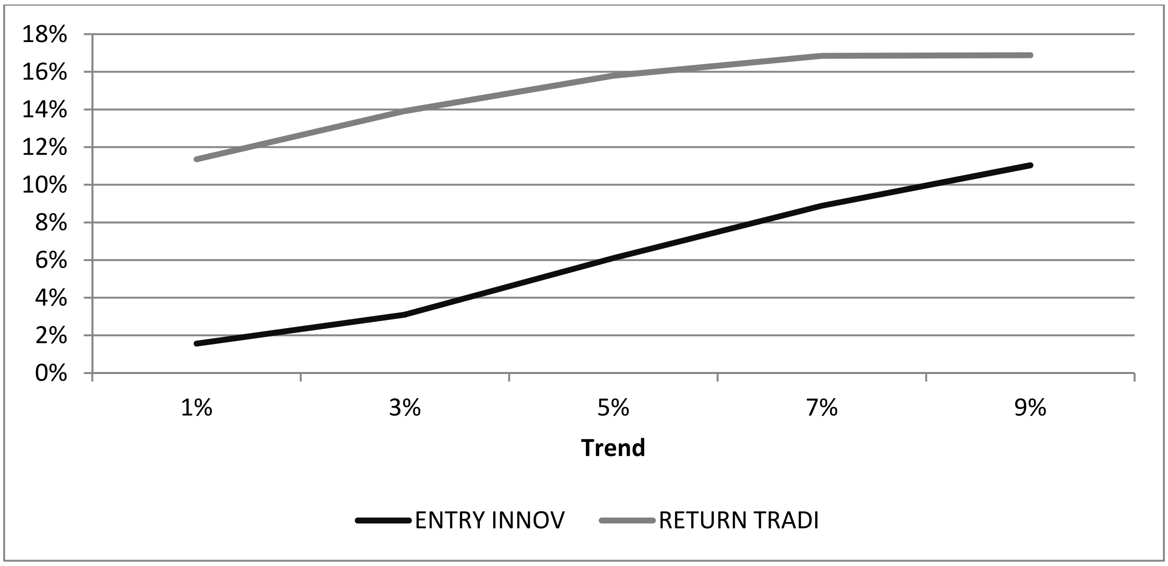


Figure 7: Share of the farm area switching between 'conventional' and 'innovative' systems, with respect to the level of the price trend



Note: 'ENTRY INNOV' stands for the share of area converted into innovative system and 'RETURN TRADI' stands for the share of area where the innovative system is abandoned.

5 Concluding remarks

We built a dynamic model of crop rotation under risk which enables to investigate the adoption of complex agronomical innovations in the presence of both yield and market risk. We based our simulations on data obtained from real farmers currently experimenting innovative rotations (in particular the evaluation of farmers' perceptions of yield risk). The results show that innovative systems (*i.e.*, long rotations) are almost always perceived as riskier than short rotations, in terms of production risk. The engagement into long rotations implies investment costs for farmers that are partly irrecoverable (sunk costs). By assuming the existence of positive sunk costs, our simulations show that long rotations are attractive when they are supported by an incentive premium. In the case-study, farmers have already begun to experiment long rotations and this premium consists in the non-financial support targeted to farmers brought by extension networks in the form of technical advice, knowledge, information, references, etc. The results of our simulations also show that under production and market risk, both risk aversion and a positive market price trend tends to discourage the long term engagement of farmers into long rotations. Market forces seem to have a major influence in the short term by counteracting farmers' long term efforts to improve their environmental output.

References

Abadi Ghadim A. K., Pannel D. J. (1999). A conceptual framework of adoption of an agricultural innovation. *Agricultural Economics,* 21: 145-154.

Acs S., Berentsen P., Huirne R., van Asseldonk M. (2009). Effect of yield and price risk on conversion from conventional to organic farming. *Australian Journal of Agricultural and Resource Economics,* 53: 393-411.

Apland J., Hauer G. (1993). Discrete stochastic programming: concepts. examples and a review of empirical applications. Department of Agricultural and Applied Economics. University of Minesota. staff paper series.

Baerenklau K.A., Knapp K.C. (2007). Dynamics of agricultural technology adoption: age structure, reversibility and uncertainty. *American Journal of Agricultural Economics,* 89(1): 190-201.

Blazy J.M., Tixier P., Thomas A., Ozier-Lafontaine H., Salmon F., Wery J.(2010). BANAD: A farm model for *ex ante* assessment of agro-ecological innovations and its application to banana farms in Guadeloupe. *Agricultural Systems*, 103: 221-232.

Bocquého G., Jacquet F., Reynaud A. (2011). Expected Utility or Prospect Theory Maximizers? Results from a Structural Model based on Field-experiment Data. *European Association of Agricultural Economists 2011 International Congress*, August 30-September 2, Zurich (Switzerland).

Carpentier A., Gohin A., Letort E. (2011). Accounting for agronomic rotations in crop production: A theoretical investigation and an empirical modeling framework. *Agricultural and Applied Economics Association Annual Meeting*, July 24-26, Pittsburgh (Pennsylvania).

Chavas J.P. (1994). On sunk cost and the economics of investment. *American Journal of Agricultural Economics*, 76: 114-127.

Chavas J.P., Postner J.L., Hedtcke J.L. (2009). Organic and Conventional Production Systems in the Wisconsin Integrated Cropping Systems Trial: II. Economic and Risk Analysis 1993–2006. *Agronomy Journal,* 101(2): 253-260.

Doole G.J., Pannell D.J. (2008). Optimisation of a Large Constrained Simulation Model using Compressed Annealing. *Journal of Agricultural Economics,* 59(1): 188-206.

Hardaker J.B., Huirne R.B.M., Anderson J.R., Lien G. (2004). *Coping with risk in agriculture.* CABI Publishing.

Hennessy D. A. (2007). On Monoculture and the Structure of Crop Rotations. *American Journal of Agricultural Economics*, 88(4): 900-914.

Holt C. A., Laury S. K. (2002). Risk aversion and incentive effects. *American Economic Review*, 92: 1644-1655.

Isik M., Khanna M., Winter-Nelson A. (2001). Sequential Investment in Site-Specific Crop Management Under Output Price Uncertainty. *Journal of Agricultural and Resource Economics*, 26(1): 212-229.

La France Agricole (2009). Façons culturales : le barème des coûts indicatifs. http://www.lafranceagricole.fr/gestion-et-droit/chiffres-cles-et-reperes/prix-et-baremes/facons-culturales-le-bareme-des-couts-indicatifs-pour-l-annee-2009-22700.html

Marra M., Pannell D., Abadi Ghadim A. (2003). The economics of risk uncertainty and learning in the adoption of new agricultural technologies: where are we on the learning curve? *Agricultural Systems*, 75: 215-234.

Stanger T. F., Lauer J. G., Chavas J.P. (2008). The Profitability and Risk of Long-Term Cropping Systems Featuring Different Rotations and Nitrogen Rates. *Agronomy Journal*, 100(1): 105-113.

Tanaka T., Camener C. F., Nguyen Q. (2010). Risk and time preferences: Linking experimental and household survey data from Vietnam. *American Economic Review*, 100: 557-571.

Trebreck D.B., Hardaker J.B. (1972). The integrated use of simulation and stochastic programming for whole farm under risk. *Australian Journal of Agricultural Economics,* 16(2): 115-126.

Vereijken P. (1997). A methodical way of prototyping integrated and ecological arable farming systems (I/EAFS) in interaction with pilots farms. *European Journal of Agronomy*, 7: 235-250.

Les **Working Papers SMART – LERECO** sont produits par l'UMR SMART et l'UR LERECO

- **UMR SMART**

L'Unité Mixte de Recherche (UMR 1302) *Structures et Marchés Agricoles, Ressources et Territoires* comprend l'unité de recherche d'Economie et Sociologie Rurales de l'INRA de Rennes et le département d'Economie Rurale et Gestion d'Agrocampus Ouest.

Adresse :
UMR SMART - INRA, 4 allée Bobierre, CS 61103, 35011 Rennes cedex
UMR SMART - Agrocampus, 65 rue de Saint Brieuc, CS 84215, 35042 Rennes cedex

- **LERECO**

Unité de Recherche *Laboratoire d'Etudes et de Recherches en Economie*

Adresse :
LERECO, INRA, Rue de la Géraudière, BP 71627 44316 Nantes Cedex 03

Site internet commun : http://www.rennes.inra.fr/smart/

Liste complète des Working Papers SMART – LERECO :
http://www.rennes.inra.fr/smart/Working-Papers-Smart-Lereco
http://econpapers.repec.org/paper/raewpaper/

The **Working Papers SMART – LERECO** are produced by UMR SMART and UR LERECO

- **UMR SMART**

The « Mixed Unit of Research » (UMR1302) *Structures and Markets in Agriculture, Resources and Territories*, is composed of the research unit of Rural Economics and Sociology of INRA Rennes and of the Department of Rural Economics and Management of Agrocampus Ouest.

Address:
UMR SMART - INRA, 4 allée Bobierre, CS 61103, 35011 Rennes cedex, France
UMR SMART - Agrocampus, 65 rue de Saint Brieuc, CS 84215, 35042 Rennes cedex, France

- **LERECO**

Research Unit *Economic Studies and Research Lab*

Address:
LERECO, INRA, Rue de la Géraudière, BP 71627 44316 Nantes Cedex 03, France

Common website: http://www.rennes.inra.fr/smart_eng

Full list of the Working Papers SMART – LERECO:
http://www.rennes.inra.fr/smart_eng/Working-Papers-Smart-Lereco
http://econpapers.repec.org/paper/raewpaper/

Contact

Working Papers SMART – LERECO
INRA, UMR SMART
4 allée Adolphe Bobierre, CS 61103
35011 Rennes cedex, France
Email : smart_lereco_wp@rennes.inra.fr

2012

Working Papers SMART – LERECO

UMR INRA-Agrocampus Ouest **SMART** (Structures et Marchés Agricoles, Ressources et Territoires)

UR INRA **LERECO** (Laboratoires d'Etudes et de Recherches en Economie)

Rennes, France