Risk, labour and climatic uncertainty in crop rotation optimization

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Abstract

The goal of this article is to give some guidelines when modeling farmers' rotation choices through optimization models. To improve the accuracy of such models, researchers can i) sophisticate the utility function or ii) specify the production function and the constraints of the model. Based on an interactive approach involving farmers, a preliminary discrete determinist model is built and tested under changing crops prices. Then, two discrete stochastic modeling approaches are compared; in the first one, yield risk is accounted as main source of income variability and, in the second one, risk is incorporated as a stochastic constraint of monthly inaccessible field days. Results show that risk aversion little affects rotation choice. A stochastic labour constraint accounting for field inaccessibility has considerable more impact on crops choice, especially in presence of imperfect labour market.

Key words

Crop rotation; Labour constraint; Interactive approach; Discrete stochastic programming

Introduction

In order to assess the impacts of environmental or market changes on the farm sector, agricultural economists have led constant efforts improving the accuracy of farm level models. In microeconomics, producers' decision consists in maximizing profit or minimizing costs when optimally allocating resources. But many dimensions of decision might be relevant when trying a deeply understanding of farmers' choices (Dury and al., 2010).

Risk, resources constraints (including labour) or rotation effects are widely recognized dimensions of farmers' decisions. However, some limitations can be noticed within the current approaches (Lien and Hardaker, 2001). For instance, if labour has been considered as a limiting factor of farm adjustment in some studies, it has not been much investigated in a context of climatic hazard (Apland, 1993); this context leads to changing availability in labour periods, particularly when farm plots get unattainable because of rain or soil quality. Then, in many optimization models, the solutions are led by boundary conditions (constraints), rather than by the optimization of the utility function. This type of solutions is called corner solutions; to explore them, the specifications of rotation effects and labor constraints under climatic risk can be more relevant than giving too much complexity to the utility function.

In southwestern France, the durum wheat and sunflower rotation on non-irrigated land faces many challenges (e.g., increase of weeds pressure and resistances, deterioration in soil structure, labour peaks management…). Crop diversification and rotation are a way of solving number of these problems; however, they have a limited extension (77% of the total cropland is sown with soft wheat, durum wheat and sunflower in the Midi-Pyrénées region[1]). This study thus explores, which are the important parameters when choosing a crop rotation.

Our empirical approach of farmers' decision is first based on interactive methods in order to explore determinants of farmers' rotation choices. Then, three discrete optimization models are built, allowing both testing the role of various determinants and comparing the use of different types of stochastic models.

Method

Interviews

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[1]   Agreste 2013

[2]   Roussy, C., Ridier, A., Chaïb, K., Reynaud, A. and Couture, S., (2012). A methodological way of evaluating innovative

The survey aims at bringing face to face a list of traditional determinants of rotation choice with local stakeholders' and experts' opinions. Mixing focus groups and individual interviews allows benefiting from the advantages of both techniques while outperforming their limits (Kaplowitz and Hoehn, 2001).

Interviewees are asked about different topics related to the sunflower and durum wheat rotation and the survey continues until "theoretical saturation" is achieved. Eight farmers, four public researchers from INRA (French national institute of agronomic research), six experts from Arvalis (technical institute specialized in plants) and seven agricultural cooperative experts were interviewed between April and June 2013.

Modeling

An optimization model is built that simulates farmers' rotation choice in a non-irrigated context. The choice is to use single attribute (income) utility function maximization and to focus on the feasible set of the program through activities and constraints specification; these latter are monthly specified and account for the precedent effect (i.e., the model is run at an annual time step but yields, nitrogen and phytosanitary products needs depend on previous crop grown).

In a first model, we use a classical approach of risk, where yields are stochastic, normally distributed and vary among crops (Model 1). In the second model, yields are determinist but risk is introduced through a new stochastic constraint: monthly inaccessible field days (Model 2). Thus, in this last model, production risk is implemented through its impact on workload. For both models, a mean-variance analysis is used to formalize the twin objective choice: maximizing mean income and minimizing income variance. Assuming that farmers' absolute risk aversion is constant, the Arrow-Pratt approximation can be used.

		Crop harvested					
	In Ton/Ha	Durum wheat	Soft wheat	Rapeseed	Protein peas	Sorghum	Sunflower
Previous crop	Durum wheat	4,9	6,7	2,7	2,4	6,3	2,5
	Soft wheat	--	6,7	3,3	2,4	6,3	2,5
	Rapeseed	5,4	7,4	--	2,4	6,3	2,4
	Protein peas	5,5	7,5	3,4	--	6,3	2,5
	Sorghum	5,2	7,1	--	2,4	--	2,3
	Sunflower	5,4	7,4	--	2,5	6,2	--
Mean coefficient of variation		0,07	0,03	0,11	0,35	0,06	0,10

Source: farm survey (2011) and expertise collection (Spring 2013)
Table 1: Perceived adjusted mean yields and mean yields coefficients of variation

We depict an average non-irrigated farm of Midi-Pyrénées according to regional references. The cropping area and family labour resources are set as constraints; but farmers can hire monthly labour. Subjective probabilities for yield were estimated among a sample of local farmers cropping the durum wheat and sunflower rotation[2] (Cf. Table 1). Rotational effects on crop yields were then assessed based on Viaux[3] expertise and according to local experts' opinions. Data on the number of days of plot inaccessibility (mean and standard deviation), due to rain or wind, are regional references provided by Arvalis.

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Results

Interviews

In this section recurrent items found in interviewees' speeches are presented; this leads to preliminary assumptions for the model building.

Interviews reveal the key role of income and its main components (i.e., prices and yields) in farmers' decision making. Additionally, guarantee of market opportunities appears as a necessary condition for farmers when selecting a crop. Then, farmers confess that they favor crops with no need for additional material investment. Regarding these two last criteria, the four crops usually selected in Midi-Pyrénées (beside sunflower and durum wheat) are soft wheat, rapeseed, sorghum and protein pea; the model in next section will also focus on these four diversification crops.

Importance of uncertainty issues also appears from farmers' speeches (regarding yields, weather conditions, management difficulties, etc.). Accordingly, most of the interviewed farmers have difficulties foreseeing a precise rotation over several years; they need to revise their cropping choice on a yearly basis depending on the farm situation and external context. Farmers also point out labour management issues, especially when weather conditions (wind, rain) limit field accessibility. The delegation of farming task to agricultural contractors is developing in the region but a majority of farmers interviewed still prefer handling workload on their own without external labour.

Diminution of risk and breaking diseases cycles are two reasons frequently advanced to diversify the crop acreage, but farmers face difficulties quantifying real benefits of these technologies. Indeed, few regional quantitative data exist on agronomic benefits of long rotations. Interviewees explain that this lack of services can impact farmers' willingness to try new rotations. Finally, according to farmers and extension services, in addition to crop profitability criteria, public regulation is one of the major determinants of rotation change.

Modeling

Firstly, the model is used without risk and labour or climatic binding constraints. The focus is thus only on prices and agronomic (rotational) parameters. Planting area is limited to 100 hectares. Two prices situations are compared (2009 - low prices and 2012 - high prices), assuming a constant ratio of input/crop price. Model results in 2009 show that, in a non-irrigated context, farmer's acreage is 50 hectares of durum wheat and 50 hectares of sunflower. This is in line with the observed situation in the region. Then, the results observed with the 2012 prices scenario are coherent with farmers currently reorienting toward more soft wheat and sorghum.

This deterministic model is the starting point for the building and the scan of two stochastic models taking into account production risk: model 1 with yield risk and model 2 with stochastic days of plot inaccessibility. In this part, input and crop 2012 prices are used.

In this section, yields are assumed stochastic and follow a normal distribution. The model maximizes an Arrow Pratt utility function.

The level of risk associated with a crop is measured by the gross margin standard deviation (GMSD). Soft wheat and sorghum are the two less risky crops (GMSD respectively of 44 and 68€ per hectare); this explains why they remain cultivated in a large area whatever level of risk aversion. However, when risk aversion coefficient increases, new crops appear in the rotation. For a high level of absolute risk aversion (0,01), a high level of diversification is

achieved and each crop appears in a proportional way regarding their GMSD; thus, rapeseed and pea are for instance few grown.

Finally, income level is few affected by the diversification; for instance, the income diminution is of 22% for the high level of absolute aversion (0,01). However, an absolute risk aversion of 0,0001 corresponds to a relative risk aversion of 6 for a 60 000 € level of income, and to a risk premium computed at 233 € for a durum wheat/sunflower rotation over 100 hectares. This low level of risk premium finally corresponds to a low level of income variability considering the level of expected income and it explains why, model outputs are few affected by the inclusion of stochastic yields. This result has a twofold explanation: i) income is a first order term while risk is only a second order term (in the asymptotic development of the utility function), and thus, has little effect on crop choice, and ii) in a situation of corner solutions the changing curve of the utility function only slightly impacts the final crop choice (solutions are stable). To overcome these effects, model 2 incorporates risk in a constraint rather than in the calculation of the objective function.

With the second model, the importance of considering working days when farmers cannot go on their field or make a treatment because of water issue or wind effects is precisely tackled.
When considering the sorghum and soft wheat rotation, two workload picks appear: one in September (sorghum harvest and soft wheat seeding preparation) and the other in April (soft wheat treatment and sorghum seeding preparation). However, for an average farmer entirely dedicated to his crops (i.e., without other job or livestock unit), the workload is a priori little constraining (e.g., monthly workload does not exceed 8 hours a day for a 100 hectares farm). Then, considering field inaccessibility, results show that workload can become more constraining (e.g., in September, for a 100ha farm, if farmers cannot go on their fields during 5 days, they have to concentrate their workload on the remaining days and work more than 10 hours a day). Simulations with the model 2 allow testing sensitivity of rotation choice to stochastic plot accessibility, depending on external labor price and access.

Risk aversion is first set at zero. Assuming that labor market is perfect (qualified labor always available), results show that, when external labour is over a shadow price of 129 €/ha, the introduction of a stochastic constraint on plot accessibility leads to a change in rotation choice (i.e., more diversification); farmers seek to spread their labour peaks over the year. Thus, in the case of imperfect labour market, the crop rotation choice is influenced by field accessibility.
We now test the impact of both risk aversion and field accessibility stochastic constraints. For average labour prices, the optimization results show that the increase in risk aversion coefficient affects crop choice only for high levels of risk aversion (Cf. Chart 1). Thus, the conclusion is the same as in the case of yield risk; risk introduced through an Arrow Pratt utility function does not affect rotation choice if we consider low to medium values of absolute risk aversion (around 10^{-5}); first order terms of the utility function have a dominant impact.

Our results finally highlight the relevance of considering the risk of plot inaccessibility, due to climate hazard, when studying farmers' crop choice. This also appears as a good alternative to account for production risk without introducing stochastic yields or risk aversion, which we have seen, little affect farmer's choice in a classical mean-variance analysis.
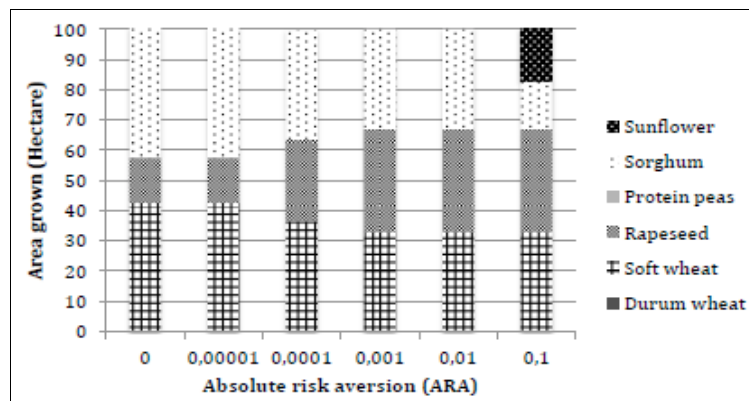
Chart 1. Impact of risk aversion increase on rotation choice with Model 2 for a 200 Euros per hectare labour price.

Discussion

In acreage choice models, beside prices, rotation effects have a dominant role as well as managing labor at peak-times. In optimization models, the solutions are then very much driven by constraints and, because of these constraints and due to the relative prices observed, some crops cannot entry the optimal acreage. It is then important to consider corner solutions, i.e., optimal solutions that are not based on the market-efficient maximization, but rather based on boundary conditions (constraints). To explore this type of solutions, this study suggests that the specifications of rotation effects, labor management and plot accessibility are at least as relevant as sophisticating the objective function (by including risk behavior parameters). A complete review of regional technical constraints and rotational effects, combining data from literature and experts' or farmers' views, appears to be a key when modeling rotation choices.

Risk aversion does not appear as a high weighting parameter when explaining farmers' choice, considering the level of yield variability reported by farmers (subjective probabilities), compared to the mean level of gross margins. Subjective probabilities could also be assessed concerning the risk of plot accessibility. In this study, the input data on weather are measures observed by scientists and are supposed normally distributed. Even if surveys are time consuming, farmers' perceptions about plot accessibility could be collected to improve accuracy of such a distribution.

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