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Economic impacts of drought on agriculture

The scientific collective assessment on "Agriculture and drought" steered by INRA in 2006 showed a lack of quantitative analyses on the economic impact of a drought in France. In response, the INRA economists have built an original coupling between the STICS agronomic model developed by INRA and an economic model. The aim was to assess the cost of drought episodes to a representative farmer of the Midi-Pyrénées region and to determine whether his short or long term decisions help reducing this cost significantly. The results obtained indicate that, in the short term, the cost induced by the drought can be high. In the long term, that is to say if farming systems can be modified by the farmer, the cost induced by drought is attenuated in a visible way by these additional adaptation capacities. Moreover, the implementation of early-warning drought mechanisms may be beneficial to Midi-Pyrénées farmers.

The stakes relating to climate change in agriculture

In its last report, the Inter-governmental Panel on Climate Change (IPCC) points out that the warming of the climate system is unequivocal, as it is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level. This report specifies that in Southern Europe, more difficult climate conditions (drought, higher temperatures) and a drop in the availability of the water resource are to be expected.[1] According to the European Environmental Agency, the climate change process in the Northern European countries will also lead to an increase in summer drought episodes. From 1976 to 2005, the French territory was concerned by 13 drought episodes in one of its regions. This corresponds to around one drought occurrence 2 years in 5, that is to say twice as much as in the past (12 episodes from 1905 to 1965), see Itier (2008).

So the question is no longer whether agriculture has to adapt to climate conditions that will be different from what we are currently experiencing but how it will be able to do this. It is an important question because agriculture is the economic sector for which drought episodes result in the highest losses. In France, the loss due to the 2003 drought was assessed at 590 million for agriculture against 300 million for the energy sector (in Portugal, the cost of the 2004 and 2005 droughts was respectively for industry, energy and agriculture 32, 261 and 519 million Euros). These high costs fully justify to assess the adaptability of agriculture to climate changes and particularly to drought.

Adaptation to drought risk

The adaptation of agriculture to the drought hazard is either a matter for collective decision (reorganization of productive sectors, water transfers between regions, new supply sources and so on.) or individual decision (modifications of technical itineraries, changes in cropping systems, risk cover by insurance, and so on), see Amigues et al. (2006).[2] We limit ourselves here to the analysis of agriculture's technical adaptability to drought

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[1] Four European countries (Cyprus, Malt, Spain and Italy) are already in a situation of water stress, that it is to say that they use more than 20% of the long term water resources available.

[2] Genetic adaptation is another possibility. Although the media have highlighted interesting results as regards surviving drought, the maintenance of high yields in conditions of water stress through genetic improvement is not yet on the agenda, Itier (2008).

risk through individual decisions, distinguishing between short and long term strategies.[3]

On the short run (that is to say on an intra-annual scale), the choices of cropping and irrigation technologies have been made and only the variable factors (water, fertilizers, pesticides and so on.) can be adjusted according to the occurrences of climate risk or the farmer's anticipations. The question is then to determine whether the variable production factors help limit the impact of drought risk on the farmer's objective function. The farmer's adaptation to the climate risk through the decisions to modify irrigation has often been evaluated through mathematical programming models. In terms of public policies, an important question which emerged from the literature on optimal irrigation management under uncertainty is the measurement of the value of information to the farmer: how much would the farmer agree to pay to have access to an information correlated with the risk he must face.[4] For instance, an American survey has determined the amount that a farmer would be ready to pay to have access to a more detailed information on the soil water level, the plant growth and the climate, this amount depending on risk preferences and is substantially increasing if the water resource is limited. This survey shows that the value of information is all the higher when the water for irrigation is limited and when the water retention capacity of the soil is low. In the long term (that is to say on a multi-annual scale), both the irrigation technologies and the choices of cropping-system can be modified by farmers in order to lessen the impact of droughts. In California for instance, an intensification of the use of irrigation technologies after 5 years of drought between 1987 and 1991 has been observed (for instance over that period, for fruit and vegetable cropping, drip-feed irrigation increased by 40%). In the long term, a way to attenuate the impacts of drought consists in modifying the cropping systems, that is to say the crop rotations, in order to favour varieties that are more resistant to water stress. According to Amigues et al. (2006) the substitution of irrigated maize for irrigated sorghum allows a 50% economy on volumes of water. These results obtained in France in experimental conditions raise some implementation issues at a larger scale (sector adaptation, fall in margins) that have so far been little studied, at least in the French context. More generally, we must mention that changes in cropping systems are one of the factors in agricultural adaptation to climate change highlighted by the IPCC in its last report.

An approach coupling economic and biophysical models

In order to assess the adaptability of agriculture to drought risk, the INRA economists have elaborated an original coupling between the agronomic model STICS developed by INRA and an economic model of production.[5] The aim of this study was to assess the cost of drought episodes for a representative farmer of the Midi-Pyrénées region and to determine whether his short or long term decisions help attenuate this cost in a significant way.

This modelling work is complex because of the dynamics between climate, agricultural productions and farmers' decisions. In this model which takes into account the climate history from 1972 to 2005, including five years of drought, the number of cropping systems used by a same farmer is limited to three representative systems:

- system A: monocropping of maize (consumes a lot of water)
- system B: durum wheat/sorghum rotation (consumes moderate amounts of water)
- system C: durum wheat/sunflower (consumes very little water).

In order to limit the economic impact of a drought in the short term (on the intra-annual scale) when cropping plans are already set, farmers can only modify the irrigation decisions (possible combinations between irrigation dates and water quantities to supply) associated with the same cropping system. Moreover, in the long term, the farmers' response consists in deciding which proportion of the farming area must be allotted to each of the three cropping systems in order to maximize the total expected profit.

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[3] Another way for a farmer to be covered against drought risk is to turn to public or private insurance.

[4] A measurement of the value of information is a key element in carrying out a cost-benefit analysis of the implementation of early-warning drought mechanisms.

[5] This study is referenced in the appendix to the final report of the "drought and agriculture" assessment. See also Reynaud (2008) for a more recent version of that work.

Table1: Drought cost to the representative farmer of Midi-Pyrénées.

		1972-2005			Dry Years[a]		
Cropping systems		**A**	**B**	**C**	**A**	**B**	**C**
Soil 1	**Gross margin (euros/ha)**	472.3	669.5	595.3	436.7 -7.5%	612.5 -8.5%	532.5 -10.6%
	Irrigation (mm/ha)	134.6	10.3	--	210 +56.0%	12 +16.5%	-- --
Soil 2	**Gross margin (euros/ha)**	917.4	725.3	746.7	628.6 -31.5%	725.8 +0.1%	664.48 -11.0%
	Irrigation (mm/ha)	157.7	12	--	246 +56.0%	12 +0.0%	-- --
Soil 3	**Gross margin (euros/ha)**	932.0	742.1	778.1	718.1 -23.0%	702.5 -5.3%	675.8 -13.1%
	Irrigation (mm/ha)	145.7	10.3	--	282 +93.5%	10 -2.9%	-- --

[a] Dry years correspond to 1976, 1989, 1990, 2003 and 2005.

Gross margin and irrigation correspond to annual averages calculated over all the years for column 1972-2005 and over the dry years for 'dry years' column. Percentages correspond to the deviation from column 1972-2005. For example, for a dry year, the average gross margin of cropping system A and soil type 1 is 7.5% lower than the average gross margin calculated over the whole period.

The farmers' imperfect knowledge of the future situation gives an uncertain aspect to profit. Farmers' preferences are represented by a utility function with a constant relative risk aversion. Then the economic model is calibrated by using data from the Midi-Pyrénées Regional Direction of Agriculture.

The cost of droughts for the representative farmer of the Midi-Pyrénées region

In table 1, we show the results of the economic simulations for three soils representative of the Midi-Pyrénées region (soils 1, 2 and 3 correspond respectively to soils with a low, median, and high water reserve). At first, we limit ourselves to a discussion on the level of gross margins and optimal irrigation levels.

In terms of gross margin fluctuation with regard to the 1972-2005 average, cropping system A (maize monocropping) records the highest changes due to dry years: from - 7.5% to -31.5% according to the soil. The impact of dry years on the average gross margin with cropping system C (durum wheat - sunflower) seems to be independent of the soil type. The average gross margin loss varies from -13.1% for soil type 3 to -10.6% for soil type 1. Cropping system B seems to benefit slightly from dry years with soil type 2.

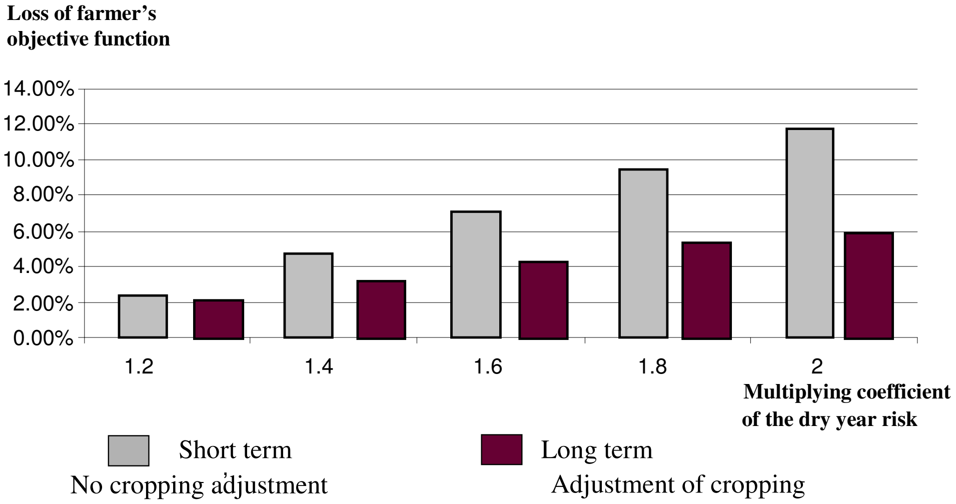
Once again, system A is the most sensitive to the impacts of drought on optimal irrigation levels. For instance, over 1972-2005, the average optimal irrigation is 145.7 mm/ha for cropping system A and soil type 3. In dry years, we note a 93.5% rise and the average optimal irrigation goes up to 282 mm/ha. It should be noted that the rise in average optimal irrigation depends on the water price paid by farmers. If we multiply the price of water by two (the water price going from 0.064 to 0.128 Euros per m^3), the average optimal irrigation in case of drought goes down to 210 mm/ha against 282 mm/ha previously (-25.5% in volume). This expresses the fact that even in a maize monocropping system, farmers are sensitive to fluctuations in the water cost.

The impact of dry years on optimized gross margin and on the irrigation decisions of the Midi-Pyrénées farmer seems important with system A (maize monocropping) - an average gross margin loss of 20.7% for the three soils - very moderate with cropping system B - an average gross margin loss of 4.6% for the three soils and relatively high with cropping system C - an average gross margin loss of 11.6% for the three soils.

A measurement of the farmer's adaptability facing an increased drought risk

The coupling of the farmer's economic decision model with the cropping model STICS allows the adaptability of the Midi-Pyrénées farmer facing an increased drought risk. To do so, we modify the probabilities associated with the climate years by giving a greater weight to drought years (1976, 1989, 1990, 2003 and 2005), then we solve the farmer's optimisation programme. In what follows, we apply a multiplying coefficient to drought risk (from 1 to 2), where a coefficient equal to 2 means that the frequency of occurrence of a drought year is twice as high as in the equiprobable case.

Figure 1: Impact of an increase in frequency of drought years on the objective function of the representative farmer in Midi-Pyrénées.

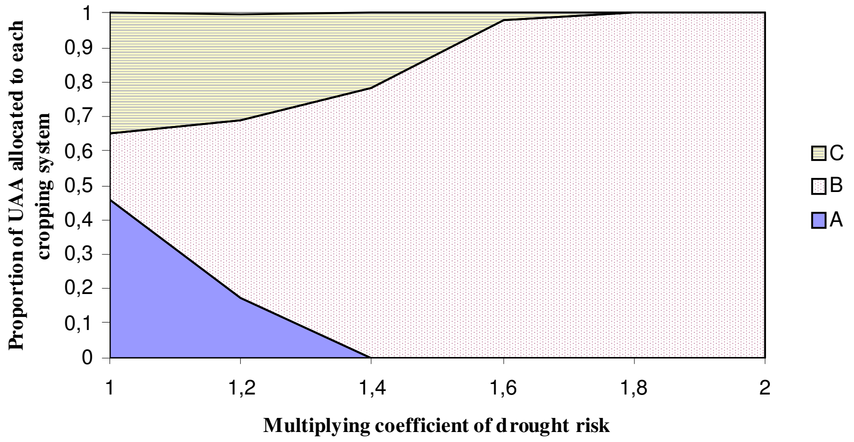


In the short term first, when the farmer can only modify his intra-annual irrigation decisions, the loss following a moderate increase (+20%) in drought frequency remains moderate itself (loss of 2.36%, see figure 1). Therefore, the choice of irrigation strategy helps limit the impact of an increase in the frequency of dry years on the objective function when this frequency is moderate. Conversely, when the drought risk is multiplied by 2, the loss in terms of the objective function of the Midi-Pyrénées farmer becomes substantial (-11.78%). The short term flexibility offered by the irrigation choices does not help to limit the economic loss in a significant way if there is a strong increase in frequency of dry years.

However, in the long term, the strategic irrigation choice combined with a re-allocation of areas between cropping systems helps limit the impact of a strong increase in the frequency of dry years on the objective function. The loss related to the increase in drought frequency does not exceed 6.08% of the objective function of the representative farmer: the re-allocation of areas between systems A, B and C as well as the intra-annual adjustments of the irrigation strategies appreciably attenuate the impact of the increase in drought risk on the objective function of the representative farmer (expected utility).

This result must be analysed in the light of the optimal choices of cropping patterns which vary in a very significant way with the increasing intensity of droughts (Figure 2). While we expect the choice for the least water-consuming system C to prevail, it is the intermediate system B which is selected. This result can only be analysed in the light of the farmers' behaviours towards risk. In order not to face a too strong decrease in his profit if a bad climatic realisation occurs, the farmer is ready to opt for the cropping systems which do not provide the highest gain in a "normal" climatic year. Here, the intermediate system durum/sorghum selected in the case of very high drought risk provides low production costs but also quite low yields.

Figure 2: Impact of a rise in frequency of drought years on the optimal allocation of the land to cropping systems (long term choice)



A measurement of the impact of public crisis management policies on farms

The recent drought years saw the implementation of quantitative limitations of agricultural water use. Those restrictions are expected to accompany drought phenomena more and more. It is essential for public authorities to be able to assess the economic costs associated with such restrictions.

We know that the impact of drought risk on the farmer's objective function depends crucially on his ability to anticipate or not the possible limitations or interdiction on irrigating. The economic model helps determine the cost of droughts to the farmer according to the date from which he knows that irrigation will be restricted or banned. The model helps measure the private gains associated with the implementation of early-warning drought mechanisms set up by public authorities.

The results first show that, in terms of the objective function of a non-anticipated irrigation interdiction, the farmer's loss may be very high in the short term. During dry years, when the farmer cannot anticipate the irrigation bans in periods of low waters, the loss may reach 54% of his profit. Still in the short term, early information on the irrigation ban risk transmitted to farmers thus helps significantly limit the loss of the objective function. This may remain lower than 15% if the ban is known for certain before mid-July. However, Reynaud (2008) shows that in times of low waters, the long-term decisions by the farmer (reallocation of the areas between the three cropping systems) substantially attenuate the cost of irrigation restrictions: the loss resulting from the irrigation bans is moderate whatever their degree of anticipation.

These results suggest that it is essential for the public decision-maker to facilitate the changes in cropping systems through the implementation of incentives, technical assistance and transmission of information, for instance. They also suggest that these drought early-warning mechanisms may generate substantial gains for agriculture.

Conclusion

The impact of drought risk on the objective function of the Midi-Pyrénées farmer has been assessed by distinguishing the optimal short term decisions (choice of irrigation strategies) and long term decisions (choice of cropping systems). The method has consisted in using the simulation results of an agronomic model (STICS) in an economic model optimizing farmer's decisions.

With a given cropping system, the farmers' adaptation to drought risk (through the choice of irrigation decisions) seems to be quite limited and the economic cost induced by the drought may be high. For instance, multiplying by two the risk of dry year occurrence leads to a loss of 11.78% of the farmer's objective function. In the long term, the results of the economic simulations suggest a rather different situation. Hence, the adaptation of the cropping systems allows to limit the private cost of drought episodes to the farmer in a quite considerable way. For example, the loss resulting from the doubling of drought frequency is divided by two if re-allocations of land between cropping systems are possible (6.08% against 11.78%). This last possibility, combined with the intra-annual adjustments of irrigation strategies, attenuate the impact of an increased drought risk on the representative farmer's objective function.

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For further information

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