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Investigating Operational Decision-Making in Agriculture

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Abstract: Farmers, in their role as production managers, have to make daily management decisions about the technical operations to be performed on the biophysical components of their farms. These decisions have important implications in terms of the sustainability of the farm business and deserve in-depth examination with a scientific approach. The traditional decision research paradigm assumes an idealized decision situation in which the farm manager knows all the relevant alternatives, their consequences and probabilities, and has fixed preferences and possesses the cognitive capacity to efficiently process them. Many studies have shown that the farmer's decision-making context does not meet these assumptions. We propose that our understanding of the decision made could be increased by focusing on the natural strategies used by farmers. We present some preliminary thoughts about the issues to be addressed, in particular, the various key notions such as objective, preference, uncertainty, anticipation and rationality. Particular attention is given to the heuristics that farmers use to: (i) select the relevant information to be taken into account; and (ii) simplify the decision process and make it easily tractable. We argue that a bounded rationality approach is required to examine *in situ* individual management behavior, explain performance differences between farmers and help identify possible improvements.

Keywords: *bounded rationality; mental model; action; uncertainty; preference*

1 INTRODUCTION

When managing an agricultural production system, farmers make different types of decisions that range from setting long-term objectives or commitments (e.g., overall production target, buying extra land or expensive machinery) to taking short-run actions to drive the production process thanks to technical operations. The decisions of the first type are said to be strategic and are amply addressed in the agricultural production literature. The other ones, referred to as operational decisions, are the output of an ongoing cyclical process by which the farmer determines, at least on a daily basis, the operations to be performed. Studying operational farm management behavior is becoming increasingly important because: (i) decision-making (including operational) is becoming more complex and knowledge-intensive in agriculture; (ii) it is a key factor in performance analysis (economic, environmental, organisational); and (iii) for many reasons related to the changing context of agriculture (climate change, environmental issues, market and legislation pressure), there is a growing need for a change in management practices. Understanding why some farmers appear to be more successful producers than others is of central importance in farm management research (Gray et al. 2009; Rougoor et al. 1998; Nuthall 2011). More than ever, science is needed to support the development of new management practices that are critical for coping with new challenges. The objective of this article is to present a preliminary exploration of what is involved in an operational decision-making process and which issues to address in order to make it an object of scientific study.

Farms that operate in similar physical and economic environments have often very different performance outcomes (Solano et al. 2006). Numerous farm management studies have used surveys to measure the socio-economic variables that define the characteristics of successful farmers. Research shows that the difference is mainly due to the farm manager’s decision-making skilfulness, the faculty for dealing with uncertainties, and the ability to properly balance a wide range of factors and adapt to changes. The production performance is critically dependent on the ability of the farm manager to deal with the right problems and opportunities at the right moment in the right way. The majority of farm managers make operational decisions on the basis of knowledge that is largely tacit, resulting from years of experience of outcomes of past decisions and interactions with colleagues and advisors. A limited number of in-depth studies have actually examined the process by which a farmer selectively combines the different types of information that play a role in solving the decision problem (see Gladwin (1989), Öhlmér et al. (1998), Fountas et al. (2006) and McCown (2012) for examples). Such a study could significantly help to identify strengths and weaknesses of a decision behaviour and, therefore, to improve the farmer's managerial ability.

An explanation of decision-making behavior can be shaped by examining the manager's mental model (Johnson-Laird 1983). A mental model is a personal, internal representation and inferential process that is used to: (i) interact with the system to be controlled and the world around it; and (ii) take control actions consistent with the manager's personal view. The mental model conveys the specific understanding that the farmer has about his management problem. Mental models thus act as a repository of decision-relevant information and as an inferential framework. The focus on the decision process, rather than the outcome of the decision process, is consistent with the shift of emphasis between cognitive psychology and normative approaches in economics. Understanding how people arrive at their choices is an area of cognitive psychology (Klein et al. 1993) and other disciplines such as behavioural economics, and more generally management science and artificial intelligence (Simon 1996). In fact, the main metaphor attached to this perspective conceptualizes decision-makers as information processors who use processes of perception, categorization, storing, prediction and other types of problem solving.

Section 2 of this paper outlines what characterizes operational decision-making in agriculture. Section 3 introduces some of the most salient features of the mental process involved in the decision-making process.

2 WHAT IS OPERATIONAL DECISION-MAKING ABOUT?

A farm system can be decomposed into three constituents (Martin-Clouaire and Rellier 2009): a decision system (i.e., the farmer is considered as a manager), an operating system (i.e., resources such as the labor force, machinery, inputs), and a biophysical system (i.e., soils, crops, livestock, etc.). These systems are in constant interaction and influenced by external factors (e.g., weather, epidemic outbreak). This paper focuses on the decision system that has so far been essentially studied within the simplistic rule-based decision paradigm. This section revisits the notion of operational decisions, which are the output of the decision system and the input of the operating system.

2.1 Organizational and time-related constraints

Production management in agriculture involves daily, or even more frequent, decision-making moments at which the farmer decides which actions to take to be executed immediately. The determination of these actions is the process that we call operational decision-making.

The chosen actions are undertaken with a view to achieving an intended result and are not improvised. They serve general production goals and are consistent with a plan that expresses the farmer’s production logic. The plan concerns the temporal organization and the tentative coordination of work and required resources. At a given time, such a plan is the result of reflection on prior experiences of production practices, the anticipation of particular goals and probable occurrences of important events. Because of this, plans are not rigid in the sense of a definite and precise specification of the execution steps (Martin-Clouaire and Rellier 2009; 2011, Dury et al. 2013). A plan guides the flow of work to be done in a responsive manner and can be adapted to different circumstances. Because the context of execution cannot be fully predicted, actions are inevitably situated and require an operational decision-making process responsible for determining actions that are admissible according to the ongoing plan and appropriate given the current situation. Although the actions are incompletely specified by the plan, they are often bound to temporal constraints such as the earliest and latest execution time of execution. Operational decisions thus depend on tactical (work planning) and strategic (goal setting) commitments that provide guidelines but that also impose constraints. Moreover, a plan provides a framework for monitoring actions, and allows the user to determine whether or not he/she is achieving or moving toward the objectives through the expected intermediary states.

A common oversimplification about operational decision-making in the farm systems modelling literature is that decisions are made independently of each other, without regard for anything that has gone before and ignoring that they are made in compliance with the overall production logic expressed by the ongoing plan. Operational decisions are made within a context of previous decisions and have decisional consequences. Every decision made affects the decision stream and the sets of alternatives available immediately and in the future. Therefore, operational decision-making has to consider future actions to facilitate (or enable) the applicability of the plan: what seems good at one point can be in conflict with what is best overall. The present decisions might strongly restrict the freedom for the future ones and, therefore, reduce the possibility to act optimally in the future if some unfavorable circumstances occur. For example, the farmer may be initially inclined to wait an extra week before applying a chemical treatment to a certain wheat plot. However, given that the same week will probably be extensively devoted to maize sowing activities, the farmer may finally choose to spray the wheat immediately in order to avoid the possible conflict. More generally, the actions might have both short- and long-term consequences, some desirable and some possibly undesirable, therefore requiring an anticipatory approach.

Since the decision environment continues to evolve as time passes, it is often advisable to put off making a decision until more favorable conditions are met. Information and alternatives continue to grow as time passes. Therefore, in order to have access to the most information and to the best alternatives, it might be better not to commit too early. Nonetheless, it is obvious that some alternatives might no longer be available if too much time passes, making the hoped-for better conditions turn out to be worse. Operational decision-making is clearly confronted with the constraint of the cut-off date for the decision: delaying provides some benefits (e.g., more information) and involves some risks (e.g., alternatives that become unavoidable). Moreover, since some operations need to be done within a given time (e.g., sowing corn in April), the notion of urgency can appear when the deadline of a given operation approaches. By integrating the time available to execute an operation and the importance of its impact, farmers can then define priorities. Little focus has been given to urgency and priorities within farm management literature, whereas they are key notions at the operational level.

2.2 Driving factors in operational decision-making

In addition to the plan, several other factors influence operational decision-making and may vary among individuals. They include past experience and knowledge, perception of the current state and belief of what might result from particular actions, goals and preferences, as well as other factors that concern the role of effect in decision-making. Understanding these factors and the way they are handled in the decision process (next section) is important to understand the decisions made.

Farmers' decisions are responsive to the data that they value the most, such as the current state of the biophysical system that is observed through the assessment of some physical properties (e.g., soil moisture) or personal indicators (e.g., crop vigor) that provide a synthetic informative clue. Naturally, weather forecasts, market and regulation information are also included. Farmers might also use reports from extensions services or advisory services (e.g., on regional pest outbreaks). These sources are often pervaded by various types of imperfections such as uncertainty (the stochasticity of weather), imprecision (poor or erroneous measurements) and bias (partisan opinions). These imperfections are a potential cause of adverse outcomes or negative impacts on production. Understanding the way farmers perceive and deal with such risks is thus very important and is especially challenging (van Winsen et al. 2013): How do farmers deal with these risks and how are different attitudes characterized? Is there any room for a quantitative measure or treatment of these aspects? How are they considered in the decision-making process? The work of Lipshitz and Strauss (1997) is one of the rare attempts to investigate the role of uncertainty in decision making by experts (not in agriculture unfortunately).

The farmers' goals and intrinsic values (e.g., ethical principles) are among the driving forces involved in the operational decision process. They may concern very different aspects including agronomic and economic targets, the survival of the farm, family wealth, biodiversity conservation, leisure time, etc.

They may be of various natures, ranging from mandatory requirements (e.g., contractual delivery conditions) to desirable benchmarks (e.g., income greater than a given threshold) or optimization objectives (e.g., yield maximization, minimization of environmental impact). On the basis of these values and goals, farmers can derive criteria that are a necessary step toward building a basis for comparing alternative choices. Since some goals may be contradictory (e.g., increasing both the number of irrigations per field and leisure time), the criteria should be supplemented by preferences (i.e., importance of specific criteria in the situation). Despite some recent works (Dury et al. 2010; Nuthall 2011), eliciting farmers' decision criteria and preferences together with their context-dependent dynamics remains a challenge.

The most important factor to influence farmers' decisions is past experience (Nuthall 2012). In fact, decision-making behavior is highly determined by knowledge about the functioning of the production system in response to external factors and actions. This knowledge comes from education and, for the most part, from experience acquired through years of farm management practice. How is this essentially tacit knowledge structured and made available when a decision must be made? How is knowledge about biophysical mechanisms articulated with action-oriented knowledge? Experience makes it possible to quickly recognize the similarity of the present situation with one previously encountered and solved before (Fountas et al. 2006). How can knowledge and experience be conceptualized so as to lend itself to analogical reasoning?

3 UNDERSTANDING FARMERS' MENTAL CHOICE PROCESSES

3.1 Need for a paradigmatic change

The farm management field has long been dominated by agricultural economists who were themselves strongly influenced by the rational choice approach of microeconomics. They typically considered the decision problem through quantitative models based on the theory of expected utility and the assumption of full rationality. The seminal work of Simon (1955) on bounded rationality renewed the perspective on human decision-making by considering the limitations of available information, the available time to solve a decision problem and the cognitive capabilities of the decision-makers. The application of the classical expected utility framework to the operational decision-making level is severely hindered for several reasons: (i) probabilities about the possible effects of the actions and their respective worth (and, thus, utility functions) are extremely difficult to formalize and to obtain; (ii) what has to be solved is a sequence of operational decision problems that are all different and therefore require a huge amount of information to be collected and stored; and (iii) computation time (and capacities) needed to compare alternatives are limited, especially in the case of a situation of urgency. Therefore, how do farmers make operational choices? These economic models (Chavas 2004) generally do not spell out the procedures by which decisions are made (see Öhlmér et al. (1998) for an exception). However, to answer this question, we need to understand the mental process involved in decision-making. Mental models are personal, internal representations and inferential processes that managers use to: (i) interact with the system to be controlled and the world around them; and (ii) make decisions about control actions consistent with this personal view. Mental models are constructed by individuals based on their unique understanding of the world, life experiences, perceptions, goals and values, and managerial attitude.

Simon (1996) argued that any type of serious, complex decision problem involves both deliberate (i.e., causality-based) and action-oriented thought. Deliberate thinking is controllable, conscious, and relies on knowledge about the functioning of the system. Action-oriented knowledge is essentially based on experiential knowledge and allows rapid, automatic and relatively effortless decision-making. Deliberate thinking is used in situations either where the individual cannot rely on past experience or with respect to events that will possibly occur in the future. What is the role played by such causal knowledge in operational decision-making in agriculture and how is this type of reasoning articulated with the use of action-oriented knowledge? Some insights are provided in McCown (2012).

Since logical deliberation requires elaborate reasoning and time, farmers very often use action-oriented knowledge. For many researchers who adhere to the bounded rationality philosophy (see, for example, the naturalistic decision-making theory of Klein et al. (1993) or the fast and frugal heuristics of Gigerenzer and Gaissmaier (2011)), decision-makers use heuristics. These reasoning shortcuts (rules of thumb), make it possible to effectively find good enough solutions when the best ones cannot be obtained. Simon argued that because decision-makers lack the ability and resources to arrive at (or even formulate the notion of) an optimal solution, they instead apply their rationality only after having greatly simplified the set of possible choices. Thus, the decision-maker is a ”satisficer”, one seeking a satisfactory solution rather than the optimal one. Similar notions were used in agricultural system models in which the management component was represented as a set of decision rules (e.g., Aubry et al. 1998; Cros et al. 2004; McCown 2012). The issue is now to characterize the types of heuristics invoked by farmers and the inferential mechanism that underlies their use.

In order to facilitate the investigation of the decision-making process, we distinguish two parts: (i) the framing of the current decision problem through the selective collection and transformation of information; and (ii) the choice of actions based on the combination of the collected information with the other knowledge about the farmer's background and aspirations. However, the reader should keep in mind that these two sub-processes are highly intertwined (Öhlmér et al. 1998). For example, while evaluating an alternative, the farmer may seek additional information that is deemed essential at this stage.

3.2 Search, selection and perception of information

Information is required throughout the choice process, from problem framing to decision evaluation. However, information is not always readily available. It may be necessary to retrieve it from historical records, collected from observations or from external sources (e.g., advisory services). In many cases, information may require some preliminary processing to be transformed into a synthetic piece of decision-relevant evidence. Decision indicators need to be developed by combining directly observable data. In any case, farmers have to go through a search process and, as mentioned earlier, they have to carefully select what to search for in order to maintain the rapidity of the decision process. Therefore, the decision problem is significantly truncated by restricting the number of elements taken into account. Reducing the amount of information has the effect of streamlining the subsequent steps of the decision process. The selection process certainly relies on some ready-to-use heuristics resulting from the farmer’s experience, but it will probably involve some reasoning as well. In particular, it seems that this process involves a preliminary situation assessment phase to evaluate if everything is as expected or if potential anomalies are visible.

Investigating how farmers select information raises a set of questions. What types of heuristics are mobilized to scrutinize only some information while avoiding cognitive biases that put the decision process on the wrong track? Do they rely more on (lend more credence to) expected observations and plain facts? Do they tend to dismiss information or observations that are perceived as uncertain? What are the patterns that are used in the situation assessment phase and how is the pattern matching done? What is the importance of perceptions, skills and biases? What type of inference follows the identification of an anomalous situation and by what mechanism is the decision process changed in order to be more precautionary? Do heuristics play a role in diminishing the need to store information for potential future needs?

3.3 The process of choosing actions

The selective collection of information addressed in the previous subsection yields the basic material to be used in the action choice process in combination with the goals, preferences, constraints and relevant knowledge of the farmer. We have seen that optimization procedures that would treat all information and compare all alternatives are materially and cognitively impossible in the context of operational decision-making. Consequentially, which inferential procedures do farmers use to derive satisfactory solutions with a partial view of the current situation given their bounded cognitive capacities and limited time to be allocated to this task?

A first proposal to simplify the decision problem is to reduce the number of alternatives to be treated. However, the question remains as to how farmers select (or eliminate) alternatives and, ultimately, how they compare them. We hypothesize that in the context of operational decisions, non-urgent candidate solutions are discarded if others are; but what does happen in the other cases?

Classical theory assumes that the goals to be achieved and their relative importance in any decision situation are either predetermined or clear, and representable by utility functions. In operational decision-making, the goals are not given. They are shifting (some develop while others disappear as the context evolves) and are sometimes vague (e.g. under the form of reference points used as basis for decision) as reported by Öhlmér et al. (1998). Therefore, a central problem is to determine which objectives are the most important in the current situation. Farmers often have to deal with a multitude of objectives, many of which may be conflictual. It would also be informative to explore the way decision-makers change their minds (beliefs, views, goals, preferences, priorities) during a decision-making episode and between two of them that are close in time (i.e., where the situation has not changed much in between). The choice problem may have been reframed or values/attitudes revised as a result of changes in the conditions or other circumstances. Another possibility to make the choice problem tractable is simply to reduce the number of goals and choice criteria, keeping only the most important ones in terms of the farmer's experience. Some alternatives could then be immediately eliminated because they do not give satisfaction with respect to the most important criteria or to enough of them. However, it is still necessary to compare alternatives given criteria that might not be of the same nature. Literature on multi-criteria analysis can provide some insight but further research is needed.

Comparing pro and cons (i.e., polarizing) can be another way to choose an alternative. The issue of making decisions on the basis of arguments that either support or discard the candidate solutions has recently been the object of renewed attention in disciplines such as artificial intelligence (Dubois and Prade 2008) and cognitive psychology (Raufaste and Vautier 2008). The idea has also been explored by Tversky and Kahneman (1992) in their prospect theory where the importance of positive and negative aspects is measured separately. However, qualitative approaches (Bitsch 2000; Bonnefon et al. 2008) seem more appropriate to comply with information, time and the cognitive constraints of operational decision-making.

There has been very little attention given thus far to understanding how and when farmers can make effective use of analogies drawn from their existing mental models when faced with significantly new contexts. How can analogies be conceptualized? Can they help to reduce the complexity and uncertainty of the new decision problem and how can they produce fresh insights?

The treatment of uncertainty is another major issue. How do individuals behave when faced with a risky choice? Our understanding of uncertainty management in operational decision-making is quite limited. Most risk-related works have actually focused on probabilistic representations of risk, including in prospect theory (Tversky and Kahneman 1992). Within this framework, modelers consider that the decision-makers distort probability distribution (e.g., give too much weight to some of them through loss aversion). However, these models remain in the realm of optimization approaches that have raised much criticism because of the perfect rationality hypothesis underlying them and the overly simplistic view that they convey. Several farm management studies (van Winsen et al. 2013) showed that farmers seem to follow a different track in practice because: (i) they lack accurate quantitative data (frequency and potential loss); and (ii) the processing of probability distribution on a daily basis requires computational treatment that is neither easy nor convenient for them. Moreover, it seems that much processing is done in a qualitative manner.

4 CONCLUDING REMARKS AND CHALLENGES FOR FUTURE WORKS

The preliminary exploration presented in this paper assumes that farmers decide what to do on the basis of experience and are guided by a dynamic production management plan. They seem to derive or adjust their goals and preferences dynamically to meet the needs and the perception of the current situation. The final choice stage probably involves only a few alternatives and it seems that no extensive generation of options takes place. In other words, the farmer's decision process is more consistent with the bounded rationality perspective than with the omniscient optimizing one. The traditional decision research paradigm is simply not relevant in the setting of operational decisions.

Understanding decision making in such complex environments requires methods that shed some light on the nature and role played by experiential knowledge, perceptual and inferential processes, situation appraisal and information gathering strategies. The naturalistic decision-making framework

(Klein et al. 1993; Lipshitz and Strauss 1997; Schraagen et al. 2008) that focuses on the study of decision-making processes in real-world settings definitely has some theoretical support to offer as a starting point. In particular, the techniques of cognitive task analysis (Crandall et al. 2006) developed in this framework provide a set of useful tools, including structured interviews and methods of work observation, which may be applicable to elicit the mental model underlying the farmer's decision process. However, the understanding of the various forms of heuristics used and the way they are combined with uncertainty and preferences is still the major challenge. This requires additional theoretical work that, we believe, should be based on a thorough survey and analysis of how farmers make operational decisions in situation. From this empirical investigation, we plan to develop conceptual and simulation models of the farmers' mental models identified. Modelling is expected to provide an efficient communication means as well as a framework to support the experimental validation of the empirical findings.

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