COMPLEXITY, RISK AND JUDGEMENT: AN ESSAY WITH REFERENCE TO ARGENTINE AGRICULTURE

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1. Introduction

Decision-making is of central interest for multiple disciplines, among these economics, management, psychology and political science. Each discipline favors different approaches to the study of choice. In the case of orthodox economics, focus is placed on the individual and on the rational (i.e. perfect knowledge and utility maximizing) framework. But alternative lines of thought challenge the above. One results from the work of Herbert Simon, in particular his concept of "bounded rationality". More recently, work by cognitive psychologists Daniel Kahneman and Amos Tversky has produced intriguing results concerning biases in human thought processes, challenging many of the long-held assumptions by economists in their work on consumer and producer behavior.

The objective of this essay is to bring together some separate strands of decision processes mentioned previously. Focus is on analyzing the relevance of these concepts for understanding of a particular agent: the agricultural firm. Agricultural producers have of course been subject to considerable study as relates to their decision-processes. No attempt is made here to present even a small fraction of research done on the topic. Rather, focus is placed on selected issues and controversies and on possible gaps that merit further work. Selected cases of Argentine agriculture are presented to illustrate the relevance of the topic.

Following this introduction Section II reviews approaches and issues related to decision-making. In Section III focus in placed on the agricultural firm, particularly on the decision-environment surrounding the producer, and the implications of alternative decision-theories for improved understanding decision-making. Three important books on decision processes in agriculture are briefly reviewed. Decision cases from Argentine agriculture are presented in Section IV. Section V concludes.

The focus of the paper is on understanding the relevancy and role of risk for resource allocation and management in agriculture. To what extent do producers sacrifice profits to reduce risk? How is risk evaluated, and what difference if any, does "risk" have with "uncertainty" or with notions such as "ambiguity"? How should effort be allocated by agricultural economists to understand decision processes?

2. Decision making in firms

2.1. Alternative views of the firm

The firm as a production function, and the firm as a nexus of contracts are the two important analytical approaches used for analyzing producers in a market economy. The former is a highly simplified model where a set of inputs enter a "black box" and through unspecified transformation process emerge as one or more outputs. Prices are attached to inputs and outputs. Under competitive conditions, these are exogenous to the firm. Assuming profit-maximizing behavior, and given a production function and market prices, insights on output supply, factor demands, costs, returns to scale and input substitution obtain. If the impact of risk is to be analyzed, utility is substituted for profit-maximization as the objective function. But this is only a first step, also necessary is the inclusion of how the choice set is arrived at, how uncertain states of nature are conceptualized, and how probabilities of these states are elicited for decision purposes.

The production function (or "black box") approach to the firm is a basic building block of the theory of markets: interactions between consumers as demanders (and suppliers), and producers as suppliers (and demanders) result in prices and quantities. As relates to the firm, the objective is not to understand inner working of this entity, but to derive the implications of its existence as a market participant. Notwithstanding the above, this approach also allows evaluation "behavioral" aspects, in particular different dimensions of firm-level efficiency.

The conventional microeconomic model assumes that producers operate in a "technically efficient" manner, i.e. "on" the production surface. But empirical research provides evidence of departures from efficiency in the sense that output falls below what is technically feasible (see Ray, Chambers and. Kumbhakar, 2022). If $\boldsymbol{y}$ and $\boldsymbol{x}$ correspond respectively to an index of output and input, inefficiency implies $\boldsymbol{y} < \boldsymbol{f}(\boldsymbol{x})$. This situation results in divergence from the "ideal" model of firm behavior. Less than maximum (technical) efficiency is a consequence of imperfect knowledge as it results in less output for a given amount of effort (input use), or more effort for a given amount of output. Understanding these and related efficiency issues poses challenges in data gathering and analysis, and in conceptualizing how relevant knowledge is captured, processed and acted upon by producers.

As an alternative to the black box approach mentioned above, the firm may be analyzed focusing attention contractual relations. The firm is seen here as a central nexus in a set of bilateral contracts. As pointed out by Ricketts (1987[1994]), the Edgeworth box, and not the production function, is the basis for the analytical framework to be used. The modern "Theory of the Firm" developed from this paradigm and has as an important precursor Ronald Coase's paper on transaction costs and firm organization (Coase, 1937). The contractual nature of the firm emphasizes challenges resulting from exchange, be this between the firm and an input supplier, a customer, workers, managers or its owners or representatives of owners. The prevalence of asymmetric information, of conflicts of interest and of mild or severe opportunism constitute the crux of decision complexity.

In the context of the Theory of the Firm, focus on the producing unit as a contracting agent leads to the "principal-agent theory" where the objective is understanding the characteristics and information demands of optimal contracts between economic agents. In an early paper Simon (Simon, 1959) contrasts the "orthodox" approach with alternative theories of decision-making. His essay draws on psychological theory and makes a plea for increased attention to real-world decision processes. Simon is critical of the "maximizing" postulate pervasive in the analysis of consumer and producer behavior. He offers the alternative of a "satisficing" approach, where decision makers engage in search, arriving at solutions that are "good enough" given the costs involved. Aspiration levels play an important role both in triggering search behavior, as well as in determining when the search process peters out. Aspiration levels are not fixed but are adjusted upwards or downwards in response to the perceived gap between achieved and "desired" (aspiration) performance. An important aspect of Simon's work on decision making is his emphasis not on choice between known alternatives, but on search processes generating opportunities for choice: alternatives are not given but must be found.

How the firm is modelled affects the type of decision processes that can be analyzed: the firm as a production function allows analysis of aspects such as departures from technical or allocative efficiency, and hopefully identification of factors behind such departures. Important aspects such as the impact of human capital on adaptation to changing relative prices, or input marginal productivity can be addressed (see, e.g Huffman, 1977). In turn, insights from the contractual approach to the firm can suggest questions to be asked relative to the impact of incentive schemes for workers, vertical integration or dis-integration, land tenure arrangements, choice of financing schemes and other aspects.

2.2. Decision under risk

In its simplest form, the analysis of decision-making under risk requires the profit objective function to be replaced by one where "utility" is the relevant maximand. The problem arises when an attempt is made to replace general concepts with those appropriate for empirical analysis. A simple experiment is proposed to evaluate thought processes in risky choice (see Box 1). This experiment has only been carried by the author only in exploratory form and is presented here for illustrative purposes.

For Question 1, arriving at a "best choice" requires introspection as relates to the utility ($\boldsymbol{U}$) of possible consequences ($\mathbf{x}$): $\boldsymbol{U(x)}$. It also requires an intuitive understanding that the "best" alternative is that resulting in maximum Expected Utility:

$$U(Guess\ die\ D_i) = \left(\frac{1}{3}\right)U(300) + \left(\frac{2}{3}\right)U(0) \quad (1)$$

Box 1
The experiment – Estimating the value of Sample Information

A bag contains three dices. Dice "1", "2" and "3" have, respectively, 4, 6 and 8 faces marked with sequential numbers starting with 1.

One dice is extracted randomly from the bag. You are offered the choice of guessing what die was extracted. If you guess correctly, a prize of US$ 300 is won. Incorrect guess + results in a prize of US$ 0 (neither gain or loss).

Question 1

You may choose to sell the right to play the game to one of the numerous onlookers in the room.

Q1: What would be the minimum price you would demand (your "Willingness to Accept, WTA) in order to sell the right to play the game?

Questions 2 and 3:

Identical scenario to Choice 1, but now you are offered the possibility, prior to guessing the die that was extracted, of knowing what number that results from rolling the randomly extracted die (obviously, the person rolling the die does this without you seeing which die was originally extracted):

Q2: What would your WTA be now?
Q3: What amount – if any – would you be willing to pay to be informed of the number that results from rolling the randomly chosen die?

For Questions 2 and 3, an "intuitively reasonable" answer requires a quantum leap in cognitive processing. Let $\boldsymbol{P}(\boldsymbol{D}_i)$ represent the prior probability of the ***i-th*** die, then on receiving the information that having rolled the randomly extracted die, a certain number (z_k) obtains, using Bayes Theorem the posterior probability $\boldsymbol{P}(\boldsymbol{D}_i|\boldsymbol{z}_k)$ results

$$P(D_i|z_k) = P(D_i)P(z_k|D_i)/\sum_{i=1}^{8} P(z_k|D_i)P(D_i) \tag{2}$$

But now two additional steps are required: (a) choose what die to guess, given the posterior probabilities associated with each number selected from draw, and (b) estimate the "overall" Expected Utility resulting from weighting the each of the Expected Utilities associated with a given number, by the probability that than number finally results from the two-stage random process.

The above example suggests that the problem of decision under risk is not mainly choosing among a well-defined set of alternatives $\{\boldsymbol{a}_1, \boldsymbol{a}_2, \dots \boldsymbol{a}_J\}$ but instead one of (i) generating alternatives for choice that are not immediately evident, and (ii) judging the impact of "additional" information of the attractiveness of each alternative. And, to judge this attractiveness, the most difficult judgement to be made is not necessarily the mapping of results for each state ($\boldsymbol{S}_j$) of the world into utility: $\boldsymbol{R}(\boldsymbol{a}_i|\boldsymbol{S}_j) \rightarrow \boldsymbol{U}[\boldsymbol{R}(\boldsymbol{a}_i|\boldsymbol{S}_j)]$, but instead of correctly inferring the probabilities of uncertain states $\boldsymbol{P}(\boldsymbol{S}_j)$

From the "blackboard" example presented above it is not to be inferred that decision-makers should be educated to formally apply Baye's Theorem, or even that they should be acquainted with this concept. But it suggests that decision making is a complex endeavor, and that tools such as decision matrices or trees are only a very preliminary first step. Further, for most decisions, attempts to empirically elicit utility functions (see e.g. Winkler, 1972) may be called into question.[1]

Since Friedman and Savage's classic paper (Friedman and Savage, 1948) significant progress has been made in understanding risky choice. As mentioned above, the contributions of Herbert Simon have highlighted the limitations of the standard utility-maximizing model. Since then, the work of cognitive psychologists Daniel Kahneman and Amos Tversky have produced additional insights into decision processes (see Kahnemann and Tversky, 1977). As a result of this work, *Prospect Theory* has emerged 9999as an alternative paradigm, particularly when interest is not in understanding *how decisions should be made* (a normative question) but *how decisions are actually made* (a descriptive question). This line of work is known as Prospect Theory (PT).

In contrast with the Von-Neumann Morgenstern expected utility theory (VNM EU), Kahneman and Tversky's PT theory explains choice by evaluating consequences comparing results of alternatives with those of a "reference point". This reference point may result from prior achievements, the status-quo, expectations, objectives imposed by others (e.g. superiors in a firm) or other factors. Further, consequences from actions are not evaluated based on their total consequences, instead gains and losses are weighted separately.

How individuals map "correct" subjective probabilities into "perceived" probabilities is an additional aspect of PT. The idea here is that subjective weights are used for this mapping: "low" probabilities are corrected upwards, and "high" probabilities downwards. As an example, a 5 percent probability of obtaining a prize is transformed into a 10 percent probability. This is the "possibility effect". In the case of high probabilities, these are discounted downwards: the so-called "certainty effect" results (for example) in 95 percent of winning a prize being perceived is perceived as much worse 100 percent probability of winning.

2.3. Decision processes within the firm

The problem of efficiently organizing production is discussed by Armen Alchian and Harold Demsetz (Alchian and Demsetz, 1972). In contrast to the literature on risk, their paper does not analyze idealized decision processes, instead the focus is placed on how alternative organizational structures solve the problem of generating effort from those who form part of the firm's contractual network ("team members"). The problem is one of metering contributions by individual team members and providing incentives to discourage shirking. Contributions are evaluated subjectively (although diverse metrics can be used as a complement). Metering is done by a monitor with rights to residual returns.

Applying sticks and carrots requires an exercise in judgement: different types of signals are processed for decisions to be made. In part, processing these signals revolves around probability weighting as mentioned in the previous section: given (e.g.) that output was "low" ($\boldsymbol{O}_{\mathrm{L}}$), what is the probability that effort was "high" ($\boldsymbol{e}_{\mathrm{H}}$): $\boldsymbol{P}(\boldsymbol{O}_{\mathrm{L}}|\boldsymbol{e}_{\mathrm{H}})$. Information of this type is an input for salary, promotion, layoff and similar decisions. Alchian and Demsetz reject the theory that justifies the existence of the firm based on risk-bearing considerations. The firm is viewed instead as a process analogous to the market, where payments (prices) to team members result from the monitoring function (and residual claimant) associated with ownership. Alchian and Demsetz focus on the entrepreneur as a coordinator and monitor of the "effort" provided by team members, in contrast to Frank Knight's classical treatment of the entrepreneur as someone whose function in a market economy is the bearing of uncertainty (Knight, 1921). However, both Alchian and Demsetz, as well as Knight, emphasize the role of judgement of the entrepreneurial function: deciding in a context of unclear informational signals. The difference is that in the case of the former, judgement relates to metering input contributions, while in the latter it relates to anticipating results from courses of action and bearing the consequences of this anticipation.

Different organizational forms (e.g. individual ownership, corporate form, worker managed, professional partnership, non-profits) attempt to solve the metering and monitoring problem in different ways. For example, the "open" corporation relies on monitoring not only by the board of directors, but also by the capital market: under-performance results in opportunity for gain by outsiders who anticipate opportunities not yet taken advantage of. When ownership is separated from control, decision systems evolve to reduce incentive problems. One such system involves partitioning the decision process in four stages: (I) initiation, (II) ratification, (III) execution and (IV) control (Jensen and Meckling, 1976). Stages I and III are labelled "decision-

[1] Formal procedures of decision-analysis (e.g. Winkler, Chapter 6) are potentially useful for discrete decisions involving significant resources such as petroleum exploration, large agricultural or real-estate investment projects. But most decisions take place in a continually changing environment and involve marginal changes, where feedback is a relevant aspect to be considered.

management" and are typically carried out by senior management, while Stages II and IV ("decision-control") are under the purview of a board or external body.

The point made here is that the decision-theoretic model, while useful as a "first step" for understanding individual choice needs to be placed in a wider context where most decisions are embedded in an organizational setting, where "small" and "large" decisions coexist and are not independent of each other, and where path-dependence is a relevant factor to be considered.

3. Decisions in the agricultural firm

Climate variability, uncertainty with respect to prices and input costs coupled with imperfect contracts and in some cases imperfectly defined property rights surround agricultural decision-making. No attempt is made here to survey the vast literature related to these important topics. Instead, focus in placed instead on (i) identifying main the "threads of thought" in three important texts dealing with risk in agriculture and (ii) illustrating some of the challenges involved in improved understanding of decisions in an agricultural context.

We choose Heady's *Economics of Agricultural Production and Resource Use* (Heady, 1952), Anderson, Dillon and Hardaker's (1977) *Agricultural Decision Analysis* and Just and Pope's (2002) *A Comprehensive Assessment on the Role of Risk in U.S.Agriculture* as an introduction to important work done in agricultural decisions-making. During the half-century period ranging from Heady's to Just and Pope's book significant progress has been made both in the range, depth as well as rigor of the topics covered. However, a critic may point out that theoretical developments have outpaced empirical evidence, and probably most seriously, also outpaced relevance for decisions both in private firms as well as in a policy environment. However, these shortcomings should not blemish the elegance, logical rigor and professional excellence of work done in the area.

3.1. Early Heady's *Economics of Agricultural Production and Resource Use*

Heady's book applies rigorous microeconomics to the problems of agriculture. It is well-worth reading today. Different chapters cite classics such as Knight's *Risk, Uncertainty and Profit*, Hicks's *Value and Capital*, Stigler's *The Theory of Price* and *Katona's Psychological Analysis of Economic Behavior*. Chapters dealing with uncertainty include a general overview of uncertainty in agricultural production, the role of management and expectations, adjustments of production and resource use, instability, capital use and farm size, and factor pricing and ownership under uncertainty. The impression one gets of reading this material is how much progress can be made in understanding uncertainty, with verbal, graphical and simple algebraic models. This is in stark contrast with the highly formalized approach that constitutes the "new normal" today in most agricultural economics work.

Following Knight, Heady distinguishes between risk and uncertainty: the former including cases where probability distributions are measurable, in contrast with uncertain situations where probabilities are entirely subjective:

> In summary, *uncertainty* refers to future events where the parameters of the probability distribution cannot be determined empirically. It involves making decisions with less than perfect knowledge. Anticipation of the future can be formed but there is no way that the entrepreneur or administrator can assemble enough homogeneous observations to predict the relevant probability distributions (Heady, p,443)

Modern decision theory (see e.g. Winkler, 1972) emphasizes the subjective nature of probability, thus blurring the distinction posed by Heady. However, as in Heady above, some behavioral economists (see e.g. Dhami, 2016, p. 83) distinguish risk from uncertainty according to whether objective or subjective probabilities form the basis for choice. Recent developments in behavioral economics introduce the concept of *ambiguity* to refer to situations where the *source* of uncertainty is of importance. This is sometimes referred as *source-dependent uncertainty* (Dhami, p.284).

Heady analyzes the impact of risk on production decisions. Shifts in the production function because of (for example) weather variability result in shifts in input marginal productivity. Optimal ex-ante input levels can result, ex-post, in over- or under-input utilization. Since Heady's tome this issue has received considerable attention. Growing concern for climate change and associated weather variability, coupled with environmental regulation in the use of certain inputs (fertilizers and ag-chemicals) will probably result in increased interest in this line of work.

Although Heady's book is firmly rooted in neoclassical production theory, his treatment of decision-making takes a broad approach, touching subjects ranging from the human agent, the agricultural household, tenancy systems and capital rationing. The need for this "overall" approach to risk anticipates some of the conclusions on risk studies arrived by Musser and Patrick half a century later (Musser and Patrick, 2002).

3.2. Anderson, Dillon and Hardaker's *Agricultural Decision Analysis*

Anderson, Dillon and Hardaker's *Agricultural Decision Analysis* is a sophisticated treatment of decisions in an agricultural context. It includes an up-to-date list of references (as of mid-1970's) of both theoretical works in economics and statistical decision theory, as well as a review of empirical applications in agricultural economics. The work originated from a notable research program on risk in agriculture carried out in the University of New England (Australia). Production conditions in this country (in particular, low and variable rainfall) probably influenced the author's work on the subject.[2] Core concepts related to risk and decision making covered in the book include subjective probability, uni- and multi-dimensional utility models, risk analysis and production, whole farm planning and investment decisions. The last chapter covers evaluation of alternatives under unknown preferences.

Decision making in a "personalistic" (Bayesian) perspective is emphasized. The following is their interpretation of Bayes Theorem:

> Overall, the most important feature of Bayes' theorem is that it provides a logical mechanism for the consistent processing of additional information. Many experiments have shown that man's intuition is an inefficient basis for such processing. When acting on the basis of intuition, the great majority of the people exhibit conservatism. They do not extract as much information from the available evidence as they should (Anderson, Dillon and Hardaker, p. 55).

Two additional snippets are worth pointing out. The first relates to the estimation of probabilities (e.g. crop yields) when few historical data points are available. The "sparse data procedures" described in page 43 provide a practical method of deriving such probabilities. When historical data are not available, or if available of less-than-ideal relevance, subjective estimation of the Cumulative Distribution Function (CDF) is an alternative. In page 23 two procedures for such estimation are presented: The "visual impact" and the "judgmental fractile" methods. The importance of this is the emphases on mapping "intuitive" concepts related to uncertainty, buried in people's minds, into quantitative measures amenable for improved decisions.

A second intriguing topic relates to the estimation of utility functions. One alternative presented by the authors is the "ELCE" (Equally Likely Certainty Equivalent") method. Figure 4.3 (page 73) presents results from such an exercise. As expected, the figure shows a concave function for gains (risk aversion), but initial results show a *convex* function for losses. The authors deem necessary to correct these "apparently inconsistent" results extrapolating the concave function for gains into the domain for losses. It is worth quoting their observation:

> When eliciting utility functions for gains, it is frequently observed that the curve obtained after an initial cycle of questioning reveals a convex shape for losses, implying an attitude of risk preference that may be superficial and false. This difficulty is usually avoided by working with assets rather than gains or losses (positive and negative increments to present assets), and for this reason we recommend structuring decision problems and preference interviews where possible in terms of net assets (Anderson, Dillon and Hardaker, p.74).

[2] As an Argentine agricultural economist, I cannot be but impressed by the pioneering work done by the "New England" school of agricultural economists. Many of their writings resonate clearly to me, probably by some shared similarities in the agriculture of both our countries.

Worth noting is that the empirical results mentioned above – to them possibly "superficial and false" agree with Kahneman and Tversky "Prospect Theory", whose seminal paper was published in ***Econometrica*** in 1979, that is two years after the publication of *Agricultural Decision Analysis*. A notable example of Karl Popper's "conjectures and refutations"!

3.3. Just and Pope's *A Comprehensive Assessment on the Role of Risk in U.S.Agriculture*

Jumping two and a half decades ahead, we arrive at Just and Pope's ***A Comprehensive Assessment on the Role of Risk in U.S.Agriculture***. No attempt is made here to summarize the range of topics covered in this multi-author volume. However, a cursory review of the table of contents shows these include a discussion of the relevance of expected utility for decision-making in agriculture, non-expected utility models, information processing and judgement bias, contracts and risk, experimental techniques, finance and risk bearing, the role of liquidity in agricultural production and risk management and the environment. A section summarizing conclusions includes a chapter on the issue of whether risk (and what types of risk) matter in agriculture, and another evaluating past progress and future opportunities for risk research.

Most work on risk and decisions have focused attention on utility-maximizing choice. However, in Chapter 5 of Just and Pope's book, David Just analyzes a different, though related problem: information processing in the face of uncertainty. The basic Bayesian model presented in Section II above is extended by Just resulting in the following model:

$$p_{t+1}(x) = \frac{p(x)_t^{R(l,p,z)}\, l(\theta|x)^{L(l,p,z)}}{\int_{-\infty}^{\infty} p(x)_t^{R(l,p,z)}\, l(\theta|x)^{L(l,p,z)}\, dx} \qquad (3)$$

Where $\boldsymbol{p}_t$ is the density representing beliefs in period *t*, ***l*** is the likelihood function representing new information in period ***t***, ***z*** indexes individual circumstances, and ***R*** and ***L*** are weights representing recall ("remembering") and learning ($\boldsymbol{R} = 1\text{-}\boldsymbol{L}$) (Just, p.91). In the above parameters ***R*** and ***L*** act as weights on, respectively prior probabilities and "new" information. These weights are a function of the individual circumstances surrounding the decision-maker.

The author argues that to understand risky choice, attention must be given to how information is obtained and processed and to the limitations of the human agent in involving in carrying out such a process. The approach is then closely related to Herbert Simon's work cited in Section II above and emphasizes the relevance of learning as opposed to risk-reduction via diversification, choices of input use and such aspects.

Concluding chapters of the Just and Pope's volume include a useful summary of risk research as of 2002. Musser and Patrick (Chapter 24) ask a relevant question: Does risk really matter? They find evidence that the risk-neutral, profit maximization model is not off the mark for production decisions (e.g. fertilizer levels or crop mix), however this model may not be adequate for understanding decisions related to financial structure, or investment decisions. They ask (p.546) "Does this literature suggest that risk aversion is related to survival rather than being a fundamental goal in itself? They also ask whether in the U.S. corn belt, crop diversification is mainly a response to risk, or a consequence of the agronomic advantages of crop rotation (weed and pest control), as well as more efficient use of labor and machinery inputs.

Chapter 25 by Just and Pope summarizes the book's main findings. Main issues identified include: (a) basic risks are endogenous depending on information and farmer choices, (b) risk is particularly important for intertemporal decisions, (c) the importance of the psychology of risk assessment including information processing, (d) the expected utility model still seems the most promising alternative for empirical analysis. Some considerations are also presented on the distinction between "risk" and "uncertainty", pointing out that in some cases unanticipated states of the world, or alternative courses of action may emerge, a different situation from that represented in more a conventional risk analysis framework. Examples (occurring well after the publication of Just and Pope's volume include the Covid epidemic in 2019, and the Trump drastic tariff measures announced in April 2025.

4. Decision processes and risk in Argentine agriculture

Risk has been a pervasive aspect of Argentine agriculture since the beginning of extensive crop production in the mid- to late 1800's. To shocks from severe droughts, floods, heat stress and hail, additional losses from other causes (e.g. until the 1950's locust and other plagues such as ticks in cattle) can be added. Political instability, export taxes, exchange rate controls and high and variable inflation have also impacted the agricultural firm.

Formal or semi-formal analysis of the impact of risk on decisions and resource allocation has been increasing but is still scarce. Topics such as risk-attitudes, expectation formation on price and yield distributions and determinants of risk management strategies have been very partially addressed. And part of the work has been done from an agronomic, and not necessarily economic perspective.

Evidence on the interest on risk and decision-making in Argentina include the book by Berger and Pena (2013) on the use of Monte Carlo simulation for modelling choice at the farm level. In the last decade or so, the Argentine Secretariat of Agriculture has included a department of agricultural risk, with a focus on serving as an information clearing house on issued related to risk and not on risk-research per-se. The "Seminario de Gestión de Riesgo Agropecuario" carried out periodically since 2020 is a relevant source of empirical research on risk-related aspects in Argentine agriculture.[3] A summary of this work to date – though a useful exercise – will not be attempted here.

We present three examples on risk and decision related issues in Argentine agriculture. The first relates to the apparent anomaly resulting from the weak development of a particular risk-transfer alternative represented by multi-risk insurance products. The second focuses on technological choice and risk-bearing and the third is a brief discussion on the linkage of information and production decisions.

4.1. Weak multi-risk insurance markets in Argentine agriculture

Argentine crop production is mostly carried out in "dryland" (i.e. rainfed) conditions. Crop yields are thus dependent on adequate rainfall during the growing season. But rainfall is one of several random factors affecting yields: hail, frost, heat waves and floods also play their part. A first analysis of production in the 25-year period beginning in 2010 shows that severe weather-related events can be expected: in 2008, 2017 and 2022 aggregate (whole-country) output drops from the previous period [$100*(Q_t/Q_{t-1} - 1)$] were, respectively 36, 19 and 34 percent. Whether these output drops are a result of "normal" weather variability or respond to longer term trends associated with climate change is a relevant issue to be explored. Production variability at the farm level is considerably greater than that suggested by aggregate figures: even if "abnormal" weather factors are ignored, inter-year variation in crop yields at the farm level is non-negligible, particularly in some production areas.

Risk-transfer via agricultural insurance appears as a useful alternative for the managing on production risks. However, in Argentina the agricultural insurance market has developed only for low-probability events + severe damage situations (fundamentally hail) and not for "multi-risk" conditions, where indemnity payments occur independently of random (e.g. drought, flood, heat) factors causing shortfalls. For example, multi-risk agricultural insurance products accounted for only 1.3 and 2.2 percent of total agricultural insurance market in, respectively, 2022 and 2023 (Superintendencia de Seguros de la Nación). The small volume of this market may be the result of demand or supply factors (or both). As relates to demand, some estimates suggest Willingness-to-Pay (WTP) values that could possibly cover delivery costs by insurance firms (Gallacher, 2011, Gallacher and others, 2015). However, these WTP figures obtained by conventional survey methods may well overstate "true" demand.

Kahneman and Tversky (K-T) provide an intriguing psychological perspective on risk-attitudes that may explain situations such as above. Kahneman's "structure in four" decision model is based on a "Asymmetric Value Function" that departs from the standard Von-Neumann Expected utility function. In contrast to the V-N EU model, the K-T function is defined over gains and losses evaluated separately. But the K-T decision model incorporates another departure from the V-N EU model: "perceived" probabilities depart from the "correct" subjective probabilities that an unbiased decision maker would consider.

[3] See https://repositorio.inta.gob.ar/xmlui/handle/20.500.12123/16189

Under the K-T model, a decision-maker faced with losses (e.g. shortfall in crop yields) may reject a fair bet when probability of loss in low (thus acting as risk-averse), and surprisingly, accept a fair bet when probability of loss is high. Table 1 illustrates the possible impact of reversals in behavior for losses on selected risky decisions in an agricultural context. As relates to losses, "catastrophic" but low-probability losses such as hail damage may the trigger purchase of insurance, while higher probability but moderate losses (such as resulting from weather variability) result in weak demand for this risk-transfer alternative. The hypotheses here is the "low" probabilities are over-weighted, leading to biased attractiveness of the no-risk alternative (insurance). In contrast, probabilities associated to "moderate" losses are higher, and these probabilities are under-weighted relative to true values: e.g. a "rationally correct" probability of loss of 0.80, is mapped into a "perceived" probability of 0.65, reducing then the incentive for eliminating via insurance production variability of this type.

Table 1: Kahneman's "Pattern of Four" and Agricultural Decision-Making

Probabilities	**Gains**	**Losses**
High	**<u>Example</u>**: Technology Choice **A_1**: Traditional Technology Returns = $ 10.000 (p=1.00) **A_2**: Modern Technology Returns = $ 12.000 (p=0.90) Risk averse: no adoption	**<u>Example</u>**: Multi-risk insurance against small/moderate yield losses **A_1**: Does not purchase Loss = $ 10.000 (p=0.70) **A_2**: Purchases Premium = $ 7.000 (p = 1.00) Risk preference: does not purchase
Low	**<u>Example</u>**: Store grain and speculate or sell **A_1**: Store grain speculating on price increase Returns = $ 10.000 (p=0.10) **A_2**: Sell now Returns = $ 1.200 (p = 1.00) Risk preference: stores and speculates on price increase	Example: Insurance against low-probability, high loss events (e.g. hail) **A_1**: Does not purchase Loss = $ 40.000 (p=.05) **A_2**: Purchase Premium = $ 2.000 Risk aversion: insures

In the case of gains, risk-aversion may result in the slow adoption of certain profitable (i.e. lo probability of failure) technologies, while low-probability but potentially high return alternatives may be evaluated from a risk-preference perspective.

4.2. Agricultural Technology: Risk-Return Tradeoffs?

As discussed in Section III (in particular, Musser and Patrick's paper) the issue of to what extent producers choose "safer" alternatives over those with higher expected returns but riskier outcomes has been the focus of considerable research. However, no clear-cut answer emerges. Or, as Musser and Patrick suggest, risk aversion is relevant for some decision scenarios (e.g. long-term investments, financial structure) but not for others (e.g. choice of fertilizer dose).

Reduction of risk, but without sacrifice in expected returns appears to be the objective of much agronomic research. That is, focus of attention does not seem to revolve around understanding how to reduce risk per-se, but instead on discovering how returns can be maintained, or even increased, while simultaneously decreasing variability.

Late-planted corn technology illustrates the above. In Argentina, conventional corn (until the early 2000's the main alternative) is planted in September-early October. This results in highly drought sensitive crop stage occurring in December – early January, a period with non-negligible water stress – and thus yield reduction.

Recent developments (resistance to pests) allow later plantings of the crop, thus reducing yield variability, without sacrifice of expected yields. In relation to this, Otegui and others (2023, p 320) report Cumulative Distribution Functions (CDF's) of conventional (***C***) and late-planted (***LP***) corn: visual analysis of these CDF's shows the ***LP*** technology shifted everywhere to the right of the ***C*** alternative. The conclusion is that probability of yields being less than any given threshold is always lower for the ***LT*** as compared to the ***C*** technology. In decision-theoretic terms, research is oriented to the discovery of alternatives that "dominate stochastically" – alternatives that produce improved results for all states of the world (see, e.g. Anderson, Dillon and Hardaker p. 281).

Adoption of late-planted corn technology increased from 31 percent of planted area in 2010, to 64 percent a decade later (Rodríguez Zurro and Terré, 2021). Rapid adoption provides evidence of the value of alternatives that reduce risk while not sacrificing potential returns.

4.3. Information and Resource Allocation

The second example that merits attention is the impact of information on resource allocation decisions. Information is an input to expectations via probabilities of states of the world. As discussed previously, expression [3] of Section III outlines the Bayesian model of probability revision, as affected by recall of events and the learning process. As discussed by Anderson, Dillon and Hardaker (p.109), decision-analysis procedures can be used to estimate the value of (imperfect) information signals.

Messina, Hansen and Hall (1999) and Bert and others (2006) apply the above concepts to crop production in Argentina. They compare optimal resource allocation patterns with and without information (in this case, weather forecasts), and estimate the value of information signals received. The point made here is that information is an input for improved decisions. In a sense, risk reduction is a "by product" and not an objective per-se.

The abundant literature on the impact of management on production efficiency (see, e.g. Papadopoulos, 2022) focuses on two related issues: (i) the measurement of different dimensions of efficiency but also (ii) explaining the determinants of differences in efficiency. Among these, information availability and producer learning processes have a central role (expression [3] above). For example, in Argentine dairy production differences in efficiency can be explained by differences in managerial characteristics (Gallacher and Lema, 2018). The decision processes that underly such differences is then a relevant topic to be analyzed.

Once more, the basic problem to be analyzed does not appear to be one of "risk-return" tradeoffs, but instead one of reducing risks and increasing profits: i.e. moving closer to the Expected Returns – Risk efficient frontier.

5. Conclusions

Decision-making in the presence of uncertainty characterizes the agricultural sector. An enormous amount of research has addressed this issue. Since the work done in the early 1950's, significant progress has been made. However, a cursory review of the literature suggests opportunities remain for further work. As an example, although agricultural producers have been characterized as risk-averse, empirical evidence not always results in clear confirmation of this hypotheses. Possibly significant differences in producer behavior can be expected in developed-country situations, where in the event of production shortfalls, capital markets allow smoothing of consumption and investment patterns over time, as compared to less developed economies where this is only partially possible.

Production and price variability are not the only causes of risk. Uncertainty with respect to property rights (or contracts in general), environmental regulation and labor litigation are additional sources of complexity of decision-processes.

Selective evidence presented here suggest that agricultural producers possibly place more emphases in discovering "stochastically dominant" alternatives, than on making marginal adjustments via risk-return tradeoffs. The problem then is how to increase returns for any given risk, or how to reduce risk for a given return. Movements "towards" the efficient E-V frontier is what is to be aimed for.

Estimating the value of information signals such as weather forecasts, soil fertility or water availability diagnosis, productivity differentials of crop varieties under different conditions appears as a relevant for research. Information is an intangible with "value" that can only be discovered with appropriate decision-models. But given the non-rival nature of the information input, returns to this line of work can be expected to be high.

More generally, recent developments in behavioral economics (e.g. Dhami, 2016), coupled with progress made in the use of experimental methods (List, 2025) open many opportunities for productive work in the area of risk, uncertainty and complexity in agricultural production.

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