DECISION-MAKING CRITERIA IN UNCERTAINTY AND RISK IN THE AGRICULTURAL SECTOR

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Purpose. The objective of this research is to find out and analyze the standards that farmers, policymakers, and other significant stakeholders in the agriculture sector use to make decisions under conditions of risk and uncertainty. Our objective is to contribute to the body of knowledge in agricultural economics by critically examining these standards and offering comprehensive analysis that can contribute to more adaptable and resilient decision-making.

Results. The importance of decision-making in light of risk and uncertainty was clearly emphasized to predict and illustrate the understanding of the variables that affect decision-making in the agricultural industry. Important patterns, trends and variables that have a significant impact on decision outcomes were detected by combining quantitative analysis with qualitative assessments. With several alternatives, internal and external conditions and many possibilities, criteria that help make the right decision, maximize return or minimize the cost of risk and uncertainty were highlighted for stakeholders seeking to improve decision-making processes and adaptability to changing obstacles, while trying to abandon the scientific basis in modeling the reality of the agricultural sector.

Scientific novelty. This study advances the subject by providing a wide and relatively new perspective on the criteria that used in agricultural decision-making in the face of uncertainty and risk. Although decision-making in agricultural situations has been studied in the literature before, our study is distinguished by its focus on the criteria that are used when there is uncertainty and risk. We hope to shed light on new ideas that can improve agricultural economics theory and methods by exploring this area.

Practical value. The study has a wide range of practical applications. A more detailed understanding of the decision-making factors found in this study will be useful for farmers, legislators, and agribusiness experts. Given an ever-changing environment, simulate realistic obstacles and identify available alternatives under various conditions, the ultimate practical value of more resilient and sustainable agricultural practices is enhanced through risk management measures, resource allocation and policy formulation.

Key words: agricultural sector, decision making criteria, uncertainty, risk, payoff matrix, risk management.

Introduction. Managers of agriculture cannot make choices without taking into account the future, as well as the risk and uncertainty it entails. Even if we try, we cannot completely remove risk for the future is unknowable. It is necessary to have a
deeper awareness of the different risk sources, their likelihood of occurring, and their effects on the business’s financial performance in order to identify these appropriate risks.

Decision-making plays a central role in the management process. Farmers must make important choices on crop selection, sowing rates, and fertilizer treatment, especially in the early parts of the cropping season. Farmers rarely have perfect certainty about how their decisions will turn out. When choices contain several variables and possible outcomes, uncertainty develops. There are, nonetheless, a few situations in which farmers may predict the results of their decisions with confidence.

In the ever-changing agricultural world, a variety of uncertainties and hazards inevitably impact decision-making processes. The agricultural sector is confronted with difficulties as the world’s population continues to rise, such as resource limitations, volatile markets, and unpredictable climates. In order to traverse the complex web of uncertainty, this calls for a comprehensive grasp of the decision-making criteria used by agricultural stakeholders.

The agricultural sector differs from other sectors due to its reliance on natural conditions, seasonal nature of production, and the importance of soil in creating a productive environment; focus on living things such as plants and animals, prevalence of product diversification in the agricultural industry, and the low supply and demand elasticity of agricultural products. Production, marketing, finance, technical advancements, socioeconomic traits of farmers and agricultural policy are all risk variables that have an impact on the agricultural business.

Farmers face uncertainty challenges related to weather, prices and diseases. Many farmers live on the edge of extreme uncertainty, oscillating between surviving with difficulty and achieving some prosperity. These risks are not under the control of farmers, but some farmers have found ways to adapt to them and manage them effectively.

Agricultural actions carry unknown and unpredictable repercussions, making farming a dangerous job. Risk management is crucial for both lessening the possibility of unfavorable outcomes and lessening their effects. By recognizing potential occurrences and evaluating their importance and diversity, agricultural decision-making may be made more efficient.

Due to its nature and the variables impacting it from both an economic and environmental perspective, the agriculture industry faces more risks than other economic sectors. Decisions about marketing, finance, and production in agriculture are influenced by these risks. This research attempts to shed light on how to manage risks in agricultural operations by minimizing them and streamlining the decision-making process in order to improve resources, boost revenue, and maintain stability in the face of risk and uncertainty over demand, pricing, and weather. This is to protect agricultural
supply networks affected by output fluctuations, seasonality, and climate change, as well as food security during emergencies like the COVID-19 pandemic and the Russo-Ukrainian war.

**Review of literature.** Decision-making in agriculture is a complex process, especially when faced with uncertainty and risk. This article synthesizes insights from various studies to explore effective methodologies for decision-making in the agricultural domain.

Pazek & Rozman (2009)’s study investigates decision-making in the production and sale of oil pumpkins under uncertain circumstances. The paper evaluates different decision criteria, including Wald’s, Hurwicz’s, Maximax, Savage’s, and Laplace’s, employing game theory principles. The maxmin rule within game theory emerges as a valuable approach for optimal decision-making in this specific agricultural context.

Drawing inspiration from financial risk, AscoughII et al. (2002) introduce an “impact matrix” to assess risk within agroecosystems. This innovative framework incorporates a range of potential environmental indicators, providing a user-friendly tool to assess diverse scenarios. The study emphasizes the importance of decision analysis and economic indicator tools for formulating and evaluating agricultural management systems that prioritize both ecological sustainability and economic profitability.

Kuzman & Prodanovic (2017), contribute by defining procedures for enhancing decision-making under risk and uncertainty in agriculture. The paper emphasizes the reevaluation of techniques and strategies to lower risks in agricultural production. Decision trees, profitability matrices, and cumulative distribution functions are recommended for choosing between riskier alternatives, providing valuable insights into risk and uncertainty drivers in agriculture.

Nelson (1988)’s work provides a comprehensive framework for risk management in farm management. The study highlights the various hazards farm managers face, emphasizing the need for well-informed decisions in the face of risk and uncertainty. The contributions include discussing different types of risks, such as production risk and human risk, aiming to assist agricultural managers in making wiser decisions and effectively managing risk.

Capitanio (2022)’s research introduces a “green portfolio” approach that integrates private risk management tools with state interventions. The paper offers a theoretical framework for controlling income risk in agriculture and discusses the differences between assessing risk and uncertainty. A novel risk management suggestion emphasizes the importance of a close working relationship between banks and agricultural enterprises. The research concludes by proposing a three-dimensional system, the “risk box”, for categorizing risk-generating occurrences based on frequency, harm intensity, and correlation.

**Materials and methods.** The objective of this research is to find out and analyze
the standards that farmers, policymakers, and other significant stakeholders in the agriculture sector use to make decisions under conditions of risk and uncertainty. Our objective is to contribute to the body of knowledge in agricultural economics by critically examining these standards and offering comprehensive analysis that can contribute to more adaptable and resilient decision-making.

The author introduces and outlines multiple procedures that facilitate establishing a connection between the structure of the payoff matrix and the decision at hand. These procedures are tailored to suit the specific goals and characteristics of the decision-maker. These methods include criteria under uncertainty and risk. By utilizing these approaches, decision-makers can effectively analyze and align the characteristics of the payoff matrix with their desired decision-making framework.

Descriptive analysis was used to study the risks associated with agricultural activity. Methods of mathematical quantitative analysis such as the return matrix and decision-making criteria have also been used in cases of uncertainty and risk with probabilities. Sensitivity analysis was also carried out to select suitable alternatives (Fagundesa et al., 2020). Numerical examples have been used to illustrate the methods used. Using these mathematical and methodological tools, the study aims to enhance the decision-making process in agriculture and improve overall performance through risk assessment, analysis of alternatives, and selection of optimal solutions under conditions of uncertainty and risk.

So, the study suggests using a “Payoff matrix” to choose between variables that involve risk.

Results and discussion. This study revolves around the general framework of risk and uncertainty in the agricultural activities.

1. Risk and uncertainty. Risk is most often understood as the potential for suffering a loss, but it can also be described as an unexpected departure from the anticipated outcome of an action that results in a loss and lowers the financial stability of that establishment both on its own and in the event that it is repeated (Alp & Aktürk, 2016). Because of these risks and uncertainties, prices and productivity change, this leads to significant annual variations in agricultural revenue.

Risky events or outcomes are those that can be measured experimentally, can be observed in a large number of cases or observations, and have a known probability of occurring. The probability distribution is constant for any outcome that is insured against, dangerous, or the result of natural or human forces. The dangers are defined by continuity, probability, measurements, the future, and variation (Ahmed, 2022).

Risk is a circumstance where, despite the fact that the decision’s final outcome is unknown, all of its conceivable consequences are known, and the probabilities attached to each possibility are either known with certainty or can be objectively approximated. The term “uncertainty” describes a scenario in which there may be no known probable
outcomes of a choice, and the probability of the occurrence of different conceivable outcomes is unknown and cannot be objectively calculated (Yusuf et al., 2014).

1.1. Risk in the agricultural sector. It is hard to think of a sector of the economy where risk and uncertainty are more significant than in agriculture. The impacts of risk and uncertainty on agriculture have been the subject of much research. Finding the ideal mix of activities with varied degrees of expected returns and unknown outcomes is a key component of risk management in the farming activities (Aimin, 2010).

Numerous factors affect agricultural productivity. Even though some of these variables are within the control of farmers, there are some that they have no influence over, making it impossible to predict what could happen in the agricultural industry.

In the production of agriculture, there are dangers and uncertainties brought on by the market, funding, technology, politics, and environmental factors (Zhai et al., 2022). These risks and uncertainties are brought on by things like a lack of rain during the product’s optimal growing season, an increase in product prices after sales, a shortage of labor when it’s needed (Sraïri & Ghabiyel, 2017), unanticipated failures of agricultural tools and equipment, changes in governmental policies, and more.

Product efficiency cannot be evaluated due to variances in uncontrollable factors such as wind, frost, rain, temperature, and sickness Zhai et al. (2022), among others. The revenue generated by agricultural activities also varies significantly each year as a result of shifts in input costs and agricultural product prices. Farmers must thus make decisions in a hazardous and ever-changing environment. If farmers look at how they make decisions when faced with risks and uncertainties and share their ideas about risk, they will be able to make better decisions.

1.2. Source of risk. In agriculture, when it comes to production, marketing, and financial decisions, farmers usually have to weigh both business and financial risks (Larson, 2008). There are five main causes of business risk:

- production or technical risk. which can have a negative impact on output, production, and profitability. This includes rainfall, temperature, wind, pests, fires, and theft incidents (Gomez et al., 2021);
- market or pricing risk. Which can affect both the yield of acquired and sold crops (Akhtar et al., 2019);
- technology risk stems from the possibility that future technological advancements might reduce the value of an investment made today;
- legal and social risk may originate from a number of places. These include shifting governmental regulations as well as the dangers of signing contracts for debt, input purchases, and product marketing;
- human sources of risk are frequently connected to the labor and managerial duties of the firm.

The capacity of farmers to manage risk via the use of leasing, insurance, leverage
(i.e., the percentage of the company’s assets funded with owner stock and debt obligations), and liquidity (i.e., cash reserves) is referred to as financial risk.

Most farms have hazards related to production, marketing, finances, institutions, and people. They commonly relate to one another. Production levels and the prices obtained for sold output determine an organization's capacity to pay back loans. Production financing is based on the borrower’s capacity for borrowing money and the lender’s capacity for timely funding. Often, it is necessary to take into account all of the different forms of risk (Simangusong et al., 2012).

Agricultural risks can be categorized into four types: production risk (weather, pests, diseases, technological change), ecological risk (climate change, natural resource management like water), market risk (output and input price variability, food chain connections in terms of quality, safety, and new products), and regulatory or institutional risk (agricultural policies, food safety regulations, environmental laws) (Yusuf et al., 2014). Production risk is both idiosyncratic and systemic, while price risk is systemic. Micro (idiosyncratic) risks impact individuals or households, while macro (systemic) risks affect regions or entire countries (Ray, 2021; Yusuf et al., 2014).

2. Risk management. Various unpredictable factors impact farmers’ decision-making, including fluctuating weather patterns, unexpected declines in harvest-time prices, limited availability of hired labor during critical periods, machinery malfunctions, unexpected loss of draught animals, and abrupt changes in government policies. These diverse risks contribute to the complexity of managing a farm as a business and have direct implications for the profitability of agricultural operations. Farmers must navigate and strategize to mitigate these uncertainties effectively (Kahan, 2013).

Early in the growing season, farmers must choose which crops to sow and how much fertilizer and seed to use. In the case of perennial crops and animals, it may take many months or even several years to know with certainty the production and prices acquired.

Seldom are farmers certain of the outcomes of their choices. This usually occurs when there is just one choice, and it is an easy one. In this case, farmers are well aware of the consequences of their decisions. But in most cases, it is hard to predict how a decision will turn out because there are generally several probable outcomes. Farmers often find that their choices end up being less than ideal due to the changes that transpire between the time the decision is made and the completion of its consequences (Kahan, 2013). Farmers must have all the required information on input pricing, output prices, yields, and other technical data in order to make good judgments.

The management of agricultural businesses is becoming more and more challenging because of rising capital needs, the need for businesses to adapt to changing market conditions, the rapid improvement of technology, and issues brought on by
changing climatic conditions. In order for agricultural businesses to thrive, these contemporary sources of risk must be confronted and examined (Alp & Aktürk, 2016). Whether the risk is retained (meaning the potential effects are yet to come), avoided, decreased, or transferred is one way to categorize management solutions (Capitanio, 2022).

What worries agricultural farmers the most is the possibility of a bad outcome. This really has to do with how willing the farm is to take chances. The farm’s ability to take on risk is closely tied to measures of liquidity and solvency. Agriculture has a wide range of risks and uncertainties, from weather-related catastrophes and climatic conditions to animal illnesses, fluctuating agricultural product prices and input costs like fertilizer, to financial risks including policy and regulatory risks. Agricultural risks are a component of a risk management system, which also includes all available instruments, strategies, and regulations (Alp & Aktürk, 2016).

Farmers employ “risk coping” measures post-event to mitigate dangers, often utilizing savings to avoid cutting back on consumption. This serves as a self-insurance policy, spreading the effects of adverse events over time with the expectation that circumstances will improve and reserves can be restored for future catastrophes.

When the risks are exceptionally high, it may be best to completely avoid them. This involves significant decisions such as relocating farming activities to less risky locations, investing in physical infrastructure like irrigation systems or protective nets, and engaging in less risk-averse but less lucrative income-skewing activities. In developing nations’ rural areas with limited resources and market access, this avoidance strategy is common.

Diversifying income sources is a widespread approach to risk reduction for farmers globally. This involves diversifying agricultural production, varying crops, adding crops to livestock farming, or allocating a portion of family funds to non-agricultural income sources. While effective in lowering risk, it comes at the cost of potentially forfeiting the benefits of specialization (Capitanio, 2022).

The theoretical examination of risk preferences categorizes farmers as risk-loving, risk-averse, or risk-neutral, with each category exhibiting different supply responses. Ordinary farmers, lacking the knowledge to manage market risk, may opt for low-investment, low-reward, and low-risk planting combinations due to risk aversion (Mao et al., 2023) and imperfect insurance markets, limiting their potential for increased investment in higher-risk, higher-reward alternatives (Aimin, 2010).

3. Decision-making and types in the agricultural sector. Decisions are usually made based on general conditions, especially crop prices in the previous year and current input prices, but the project may be exposed to several risks that may harm the crop or the project’s production in the present and future (Kuzman & Prodanovic, 2017).

Depending on the risks, their size, and their quality, the agricultural decision-maker
modifies the production plans (Ahmed, 2022). The typical way that risk is conceptualized is as fluctuation around or departures from the anticipated result. When considering the implementation of a new agricultural technology or venture, farmers are frequently worried about the possibility of experiencing low net revenues in addition to the predicted net revenues (Mao et al., 2023). When making decisions about production, marketing, and finances, farmers often have to consider both business and financial risks (Larson, 2008).

The choice of crops and prices at the beginning of the season is based on the price of last year’s harvest as well as the current input costs. However, there are a number of risks that could affect the crop and its composition in the present as well as in the future (Kuzman & Prodanovic, 2017).

The theoretical framework for risk and uncertainty states that economic theories are predicated on the notion that people rationally make decisions to maximize profit, benefit, or minimize costs, which are typically made under conditions of risk or uncertainty (Table 1). This framework includes events and results that can be measured experimentally and quantitatively with a fixed probability distribution (Gilles & Konkuyt, 2011). As a result, decision-making criteria should be included in both risk and uncertainty situations within a specific time period that allows overcoming potential risks through a variety of strategies and inputs under different conditions (Simangusong et al., 2012).

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Decision under conditions of uncertainty</th>
<th>Decision under conditions of risk</th>
<th>Decision under conditions of certainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Information about future events</td>
<td>Absence of knowledge</td>
<td>Partial knowledge</td>
<td>Full knowledge</td>
</tr>
<tr>
<td>The probabilities</td>
<td>Unknown</td>
<td>Probabilistic</td>
<td>Are known 100%</td>
</tr>
<tr>
<td>Type of probability</td>
<td>Subjective</td>
<td>Objective</td>
<td>Specific</td>
</tr>
<tr>
<td>Returns</td>
<td>Unconfirmed and cannot be assigned</td>
<td>Probabilistic that can be set</td>
<td>Specific</td>
</tr>
<tr>
<td>States of nature</td>
<td>More than one and unknown</td>
<td>More than one well-known</td>
<td>Single</td>
</tr>
</tbody>
</table>

*Source: Bressy & Konkuyt (2018).*

There are many methods adopted in the decision-making process in terms of difficulty, cost, time factor, surrounding conditions, information and available possibilities.

**3.1. Payoff matrix.** One of the most used techniques in decision theory when there is ambiguity in the results is the reward matrix. Each choice requires a study of the possible courses of action, prospective environmental conditions, and particular results for each possible state-activity pairing. The general form of the yield matrix in this form (Table 2).
General format of the payoff matrix

<table>
<thead>
<tr>
<th>Alternatives (Ai)</th>
<th>S_1</th>
<th>S_2</th>
<th>...</th>
<th>S_j</th>
<th>...</th>
<th>S_n</th>
</tr>
</thead>
<tbody>
<tr>
<td>a_1</td>
<td>r_{11}</td>
<td>r_{12}</td>
<td>...</td>
<td>r_{1j}</td>
<td>...</td>
<td>r_{1n}</td>
</tr>
<tr>
<td>a_2</td>
<td>r_{21}</td>
<td>r_{22}</td>
<td>...</td>
<td>r_{2j}</td>
<td>...</td>
<td>r_{2n}</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>a_j</td>
<td>r_{i1}</td>
<td>r_{i2}</td>
<td>...</td>
<td>r_{ij}</td>
<td>...</td>
<td>r_{in}</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>a_m</td>
<td>r_{m1}</td>
<td>r_{m2}</td>
<td>...</td>
<td>r_{mj}</td>
<td>...</td>
<td>r_{mn}</td>
</tr>
</tbody>
</table>


A decision-maker must take into account the effects of every potential combination. A reward matrix, which organizes the alternative outcomes, allows a decision-maker to use one of several decision-making rules (AscoughII et al., 2002).

The paradigm for hazardous decision-making outlined in this chapter is founded on the idea that farm managers must select between several courses of action, the results of which depend on factors outside of their control. Payoffs are the results of each possible combination of decisions and occurrences.

A farm manager might explicitly address risk in the decision-making process by creating a table with possible actions, occurrences, and payoffs. This chart, known as a reward matrix, is useful when weighing several options since it may help you get a sense of the range of potential outcomes for each choice (Nelson, 1988).

A choice often comprises four steps: (1) recognizing the need or opportunity for a decision; (2) formulating alternative courses of action; (3) assessing the alternatives; and (4) selecting one or more of the options. Analysis of the choice of opportunity or challenge includes examination of the relative farm position as well as the surroundings of the farm. This stage directs how to describe pertinent decision choices.

Situations requiring decision-making are categorized as risky and uncertain. A risk scenario is one in which the decision-maker is aware of both the potential outcomes and the odds of each one occurring. Under uncertain circumstances, the decision-maker is unaware of the likelihood of several outcomes (Backus et al., 1997).

3.2. Criteria for decision-making under conditions of uncertainty. Decision-making issues are categorized based on the level of knowledge about the state of nature when the decision is applied. Under certainty, the state of nature is known in advance, facilitating the decision-maker in determining actions that maximize profits. In contrast, decision-making under uncertainty occurs when the state of nature is unknown at the time of decision application.

3.3. Decisions under conditions of uncertainty. Where the decision-maker is in a position that does not allow it to know in advance the possibility of any of the variables
or circumstances expected to occur after the decision is made due to the lack of sufficient information and data and therefore difficult to predict, and under these circumstances it is possible to use a set of criteria that help to make the decision, such as the maximum minimum criterion or the maximum value in the minimum set of values, the maximum maximum criterion, i.e., the maximum value in the maximum set of values, and the minimum value criterion for maximum values of regret (Pazek & Rozman, 2009).

A. The criterion of optimism. According to this criterion, the decision-maker always tends to look at the environment in which he works optimistically, where he always expects that the environment and nature will work in his favor and will always get the best results, so the decision-maker chooses the strategy that has the highest expected return among the highest expected returns from each strategy, we express it as follows: Maxi[Max(r_ij)] (AscoughII et al., 2002).

If the results represent costs, then the strategy that has the lowest value is chosen from among the lowest costs, and the criterion is as follows: Mini[Min(C_ij)].

B. The criterion of pessimism, or the Wald criterion. The Wald criteria, also known as the pessimistic criterion. According to this criterion, the decision-maker must first ascertain the worst-case scenario for each approach before selecting the one that would yield the best results.

The idea behind this criteria is that the person making the decisions always views the surrounding environment and nature with caution or conservatism; he anticipates the worst and believes that nature and the environment don’t always work in his favor. Because of this, he constantly attempts to select techniques that allow him to minimize loss while foregoing large prospective rewards, which leads him to select the worst scenario: Maxi[Min(r_ij)] (AscoughII et al., 2002).

The highest values are chosen for each approach when the results reflect costs, and we then pick the lowest values from that group: Mini[Max(C_ij)].

C. Laplace Criterion (equal probability criterion). This criterion assumes that all possible states of nature have the same probability of occurrence, and therefore LaPlace gives each state of nature an equal probability, which is equal to (1/n) since n is the number of states of nature, so the decision maker will choose the action related to: Max R_{ij} = Max \sum_{i,j} r_{ij} / n.

The Laplace argument makes use of Jakob Bernoulli’s Principle of Insufficient Reason. “In the absence of any prior knowledge, we should assume that the events have equal probability”, is how the notion was initially stated (Pazek & Rozman, 2009). This means choosing the line for which the average return is expressed in terms of profit at its maximum (or the average return expressed in terms of costs at its minimum).
D. The criterion of realism (Hurwicz criterion). This criterion is one of the intermediate criteria, i.e. between pessimism and optimism, where it combines the worst result in each action and the best result in each action in specific proportions according to a measurement coefficient called optimism coefficient $\lambda$ (Metzger & Spengler, 2019) when $(0 < \lambda < 1)$, as this criterion takes the following formula (Kast, 2002; Pazek & Rozman, 2009): $\text{Max}_i Hi = \text{Max}_i [\lambda (\text{Max} r_{ij}) + (1 - \lambda)(\text{Min} r_{ij})]$. This criteria has the benefit of allowing the decision-maker to consider his or her own thoughts and feelings regarding the topics of optimism and pessimism.

E. The criterion of regret or loss of opportunity (SAVAGE criterion). The result of taking a certain action already resonates optimally in the current state of uncertainty. For example, suppose the choice of action $(i)$ in the occurrence of the states of nature $(j)$, the resulting return is $(\pi_{ij})$. Assume that the action $(a_m)$ is the optimal verb if we know that the state of nature is $(s_j)$ apriori and the resulting profit is $(\pi_{mj})$ the loss resulting from taking the $(a_i)$ instead of $(a_m)$ represents the value of the missed opportunity. That is, $[L_{ij} = \pi_{mj} - \pi_{ij}]$ is the way to represent missed opportunity tables (Pazek & Rozman, 2009).

It is clear from the definition of missed opportunity that the cost of missed opportunity is equal to zero in the event that the action taken in uncertainty is optimal, and the cost is positive for other actions.

The missed opportunities matrix can be found from the payoff matrix by subtracting the return $(\pi_{ij})$ from the highest return of the same column, i.e.: $(L_{ij} = \text{Max}_k \pi_{kj} - \pi_{ij})$ (AscoughII et al., 2002), given the following payoff tables; where the Table 3 represents returns.

### Table 3

Choosing the appropriate alternative (crop) under the states of nature

<table>
<thead>
<tr>
<th>Action</th>
<th>States of nature</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>S1</td>
</tr>
<tr>
<td>Crop1</td>
<td>31</td>
</tr>
<tr>
<td>Crop2</td>
<td>29</td>
</tr>
<tr>
<td>Crop3</td>
<td>33</td>
</tr>
</tbody>
</table>

Source: developed by the author.

The decision in case of uncertainty according to the data is as follows:

Maxi (Max Ai) criterion = Max $(31, 29, 33) = 33$ => Decision: Select A3;

Maxi (Min Ai) criterion = Max $(9, 9, 7) = 9$ => Decision: Select A1 or A2.

Laplace criterion: we associate equal probability for event say $[\frac{1}{3}]$ expected payoffs are: $L(A1) = (31 + 13 + 9)/3 = (53)/3 = 17.6$;

$L(A2) = (29 + 19 + 9)/3 = (57)/3 = 19.0$;

$L(A3) = (33 + 17 + 7)/3 = (57)/3 = 19.0$.

A2 and A3 has the maximum expected payoff.
Hurwicz criterion: $\lambda = 0.4$: $H_i = \lambda (\text{Maximum in } A_i) + (1 - \lambda)(\text{Minimum in } A_i)$

$H(A1) = (0.4 \times 31) + (0.6 \times 9) = 17.8$;

$H(A2) = (0.4 \times 29) + (0.6 \times 9) = 17.0$;

$H(A3) = (0.4 \times 33) + (0.6 \times 7) = 17.4$.

$H(A1)$ has the maximum return.

Minimax regret criterion: the missed opportunity (or regret) matrix is as follows (Table 4):

$\text{Min} (\text{Max } R_i) = \text{Max } (6, 4, 2) = 2$ => Decision: Select $A3$.

### Table 4

<table>
<thead>
<tr>
<th>Action</th>
<th>States of nature</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>S1</td>
<td>S2</td>
</tr>
<tr>
<td>Crop1</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>Crop2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Crop3</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

*Source: developed by the author.*

3.4. Decisions under conditions of risk.

3.4.1. Definition of risk. It may be described as a relative measure of how much the net return fluctuates around the expected value of the net return, or it may describe a situation in which investment decision-makers have sufficient data and information to allow them to estimate an objective probability distribution (Smyth & Phillips, 2014). Here, risk is defined differently from uncertainty: risk is quantifiable, defined as “the relative standard deviation of the expected investment returns and means the degree of volatility in the expected investment returns; the higher the degree of expected revenue and return volatility, the higher the risk”.

3.4.2. Decision criteria under risk. Where the decision-maker has partial information about the states of nature through the similarity of the influencing conditions and the availability of previous experiences expressed by estimating the probability of occurrence (Raybould, 2010) of each state of nature, and since these probabilities may be realized and may not be realized (Fagundesa et al., 2020), it is said that the decision-maker risks when choosing a certain alternative.

The criteria used in risk situations are divided into statistical criteria and criteria based on decision theory: the criterion of expected monetary value, the criterion of expected loss of opportunity: standard deviation, coefficient of variation (Temesgen et al., 2015), sensitivity analysis (Ahmed, 2022).

A. The criterion of expected monetary value. This criterion is also known as the Bayes criterion, and in order for us to use this criterion, it is necessary to determine the probability of occurrence of any of the states of nature, where the sum of the probabilities of occurrence of different states is equal to one, and these probabilities are either objective resulting from knowledge of the states of nature or subjective resulting...
from personal estimation about the chances of occurrence of probabilities, called prior probabilities and symbolized by Pj, where j refers to the states of nature. According to this criterion, the act with the highest monetary value (Kuzman & Prodanovic, 2017) or the lowest expected cost:

\[
\text{EMV} (a_l) = \sum_{j=1}^{k} (P_j \cdot \pi_{ij}) \quad \text{when} \quad \left( \sum P_i = 1 \right).
\]

Given: P(S1) = 0.5; P(S2) = 0.3; P(S3) = 0.2, in Table 1; Find: Decision making under risk.

- EMV for A1 = (31 × 0.5) + (13 × 0.3) + (9 × 0.2) = 21.2;
- EMV for A2 = (29 × 0.5) + (19 × 0.3) + (9 × 0.2) = 22.0;
- EMV for A3 = (33 × 0.5) + (17 × 0.3) + (7 × 0.2) = 23.0.

EMV for A3 is greater. Decision: select A3.

B. Expected opportunity loss criterion. The lost opportunity is defined as the loss resulting from taking a certain action compared to the optimal one under the current state of uncertainty (Babaker, 2007). According to this criterion, we choose the one with the lowest expected cost of opportunity loss, calculated by the missed opportunity matrix:

\[
\text{EOL} (a_l) = \sum_{j=1}^{k} (P_j \cdot L_{ij}).
\]

- EOL for A1 = (2 × 0.5) + (2 × 0.3) + (0 × 0.2) = 1.6;
- EOL for A2 = (4 × 0.5) + (0 × 0.3) + (0 × 0.2) = 2.0;
- EOL for A3 = (0 × 0.5) + (2 × 0.3) + (2 × 0.2) = 1.0.

EMV for A3 is least. Decision: select A3.

C. Sensitivity analysis. It is a method used to find out how different values of an independent variable affect the values of a dependent variable specified within a set of assumptions and within specific limits that depend on two or more variables.

In the theory of decision-making, sensitivity analysis refers to the extent to which the decision taken responds through the expected monetary value to changes in the data, and sensitivity studies the extent to which changing probabilities of states of nature affect the outcome of the decision, and then finding the probability areas of preference of one alternative over another, and the turning point in the decision (Table 5).

**Table 5**

<table>
<thead>
<tr>
<th>Alternatives</th>
<th>States of nature</th>
<th>B1 Good circumstances</th>
<th>B2 Bad circumstances</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1 (Durum wheat)</td>
<td>10</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>A2 (Soft wheat)</td>
<td>7</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>A3 (Rent the land)</td>
<td>2</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>P</td>
<td>P</td>
<td>1-P</td>
<td></td>
</tr>
</tbody>
</table>

Source: developed by the author.
We construct linear equations of the alternatives according to the new probabilities. What is required: to find the field of possibilities that determine the best alternatives for the farmer, through sensitivity analysis.

Calculating the expected monetary value functions for each alternative, where P is the probability of the first state of nature, and (1-P) is the complementary probability and concerns the state of the second nature, including the expected value of each alternative:

\[ \text{EMV}(A_1) = 10P + 2(1 - P) = 8P + 2; \]
\[ \text{EMV}(A_2) = 7P + 5(1 - P) = 2P + 5; \]
\[ \text{EMV}(A_3) = 2P + 2(1 - P) = 2. \]

By equating the expected monetary value equations for the first and second alternatives, as follows:
\[ \text{EMV}(A_1) = \text{EMV}(A_2) \Rightarrow [8P + 2 = 2P + 5] \Rightarrow 6P = 3 \]
\[ \Rightarrow \left[ P = \frac{3}{6} = 0.5 \right]. \]

It is the point of probability for not preferring between the two alternatives, and in the event that any probability is less than 0.5 in the equation of the expected monetary value of the first alternative, we find its value less than 8, which is the equation of the second alternative line, and the latter is the best, and in the event of a probability greater than 0.5, the expected monetary value of the first alternative is greater and is the best.

We represent the table in the following graph.

![Figure 1. The sensitivity of alternatives to changes in probability of states of nature](source: developed by the author.)
From the previous figure, we notice that: at the probability level \((P = 0.5)\), \([EMV(A1) = EMV(A2)]\), they are therefore both in preference; at the probability level \((P < 0.5)\), \([EMV(A1) < EMV(A2)]\), so the second alternative is preferable (soft wheat production); and at the probability level \((P > 0.5)\), \([EMV(A1) > EMV(A2)]\), so the first alternative (durum wheat production) is preferable, and in all likelihood, the third alternative (leasing the land) is not adopted.

4. The role of farm management under conditions of risk and uncertainty. The role of farm management becomes crucial in the face of risk and uncertainty, extending beyond its traditional role of developing and implementing plans based on full knowledge. In such conditions, management involves finding and developing plans aligned with future forecasts, making executive decisions, and utilizing data for optimal decision-making to achieve farmer goals.

4.1. Risk responses. Several tactics can mitigate ambiguity in farming, with diversification being a commonly suggested strategy to lower risk. Diversification can involve adding resources or diversifying with existing resources, contributing to risk reduction. By expanding resources and incorporating businesses with lower variances or negative associations, the variance of returns can be minimized.

Farmers employ various risk management strategies on their individual farms, including data gathering, timing investments, diversification, production techniques, and eligibility preservation for government programs, forward contracting, sales spread, insurance (Mao et al., 2023), and maintaining reserves. Acknowledging the role of public policy is crucial to both the necessity of risk management and the ability to respond to uncertainty.

Diversification’s effectiveness in risk reduction depends on factors such as farm goals, managerial skills, activity compatibility with available resources, and economies of scale. If a farmer integrates a diverse range of enterprises, diversification becomes a valuable tool in lessening risk at the individual farm level (Backus et al., 1997).

4.2. Countering the negative effects of risk and uncertainty. To counter the adverse impacts of risk and uncertainty on agricultural production, both direct and indirect policies are implemented. Direct policies include supporting production elements, such as fertilizers and machinery, through subsidies to encourage optimal usage. Additionally, supporting agricultural production and implementing agricultural crop insurance collectively address risk and uncertainty, providing financial security for farmers.

Non-direct policies focus on indirect strategies, like improving agricultural extension services and supporting agricultural research. These policies aim to enhance the efficiency of the agricultural production unit by providing valuable information and scientific solutions, ultimately helping farmers cope with risk and uncertainty.

4.3. Diversifying production to meet risk and uncertainty. Diversifying production
is a key strategy to mitigate risk and uncertainty. Despite the benefits of specialization, diversification involves distributing resources across various crops to minimize the impact of adverse conditions on income. Farm management plays a crucial role in choosing complementary crops to ensure a guaranteed income limit and reduce income variation.

Returns on investments are closely tied with investment risk, the higher the projected earnings, the higher the investment risk. Historically, investors have attempted to employ the range of models that are presently accessible in order to select investments with the best returns and the lowest risk. Numerous studies have been done in this field thus far to employ mathematical models in order to determine the optimal asset combination. By applying a mathematical method, Markowitz was able to choose the lowest risk and best returns in a multi-objective optimization model at the same time, producing the largest possible investment portfolio. This idea states that the investor chooses a choice among replies that are located on the efficient frontier which has responses under the best conceivable circumstances (Rasoulzadeh et al., 2022). Research indicates that although diversity may not have a substantial impact on price variance because of the strong link between crop prices, it can mitigate variability in output quantity. Farmers must choose an acceptable revenue level and variability threshold since the effectiveness of diversification in reducing internal variability depends on the amount of pricing and production variability.

4.4. Production with contracts to face risk and uncertainty. The farmer can avoid a significant degree of risk in prices by adopting contracts for crops that he intends to sell in the future, since the price will be known to him at the planning stage of production. Examples of this are the supply of legumes and dairy products to factories, the supply of meat to slaughterhouses and large markets. However, the source of risk will still exist if the farmer can contract production without the ability to contract the necessary production inputs (Kahan, 2013).

4.5. Forward pricing. When a producer and buyer agree on a price for the sale of animals or crops ahead of delivery, this is known as forward pricing. A deal is made to supply the produce at a certain cost, quantity, quality, and timing. By using this technique, farmers may lower their risk that the price they get for their produce won’t be enough to pay for their expenses. These agreements, however, prevent farmers from benefiting from any potential price increases that could happen during the harvest season (Kahan, 2013).

Conclusions. In decision-making under uncertainty and risk (DMUR), decision makers have two primary options: establishing an interval of probable outcomes or adopting discrete payoffs for each choice (scenario DMUR). Current rating techniques predominantly focus on the latter, utilizing payoff matrices to assess the relative positions of outcomes and the ordering of individual profits. The payoff matrix serves as
a budgeting tool, integrating personal probability to evaluate the risk associated with different choices, providing a structured approach for farm managers.

While risk analysis doesn’t simplify decision-making or eliminate challenges, it guides farm managers in selecting appropriate risks in an uncertain environment. It aids in navigating uncertainties and making informed choices, acknowledging that profitable and enduring farms adapt to environmental changes. Recognizing these changes is crucial in the decision-making process, considering decisions from input providers, customers, and fellow farmers. Due to individual differences and unique firm positions, diverse decisions emerge, highlighting the complexity of decision-making in agriculture. The emphasis is on choosing when and how to invest, underscoring its critical role in the agricultural context.

The payoff matrix model, and the standard evaluation criteria in the cases of uncertainty and risk, try to express the objectives, conditions and capabilities of the agricultural enterprise to face various macro and micro conditions and risks, and try to use the quantitative method in decision-making. In order to make the best decision, the decision maker follows the following sequential steps:

- definition of the problem (investigation);
- clarify and evaluate solutions (design);
- choose the most suitable solution;
- implementation and follow-up necessary to evaluate the selection and the appropriateness of the model used.

The limits of the study stem from the fact that this model is based on the assumption that decision makers have the ability to choose the alternative that achieves the best results, and this rational model focuses on four hypotheses:

- the objectives set are clear;
- the individual makes the appropriate and proper choice between possible solutions;
- alternatives and states of nature, and their possibilities are very specific and known to him comprehensively and accurately;
- the different expected results of alternatives under different states of nature are known, have full knowledge and the required accuracy.

There are alternative models that the decision-maker can choose from, relying in particular on technological development, the huge information revolution, the use of artificial intelligence, providing it with the appropriate tools and information processing to provide a base for appropriate decision-making, which also improves the efficiency of the agricultural sector in the environment of the basic needs of societies, and faces the risks associated with climate change, supply chain, and geopolitical challenges.

References


Production Research, 50(16), 4493–4523.


