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DECISION MAKING UNDER CONDITIONS OF UNCERTAINTY IN AGRICULTURE: A CASE STUDY OF OIL CROPS

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SUMMARY

In decision under uncertainty individual decision makers (farmers) have to choose one of a set number of alternatives with complete information about their outcomes but in the absence of any information or data about the probabilities of the various state of nature. This paper examines a decision making under uncertainty in agriculture. The classical approaches of Wald's, Hurwicz's, Maximax, Savage's and Laplace's are discussed and compared in case study of oil pumpkin production and selling of pumpkin oil. The computational complexity and usefulness of the criterion are further presented. The article is concluded with aggregate the results of all observed criteria and business alternatives in the conditions of uncertainty, where the business alternative 1 is suggested.

Key-words: uncertainty, Wald's, Hurwicz's, Maximax, Savage's and Laplace's criterion, decision support system, agriculture

INTRODUCTION

Typically, personal and professional decisions can be made with some difficulty. Either the best course of action is clear or the varieties of the decision are not significant enough to require a great amount of attention. Occasionally, decisions arise where the path is not clear and it is necessary to take substantial time and effort in devising a systematic method of analyzing the various courses of action. With decisions under uncertainty, the decision maker should:

1. Take an inventory of all viable options available for gathering information, for experimentation and for action
2. List all events that may occur
3. Arrange all pertinent information and choices/assumptions made
4. Rank the consequences resulting from the various courses of action
5. Determine the probability of an uncertain event occurring.

Upon systematically describing the problem and recording all necessary data, judgments, and preferences, the decision maker should synthesize the information set before using the most appropriate decision rules. Decision rules prescribe how an individual faced with a decision under uncertainty should go about choosing a course of action consistent with the individual's basic judgments and preferences (http://terpconnect.umd.edu/~sandborn/courses/808S_projects/reynolds.html).

When a decision maker should choose one possible actions, the ultimate consequences of some, if not all of these actions will generally depend on uncertain events and future actions extending indefinitely far into the future. The uncertainty is specially expressed in agriculture. Sahin et al. (2008) determine the cattle fattening breed, which maximizes the net profit for the producers under risk and uncertainties. The Wald's, Hurwicz's, Maximax, Savage's, Laplace's and Utility criterions were used. On the other hand the decision on which crops to include in crop rotation is one of the most important decisions in field crop farm management. Agronomic, economic

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and market information about each individual crop constitutes an informative basis for decision-making. There is a significant amount of valuable agronomic and market information already available on main crop production, including oil crops (Rozman et al., 2006). However, the potential for a wider range of alternative crops, including oil pumpkin (Bavec and Bavec, 2006), should be evaluated in order to determine their break-crop characteristics and the benefits and challenges which they bring to systems (Robson et al., 2002). According to Lampkin and Measures (1999), the economics of oil pumpkin depends on market price, therefore enquires with potential buyers should be undertaken. However, recent farm management research has also shown oil pumpkin production can be financially feasible assuming that the pumpkin oil can be successfully sold. Pažek (2003) and Pažek et al. (2005) conducted a financial and economical analysis of farm product processing on Slovene farms using a simulation - modelling approach that included also pumpkin oil production. In agriculture there is a lack of studies that observe the application of criteria in the situation under uncertainness. From this reason in the paper five decision rules (criteria) commonly used in decision process under uncertainty were presented and applied in the case study of production and processing of oil pumpkin:

- Wald's Maximin criterion
- Hurwicz's criterion
- Maximax criterion
- Savage's minimax regret criterion
- Laplace's insufficient reason criterion.

The paper is organized as follows; in the first part the methodology and theoretical background of the decision rules (criteria) is presented. In the second part of the paper the application of observed decision rules were presented on the example in agriculture; pumpkin oil processing (considering production area and specific selling presumption by pumpkin oil marketing). The paper is concluded with results by the observed criteria in the conditions of uncertainty in agriculture.

METHODOLOGY

Decision analysis is a systematic approach by decision making that allows managers to solve problems with uncertainty figures as a prominent factor. A normative model is developed to represent the decision making problem, facilitate logical analysis, and produce a recommended course of action. The technique is most useful in managerial situations where risk is significant. The resulting formal model is capable of generating optimal strategies for multi-stage decision making problems that involve a variety of contingencies.

Thus, the payoff (or decision) matrix M = { A , S , R , P } formally defines a decision analysis problem.

A	**S**			
	S_1	S_2	...	S_n
	p_1	p_2	...	p_n
A_1	R_{11}	R_{12}	...	R_{1n}
A_2	R_{21}	R_{22}	...	R_{2n}
⋮	⋮	⋮		⋮
A_m	R_{m1}	R_{m2}	...	R_{mn}

Where:

A - the set of decision alternatives A_i (for i = 1, 2, ..., m)

S - the set of events S_j (for j = 1, 2, ..., n)

R - the set of payoffs (rewards) R_{ij} obtained by choosing alternative A_i if state S_j occurs

P - the probability distribution applicable to S (the set of probabilities p_j describing the likelihood that state S_j will occur).

However, in the early 1950s, the discussion about criteria for decision making was lively. Several decision criteria have been proposed to resolve the problem of decision making under strict uncertainty. Some of the most important ones are furthermore presented.

Wald's Maximin Criterion

The decision-theoretic view of statistics advanced by Wald had an obvious interpretation in terms of decision-making under complete ignorance, in which the maximin strategy was shown to be a best response against natures' minimax strategy. Wald's criterion is extremely conservative even in a context of complete ignorance, though ultra-conservatism may sometimes make good sense (Wen and Iwamura, 2008). The Maximin criterion is a pessimistic approach. It suggests that the decision maker examines only the minimum payoffs of alternatives and chooses the alternative whose outcome is the least bad. This criterion appeals to the cautious decision maker who seeks ensurance that in the event of an unfavourable outcome, there is at least a known minimum payoff. This approach may be justified because the minimum payoffs may have a higher probability of occurrence or the lowest payoff may lead to an extremely unfavourable outcome (http://terpconnect.umd.edu/~sandborn/courses/808S_projects/reynolds.html).

Hurwicz's Optimism – Pessimism Criterion

The most well-known criterion is the Hurwicz criterion, suggested by Leonid Hurwicz in 1951, which selects the minimum and the maximum payoff to each given action x. The Hurwicz criterion attempts to find a middle ground between the extremes posed by the optimist and pessimist criteria. Instead of assuming total optimism or pessimism, Hurwicz incorporates a measure of both by assigning a certain percentage weight to optimism and the balance to pessimism. However, this approach attempts to strike a balance between the maximax and maximin criteria. It suggests that the minimum and maximum of each strategy should be averaged using a and 1 - a as weights. a represents the index of pessimism and the alternative with the highest average selected. The index a reflects the decision maker's attitude towards risk taking. A cautious decision maker will set $a = 1$ which reduces the Hurwicz criterion to the maximin criterion. An adventurous decision maker will set $a = 0$ which reduces the Hurwicz criterion to the maximax criterion.

The Hurwicz criterion attempts to find a middle ground between the extremes posed by the optimist and pessimist criteria. Instead of assuming total optimism or pessimism, Hurwicz incorporates a measure of both by assigning a certain percentage weight to optimism and the balance to pessimism.

A weighted average can be computed for every action alternative with an alpha-weight α, called the coefficient of realism. "Realism" here means that the unbridled optimism of Maximax is replaced by an attenuated optimism as denoted by the α. Note that $0 \leq \alpha \leq 1$. Thus, a better name for the coefficient of realism is coefficient of optimism. An $\alpha = 1$ denotes absolute optimism (Maximax) while an $\alpha = 0$ indicates absolute pessimism (Maximin). The α is selected subjectively by the decision maker.

Selecting a value for α simultaneously produces a *coefficient of pessimism* 1 - α , which reflects the decision maker's aversion to risk. A Hurwicz weighted average H can now be computed for every action alternative A_i in A as follows:

$H(A_i) = \alpha$ (row maximum) + (1 - α) (row minimum) - for positive-flow payoffs (profits, revenues)

$H(A_i) = \alpha$ (row minimum) + (1 - α) (row maximum) - for negative-flow payoffs (costs, losses)

Hurwicz decision rule is followed:

1. Select a coefficient of optimism value α .
2. For every action alternative compute its Hurwicz weighted average H.
3. Choose the action alternative with the best H as the chosen decision ("Best" means Max {H} for positive-flow payoffs, and Min {H} for negative-flow payoffs).

Maximax Criterion

The Maximax criterion is an optimistic approach. It suggests that the decision maker examine the maximum payoffs of alternatives and choose the alternative whose outcome is the best. This criterion appeals to the adventurous decision maker who is attracted by high payoffs. This approach may also appeal to a decision maker who likes to gamble and who is in the position to withstand any losses without substantial inconvenience.

It is possible to model the optimist profile with the Maximax decision rule (when the payoffs are positive-flow rewards, such as profits or revenue. When payoffs are given as negative-flow rewards, such as costs, the optimist decision rule is Minimin Note that negative-flow rewards are expressed with positive numbers.)

Maximax decision rule is followed:

1. For each action alternative (matrix row) determine the maximum payoff possible.
2. From these maxima, select the maximum payoff. The action alternative leading to this payoff is the chosen decision.

Savage's Minimax Regret

The Savage Minimax Regret criterion examines the regret, opportunity cost or loss resulting when a particular situation occurs and the payoff of the selected alternative is smaller than the payoff that could have been attained with that particular situation. The regret corresponding to a particular payoff Xij is defined as Rij = Xj(max) – Xij where Xj(max) is the maximum payoff attainable under the situation Sj. This definition of regret allows the decision maker to transform the payoff matrix into a regret matrix. The minimax criterion suggests that the decision maker looks at the maximum regret of each strategy and selects the one with the smallest value. This approach appeals to cautious decision makers who want to ensure that the selected alternative does well when compared to other alternatives regardless of the situation arising. It is particularly attractive to a decision maker who knows that several competitors face identical or similar circumstances and who is aware that the decision maker's performance will be evaluated in relation to the competitors. This criterion is applied to the same decision situation and transforms the payoff matrix into a regret matrix.

The Minimax Regret criterion focuses on avoiding the worst possible consequences that could result when making a decision. Although regret is an emotional state (a psychological sense of loss) which, being subjective, can be problematic to assess accurately, the assumption is made that regret is quantifiable in direct (linear) relation to the rewards R_{ij} expressed in the payoff matrix. This means that an actual loss of, say, an euro (an accounting loss) will be valued exactly the same as a failure to take advantage of the opportunity to gain an additional euro (an opportunity loss, which is disregarded in financial accounting). In other words, the Minimax Regret criterion views actual losses and missed opportunities as equally comparable.

Regret is defined as the opportunity loss to the decision maker if action alternative A_i is chosen and state of nature S_j happens to occur. Opportunity loss (OL) is the payoff difference between the best possible outcome under S_j and the actual outcome resulting from choosing A_i given that S_j occurs. Thus, if the decision alternative secures the best possible payoff for a given state of nature, the opportunity loss is defined to be zero. Otherwise, the opportunity loss will be a positive quantity. Negative opportunity losses are not defined. Savage's Minimax Regret criterion is formally defined as:

OL_{ij} = (column j maximum payoff) - R_{ij} - for positive-flow payoffs (profits, income)

$OL_{ij} = R_{ij}$ - (column j minimum payoff) - for negative-flow payoffs (costs)

where R_{ij} is the payoff (reward) for row i and column j of the payoff matrix R.

Opportunity losses are defined as nonnegative numbers. The best possible OL is zero (no regret), and the higher OL value, the greater the regret.

Minimax Regret decision rule is defined as:

1. Convert the payoff matrix R = { R_{ij} } into an opportunity loss matrix OL = { OL_{ij} }.
2. Apply the minimax rule to the OL matrix.

Laplace's Criterion

The Laplace's insufficient reason criterion postulates that if no information is available about the probabilities of the various outcomes, it is reasonable to assume that they are likely equally. Therefore, if there are n outcomes, the probability of each is $1/n$. This approach also suggests that the decision maker calculate the expected payoff for each alternative and select the alternative with the largest value. The use of expected values distinguishes this approach from the criteria of using only extreme payoffs. This characteristic makes the approach similar to decision making under risk.

The Laplace’s criterion is the first to make explicit use of probability assessments regarding the likelihood of occurrence of the states of nature. As a result, it is the first elementary model to use all of the information available in the payoff matrix.
The Laplace’s argument makes use of Jakob Bernoulli's **Principle of Insufficient Reason**. The principle, first announced in Bernoulli's posthumous masterpiece, *Ars Conjectandi* (*The Art of Conjecturing,* 1713), states that “in the absence of any prior knowledge, we should assume that the events have equal probability". It meas that the events are mutually exclusive and collectively exhaustive. Laplace posits that, to deal with uncertainty rationally, probability theory should be invoked. This means that for each state of nature (S_j in S), the decision maker should assess the probability of p_j that S_j will occur. This can always be done - either theoretically, empirically or subjectively. Laplace decision rule is followed:

1. Assign $p_j = P(S_j) = 1/n$ to each S_j in S, for $j = 1, 2, ..., n$.
2. For each A_i (payoff matrix row), compute its expected value: $E(A_i) = \Sigma_j\ p_j\ (R_{ij})$.
for $i = 1, 2, ..., m$. Since p_j is a constant in Laplace, $E(A_i) = \Sigma_j\ p_j\ (R_{ij}) = p_j\ \Sigma_j\ R_{ij}$.
3. Select the action alternative with the best $E(A_i)$ as the optimal decision. "Best" means max for positive-flow payoffs (profits, revenues) and min for negative-flow payoffs (costs) (http://groups.msn.com/DecisionModeling/decisionanalysis.msnw).

RESULTS

For the case of uncertainty, decision theory offers basic two main approaches. The first approach is to reduce the uncertainty case to the case of risk by using subjective probabilities, based on expert assessments on analysis of previous decisions made in similar circumstances. The second approach exploits criteria of choice developed in a broader context by **game theory,** as for the example (max-min rule), when we choose the alternative where the worst possible consequence of the chosen alternative is better than (or equal to) the best possible consequence of any other alternative. In the paper the second approach was presented and applied. For the analysis Wald’s, Hurwicz’s, Maximax, Savage’s and Laplace’s criteria are calculated and discussed in the sample of pumpkin oil production and selling. Three production business alternatives with different production area of oil pumpkins (A1, A2, A3) and three different market opportunities for pumpkin oil (S1, S2, S3) were calculated and analysed (table 1).

Table 1. Basic data aid for business alternative evaluation
Tablica 1. Primarni podaci individualne poslovne alternative

Alternative	**Quantity**	**Unit**
A1	5	ha
A2	3	ha
A3	1	ha
S1	100	%
S2	85	%
S3	50	%

The matrix 3x3 decision tables are seen in Table 2, where the financial result by the individual alternative presents the decision parameter.

Table 2. The decision matrix for pumpkin oil (based on financial parameters in €)
Tablica 2. Matrica odlučivanja za tikvino ulje (bazirana na financijskom parametru, €)

	S1 (€)	S2 (€)	S3 (€)
A1	2475	496	-4122
A2	1299	112	-2659
A3	123	-273	-1196

Wald's criterion
The Wald's criterion is an approach which the pessimistic farmer will prefer to apply. In the framework of the observed criteria the decision maker prefers the highest value of bad conditions. However, according to Wald's criterion, the farmer should select the maximum of the row minima. In the presented research the alternative 3 (-1196 €) is selected (Table 3).

Table 3. The computation results for Wald's criterion
Tablica 3. Rezultati izračunavanja za Waldov kriterij

	Minimum value (€)	Maximum of minimum value (€)
A1	-4122	0
A2	-2659	0
A3	-1196	-1196

Hurwicz's criterion
According to the Hurwicz's criterion, the farmer is between pessimistic and optimistic attitude. Each result has been weighted according to optimistic coefficient (k = 0.7). The highest and the lowest values of each business alternative has been multiplied by optimistic coefficient (k = 0.7) and pessimistic coefficient (1-k = 0.3). The highest calculated average value is selected, as seen in Table 4, by alternative 1 (495.5 €).

Table 4. The computation results of Hurwicz's criterion (calculated by k = 0.7)
Tablica 4. Rezultati izračunavanja za of Hurwiczov kriterij (računan kod k = 0,7)

	Minimum value (€) (1-k)	Maximum value (€)	Hurwicz weighted average value (€)	Maximum of Hurwicz weighted average value (€)
A1	-4122	2475	495,9	495.9
A2	-2659	1299	111,6	0
A3	-1196	123	-272,7	0

* Coefficient of optimism (k) = 0.7
Coefficient of pessimism = (1 - k) = 0.3

Maximax criterion
According to Maximax criterion, the farmer (the decision maker) chooses the best among the conditions determined for each business alternative. The decision maker is optimistic about the pumpkin oil production and oil selling conditions. The Maximax criterion showed that A1 (5 ha of oil pumpkin) was the best choice (2475 €) (Tables 2 and 5).

Table 5. The results of Maximax criterion calculation
Tablica 5. Rezultati izračunavanja Maximax kriterija

	Maximum value (€)	Maximum of maximum value (€)
A1	2475	2475
A2	1299	0
A3	123	0

Savage's criterion

Regret criterion minimizes the probable regrets for decision maker. The regret values for specific scenario were determined according to all selling scenarios whereas minimax or Savage's criterion was applied to these values (Table 6).

Table 6. The demonstration of Savage criterion calculation matrix
Tablica 6. Demonstracija matrice izračunavanja za Savage kriterij

	S1 (€)	S2 (€)	S3 (€)
A1	0	0	2926
A2	1176	384	1463
A3	2352	769	0

In the observed research the regret of the farmer will be by pumpkin oil production and 50% selling effectiveness 1463 € (Table 7). Alternative 2 is chosen.

Table 7. The results of Minmax criterion calculation
Tablica 7. Rezultati izračunavanja Minmax kriterija

	Lost opportunity maximum (€)	Minimum of maximum lost opportunity (€)
A1	2926	0
A2	1463	1463
A3	2352	0

Laplace's criterion

According to Laplace's criterion, when the probabilities of conditions are not known, the probabilities (S1, S2 and S3) are accepted as equal (0.33). No probability has priority to another one. The weighted value of each business alternative was found by multiplying by all three probabilities with 0.33 and the added together. Since, the highest value was (-383.67 €), the farmer will choose the alternative 1 (Table 8).

Table 8. The decision matrix based on Laplace's criterion calculation
Tablica 8. Matrica odlučivanja bazirana na izračunavanju Laplace kriterija

	S1 (€)	S2 (€)	S3 (€)	Sum	Laplace's sum
A1	2475	496	-4122	-1151	-383.67
A2	1299	112	-2659	-1248	-416.00
A3	123	-273	-1196	-1346	-448.67

Share of S1, S2, S3 = 0.33*

Table 9. The summarized results of suggested business alternatives of pumpkin oil production and sales
Tablica 9. Sumarizirani rezultati predložene poslovne alternative za proizvodnju i prodaju tikvinog ulja

Criterion	**The suggested business alternative**
Wald criterion of pessimism – maxmin	**A3**
Maximax criterion – maxmax	**A1**
Hurwicz criterion (k = 0.7)	**A1**
Savage criterion – minmax	**A2**
Laplace criterion	**A1**

The aggregate game criterion results showed that the most profitably alternative compatible with the assessment of criterion by decision making under uncertainty in agriculture is alternative A1 (production of oil pumpkins on 5 ha arable land and the presumption of 100 % selling of pumpkin oil) (Table 9).

CONCLUSION

In the decisions under uncertainty individual decision makers have to choose one of presumed business alternatives with the extended information about their profitability, outcomes, costs, financial results, but in the absence of any information about the probabilities of the various states of nature. The paper presented a decision making process under uncertainty in agriculture. The classical criterion of Wald's, Hurwicz's, Maximax, Savage's and Laplace's are assessed and compared in the case study of pumpkin oil production and selling of pumpkin oil. The assessment was made on the basis of financial results for individual business alternative evaluation. The results show that alternative 1 is recommended, where the farmer should prefer the pumpkin oil production on 5 ha arable land and the total oil production should be sold. We believe that there is a need to place more emphasis on determining the uncertainty in agriculture, especially in food production and food processing.

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PROCES ODLUČIVANJA U POLJOPRIVREDI U RIZIKU I NEIZVJESNOSTI: SLUČAJ ULJARICE

SAŽETAK

Kod odlučivanja u riziku i neizvjesnosti, poljoprivrednik bira između alternativa. Nema informacija o vjerojatnosti pojedinih informacija. U ovom radu predstavljamo primjer odlučivanja u riziku i neizvjesnosti aplikacijom klasičnih metoda, kao što su Waldov, Hurwiczov, Maximax, Savageov i Laplaceov kriterij, na primjeru proizvodnje i prerade uljanih tikva. U radu je predstavljena kompleksnost i korisnost računatih parametara. Rad je zaključen s agregacijom rezultata. Razultati kažu da je najprimjerenija poslovna alternativa 1.

Ključne riječi: rizik, neizvjesnost, Waldov, Hurwiczov, Maximax, Savageov i Laplaceov kriterij, proces odlučivanja, poljoprivreda

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