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AMS 518 Final Project: Crop production and insurance policy optimization

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Project Background

- In this project we explore the optimal crop production and insurance strategies for farmers under various **risk constraints**, specifically Conditional Value at Risk (**CVaR**), Value at Risk (**VaR**), and Probability Exceeding Penalty (**Pr_Pen**).
- The study acknowledges the uncertainties in crop yields and market prices **impacting** farmers' profits. To manage this risk, farmers can opt for insurance policies offering different levels of protection. It aims to identify the <u>most profitable</u> planting and insurance plans within an acceptable risk level.
- It notes the influence of climate phenomena like El Niño, La Niña, and Neutral conditions on crop yields, particularly in the southeastern US, and how these conditions, predicted by sea surface temperature, affect temperature and rainfall patterns.
- It evaluates two main types of crop insurance: Actual Production History (**APH**), and Catastrophic Insurance Coverage (**CAT**), each providing different coverage levels. The study builds upon previous research, using CVaR as a risk measure and formulating a quadratic problem to optimize planting and insurance choices for maximizing profit under specified risk levels.

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3 important weather conditions considered

Impact of each effect is different and we observe different temperatures and rainfall

Weather condition	Rainfall	Temperature	Impact on crop revenue
El-Nino	⇧	⇩	⇧
La-Nina	⇩	⇧	⇧
Neutral	⇔	⇔	⇔

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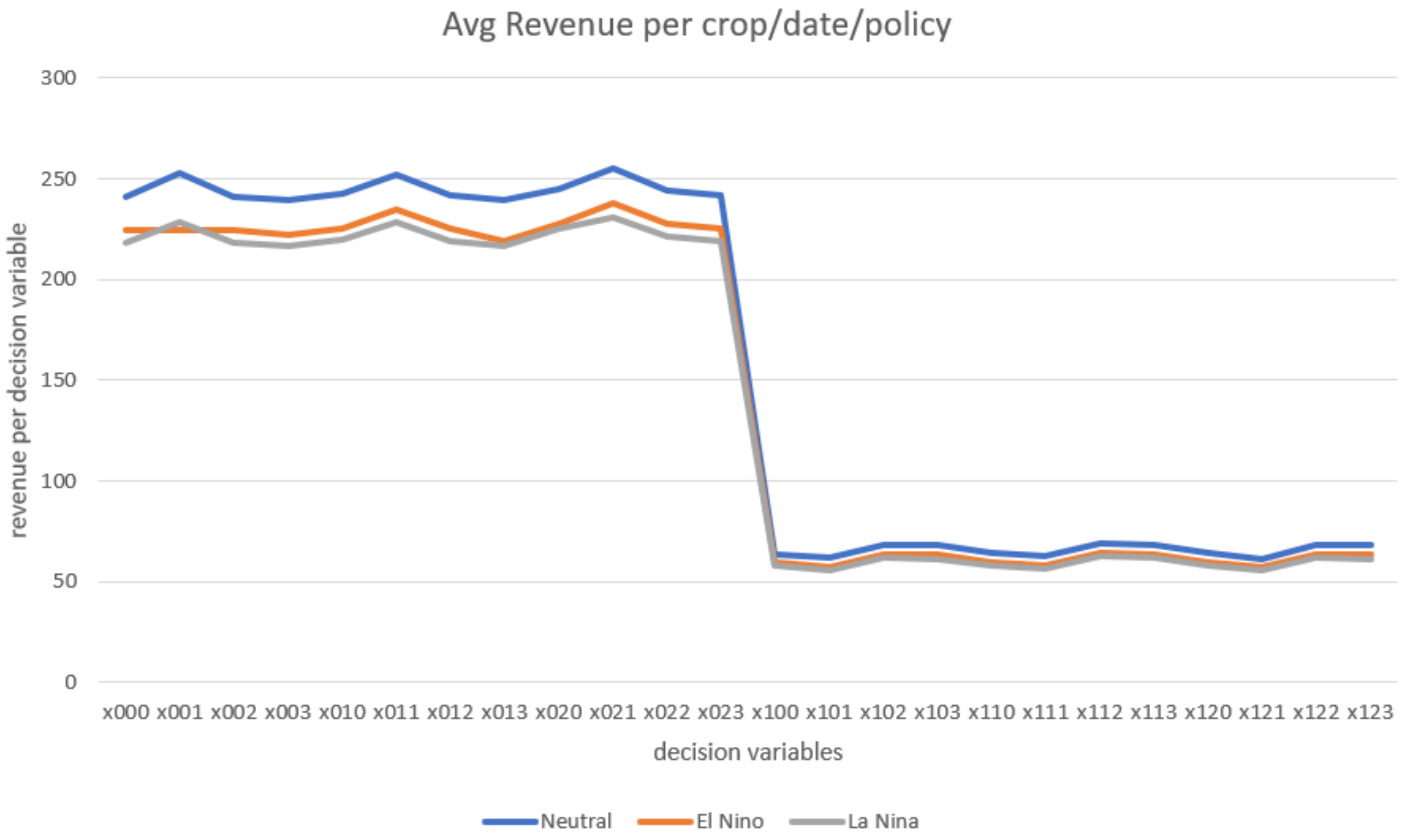

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Notations used

$K =$ number of crop types;
$T_k =$ number of planting dates for crop k;
$I_k =$ number of insurance policies for crop k;
$J =$ number of scenarios;
$q_k =$ planting area (in acres) available for crop k;
$C_k =$ planting cost per acre of crop k;
$R_{ki} =$ premium of insurance policy i for crop k per acre;
$x_{kti} =$ number of acres of land for crop k planting on date t and insured by policy i;
$x_{ki}^{a} =$ additional variable indicating selection of insurance policy i for crop k;
$\theta_{kti} =$ (random) revenue of crop k per acre planted on date t and insured by policy i;
$\theta_{ktij} =$ revenue of crop k per acre planted on date t and insured by policy i under scenario j;

$L(x,\theta) = -\sum_{k=1}^{K}\sum_{t=1}^{T_k}\sum_{i=1}^{I_k}\theta_{kti}x_{kti} =$ loss function;
$L^* =$ threshold of losses in probability exceeding penalty constraint;
$p =$ the upper bound of the probability exceeding penalty constraint;
$b =$ upper bound on $CVaR_\alpha\left(L(x,\theta)\right)$;
$v =$ upper bound on $VaR_\alpha(L(x,\theta))$;
$y_{ktj} =$ yield of crop k per acre planted on date t under scenario j;
$y_k =$ (historical) average yield of crop k per acre;
$P_{kj} =$ market price of crop k per pound under scenario j;
$P_k =$ price base of crop k per pound.

Optimization problem
Objective and constraints

Maximizing expected profit

$$\max_{x_{kti}} \sum_{k=1}^{K} \sum_{t=1}^{T_k} \sum_{i=1}^{I_k} E\theta_{kti} x_{kti}$$

subject to

planting area constraint for each crop k

$$\sum_{t=1}^{T_k} \sum_{i=1}^{I_k} x_{kti} = q_k, \quad k = 1, \ldots, K$$

joint constraint on planting area and insurance policy

$$\sum_{t=1}^{T_k} x_{kti} \le q_k x_{ki}^a, \quad i = 1, \ldots, I_k; k = 1, \ldots, K$$

each crop k can be insured by at most one policy

$$Cardinality\ Positive\left(x_k^a, w\right) \le 1, \ k = 1, \ldots, K,$$

risk constraint (CVaR, VaR, and Probability Exceeding Penalty)

$$CVaR_\alpha(L(x,\theta)) \le b$$

$$\text{or } VaR_\alpha(L(x,\theta)) \le v$$

$$\text{or } \Pr ob(L(x,\theta) \ge L^*) \le p$$

constraint on additional variables

$$0 \le x_{ki}^a \le 1, \quad i = 1, \ldots, I_k; k = 1, \ldots, K,$$

lower bounds on variables

$$0 \le x_{kti} \le q_k, i = 1, \ldots, I_k; \ t = 1, \ldots, T_k$$

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Random revenue scenario generation process and indemnity calculations

Random revenue θ_{kti} has J equally probable scenarios θ_{ktij}, which can be calculated as follows:

$$\theta_{ktij} = y_{ktj} P_{kj} + indemnity - C_k - R_{ki},$$

where

$$indemnity \text{ for APH} = \begin{cases} (y_{ki}^* - y_{ktj}) P_k, & if \quad y_{ki}^* > y_{ktj} \\ 0, & if \quad y_{ki}^* \le y_{ktj} \end{cases},$$

$$y_{ki}^* = \text{APH}\% \times y_k,$$

$$indemnity \text{ for CAT} = \begin{cases} (y_{ki}^* - y_{ktj}) P_k^*, & if \quad y_{ki}^* > y_{ktj} \\ 0, & if \quad y_{ki}^* \le y_{ktj} \end{cases},$$

$$y_{ki}^* = 75\% \times y_k, \quad P_k^* = 55\% \times P_k$$

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Parameters of the Problem

- Number of types of crop = 2 (Peanuts and Soybeans)
- Number of planting area for each crop = 50 acre
- Number of Scenarios = 1000 (for each climate: El Nino, La Nina and Neutral)
- Number of planting dates for both crops = 3
- Number of insurance policy for both crops (and its premium) = 4

1. 80%APH ($38.2/acre) 2. 90%APH ($44.8/acre) 3. CAT ($2/acre) 4. No insurance (0)

- Production cost for peanut = $520.55/acre ; Production cost for soybean = $185.67/acre
- Average yield for peanut = 3099.2 lb/acre ; Average yield for soybean = 2164.7 lb/acre
- Election price for peanut = $0.2449/lb ; Election price for soybean = $0.117/lb
- CVaR constraint: The confidence level in CVaR for the portfolio, α = 90%
- The upper bound on CVaR L x ((,)) α θ of losses w = 8000
- VaR constraint: The confidence level in VaR for the portfolio, α = 90%
- The upper bound on VaR L x ((,)) α θ of losses w = 2000
- Probability Exceeding Penalty constraint: The threshold of losses = 2000 ; The upper bound on exceeding probability = 20%

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Solution to objective and constraint statements under each risk measure

- Based on our simulated data the maximum expected revenue comes out top be **16210.5** for all three risk measures with x021 and x112 values to be 50 each with xa01 and xa12 values 1 respectively. It means that for peanut utilize the third planting date with second insurance policy, while for soybeans utilize the second planting date with third insurance policy for overall maximum revenue. For both of these cases plant 50 acres as per the constraints and optimum values.

Conclusion

- We have successfully calculated the maximum revenue under different constraints including the planting acreage for both the crops be it any situation based on the revenue generation scenarios.

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References

- Cabrera, V.E., Fraisse C.W., Letson D., Posesta G., Novak J.(2005): Impact of climate information on reducing farm risk by optimizing crop insurance strategy. Working paper (2005).
- Hansen, J.W., Hodges, A.W., Jones, J.W. (1998): ENSO influences on agriculture in the Southeastern US. J Climate 11, 404-411.
- Letson, D., Podestá, G.P., Messina, C.D., Ferreyra, A. (2005): The uncertain value of perfect ENSO phase forecasts: stochastic agricultural prices and intra-phase climatic variations. Climatic Change, 69, 163-196.
- Men, C, Liu, J. (2005): A conditional value-at-risk model for optimizing crop insurance strategy. Working paper (2005).