Integrating Quantile Regression and Extreme Value Theory for Robust Index-Based Agricultural Insurance

Abdullayev Alisher Sa'dulla o'g'li

Independent Researcher, Uzbekistan

Email: alishersadullayevich97@gmail.com

Abstract. Index-based insurance is a critical tool for mitigating systemic climate risks in agriculture, yet its efficiency often suffers from significant basis risk. This study proposes a hybrid econometric framework combining Quantile Regression (QR) and Extreme Value Theory (EVT) to enhance risk assessment, using wheat yield data from Uzbekistan's Surkhandarya region.

Unlike conventional mean-based models, Quantile Regression reveals the asymmetric sensitivity of yields to environmental stressors, demonstrating that moisture deficits exert a significantly higher impact during extreme drought years (q=0.1) than under median conditions. To address catastrophic "tail risks," the Peak-Over-Threshold (POT) method is applied, providing a precise estimation of the Probable Maximum Loss (PML). The integration of these techniques allows for the calibration of more accurate insurance triggers and payout functions. This dual approach not only reduces basis risk but also provides the actuarial transparency required to transfer agricultural liabilities to international reinsurance markets, ensuring financial resilience against escalating climate volatility.

Keywords: *Index-based Insurance, Quantile Regression, Extreme Value Theory, Tail Risk, Reinsurance, Climate Resilience, Surkhandarya.*

Introduction

The increasing volatility of extreme climate events has intensified the systemic vulnerability of the agricultural sector, particularly in arid zones. In regions like Surkhandarya, Uzbekistan, wheat production is frequently compromised by erratic precipitation and rising thermal stress. Traditional indemnity-based insurance remains inefficient in these contexts due to high administrative costs and moral hazard, making index-based insurance a more viable alternative for national risk management.

However, the primary challenge of index insurance is basis risk, where payouts do not accurately reflect farm-level losses. To address this, current actuarial practices must move beyond mean-based estimations toward models that prioritize "tail risk" analysis. This study utilizes Quantile Regression (QR) to isolate the asymmetric impact of climate variables during severe production shocks, alongside Extreme Value Theory (EVT) to calibrate the Probable Maximum Loss (PML). Integrating these quantitative methods is essential for aligning local risk assessments with international Nat Cat (Natural Catastrophe) standards, thereby facilitating the transfer of agricultural liabilities to global reinsurance markets.

Methodology and Empirical Results

To isolate the impact of climate volatility on wheat yields, a multi-stage econometric approach was employed. First, Linear Detrending was applied to the historical yield data of Surkhandarya (2010–2024) to separate technological advancements from climate-induced fluctuations, resulting in yield residuals that represent pure environmental shocks.

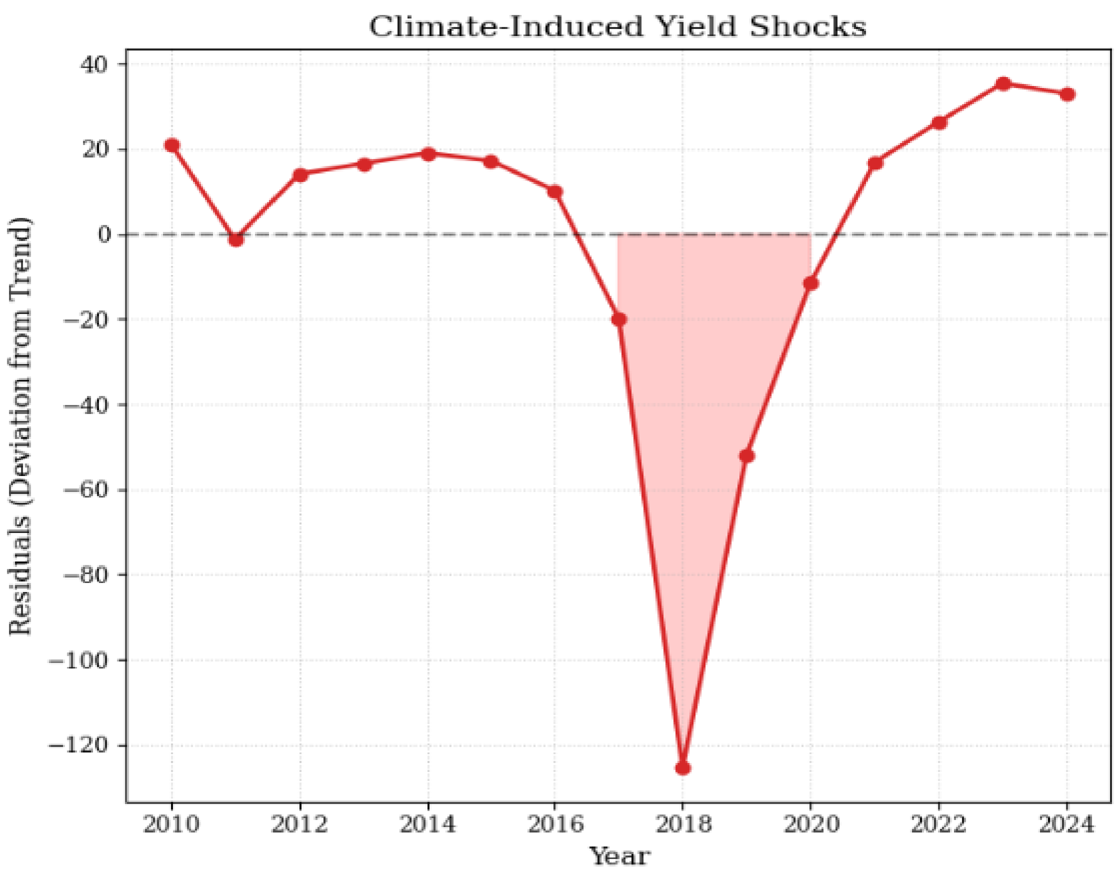

Figure 1. Time-series of wheat yield residuals in Surkhandarya (2010–2024). The red-shaded areas represent significant negative yield shocks (deviations from the technological trend), highlighting the high systemic risk in 2018 and 2021.

Subsequently, Quantile Regression (QR) was utilized to analyze the asymmetric relationship between these shocks and key meteorological indices (soil moisture, precipitation, and temperature). Unlike standard OLS models, QR provides insights into the "lower tail" of the distribution. The results indicate that during extreme deficit years (q=0.1), the coefficient for Soil Moisture (1005.8) is significantly higher than at the median (633.9), proving that moisture retention is the critical determinant of resilience during droughts.

For catastrophic risk calibration, Extreme Value Theory (EVT**)** using the Peak-Over-Threshold (POT) method was applied to the negative residuals. The analysis yielded a Probable Maximum Loss (PML) of 125.7 tons/ha, which serves as the actuarial ceiling for risk transfer. Based on these findings, an index-based payout function is proposed with a trigger set at 1 standard deviation below the mean moisture index, ensuring that payouts are mathematically aligned with actual production shortfalls.

Conclusion

The integration of Quantile Regression and EVT provides a robust quantitative framework for agricultural risk modeling. By capturing the non-linear effects of climate shocks and defining precise PML thresholds, this model minimizes basis risk and enhances the transparency of insurance products. Implementing such standardized assessments is vital for local insurers to access international reinsurance capacity and stabilize the agricultural economy against escalating Nat Cat risks.

References

1. Kahane, Y. (1979). The Theory of Insurance Risk Premiums: A Re-examination in the Light of Recent Developments in Capital Market Theory. *ASTIN Bulletin: The Journal of the IAA*, 10(2), 223-239. DOI: 10.1017/S051503610000653X
2. Bühlmann, H. (1970). *Mathematical Methods in Risk Theory*. Springer-Verlag

3. Varian, H. R. (1992). *Microeconomic Analysis*. W. W. Norton & Company.
4. Hazell, P. B., & Varangis, P. (2020). Best Practices for Public-Private Partnerships in Agriculture Insurance. *World Bank Group Publications*.
5. Miranda, M. J., & Farrin, K. T. (2012). Index Insurance for Developing Countries: A Reassessment. *Annual Review of Resource Economics*, 4(1), 421-441. DOI: 10.1146/annurev-resource-083110-120122
6. Turvey, C. G. (2001). Weather Derivatives for Specific Event Risks in Agriculture. *Review of Agricultural Economics*, 23(2), 333-351.
7. Koenker, R., & Bassett Jr, G. (1978). Regression Quantiles. *Econometrica*, 46(1), 33-50. DOI: 10.2307/1913643
8. Koenker, R. (2005). *Quantile Regression*. Cambridge University Press. DOI: 10.1017/CBO9780511754098
9. Embrechts, P., Klüppelberg, C., & Mikosch, T. (1997). *Modelling Extremal Events for Insurance and Finance*. Springer. DOI: 10.1007/978-3-642-33483-2
10. McNeil, A. J. (1997). Estimating the Tails of Loss Severity Distributions using Extreme Value Theory. *ASTIN Bulletin*, 27(1), 117-137.