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Spatial gaps and maladaptation risk: performance frontiers for climate resilience in Kenya

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Abstract

Climate-smart agriculture (CSA) is widely promoted to build resilience, yet adaptation benefits remain unevenly distributed and maladaptation risk – where households become trapped in low-yield, high-gap states – is poorly understood. Using survey data from 569 smallholder households in Western Kenya, stratified by gender and agro-ecological zone (Lower Midland Zone LMZ, Upper Midland Zone UMZ), we diagnose structural performance gaps and spatial patterns of maladaptation risk. We apply non-parametric conditional quantile frontiers ($\alpha=0.90$) to benchmark attainable maize yield given observed adaptation inputs (crop diversification, soil and water conservation). The distance-to-frontier measures how far households are from feasible performance – a diagnostic of structural inefficiency. Maladaptation risk is defined as a household simultaneously in the lowest yield quartile (25th percentile) and the highest distance-to-frontier quartile (75th percentile). Spatial clustering is assessed using global Moran’s I and local indicators of spatial association (LISA).

Results show stark agro-ecological inequality. Mean distance-to-frontier is 0.172 t/ha in the LMZ versus 0.061 t/ha in the UMZ – a 2.8-fold larger gap in the more marginal zone. Maladaptation risk is 0% in the UMZ but 15% in the LMZ (16% for male-headed, 12% for female-headed households). Global Moran’s I for frontier distance is 0.445 ($p = 0.002$), confirming significant positive spatial clustering: disadvantage is not random but geographically embedded. A policy simulation of gap-based targeting reduces mean inefficiency by 7.4% but, critically, increases within-group inequality ($\Delta\text{Gini} +0.010$ to $+0.013$). This reveals an equity-efficiency trade-off: focusing only on the largest performance gaps can inadvertently widen disparities.

We conclude that performance gaps are place-based and that maladaptation risk concentrates in geographic hotspots. Equity-calibrated, spatially targeted interventions – such as hotspot-guided extension, infrastructure investment, and tailored insurance – are essential for building truly multifunctional and climate-resilient agro-ecosystems. The framework is portable and can be adapted to other regions facing similar structural constraints.

Keywords: Agro-ecological zones, climate-smart agriculture, conditional quantile frontiers, gender, Kenya, lisa, maladaptation risk, moran’s i, performance frontiers, smallholder agriculture, spatial clustering

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