Interim Analysis Report on the Impact of the 2010 Drought in Guizhou and Population Migration Mechanisms

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1. Introduction and Research Questions

This study examines the impact of the extreme drought in Guizhou Province, China, in 2010 on agricultural vitality and county-level population migration. Using this event as a natural experiment, the study aims to explore the causal relationship between climate shocks, agricultural productivity, and rural population outflow, and to examine the heterogeneity of these effects across different geographical and socioeconomic contexts.

The core research questions are:

1. **Does extreme drought significantly affect agricultural productivity as measured by crop seasonal NDVI?**
2. **Does drought affect rural migration patterns?**
3. **How do county-level characteristics (e.g., altitude, urbanisation, population density) moderate these responses?**
4. **To what extent can the decline in agricultural vitality be linked to drought and migration?**

Research contributions include:

1. **Integrate remote sensing (NDVI), climate index (SPEI) and census data to construct a county-level panel data set.**
2. **Causality identification was conducted using the difference-in-differences (DiD) method and event study design.**
3. **Linking climate, agriculture and migration within a framework of spatial heterogeneity, with a focus on mountainous areas subject to frequent climate stress.**

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2. Data Sources and Construction

The analysis is based on county-level balanced panel data from 88 counties in Guizhou Province from 2008 to 2012. The dataset integrates remote sensing, climate, population, and administrative information to support causal analysis of the impact of drought on agricultural vitality and population migration.

Variable Type	Description	Source
Agricultural vitality	Growing-season mean NDVI masked by cropland, derived from MODIS MOD13Q1 (April–September) using a fixed cropland mask from MODIS MCD12Q1 (2010, IGBP class 12)	MODIS MOD13Q1 & MCD12Q1 via Google Earth Engine
Drought indicator	3-month SPEI (February–June 2010), median aggregated to county; treated counties defined as those with drought frequency > 0 (SPEI < −1.5 in at least one month)	SPEIbase v2.10 (CSIC), aggregated in Google Earth Engine
Migration indicator	Net migration per 1,000 persons, calculated from year-on-year population change adjusted for births and deaths; provincial crude birth/death rates applied if county data missing	2010 Population Census; Guizhou Statistical Yearbooks (2009–2013)
Controls	Growing-season total rainfall (CHIRPS), static cropland percentage (2010 MODIS MCD12Q1), mean elevation	CHIRPS daily precipitation; MODIS MCD12Q1; GEE-derived DEM
Heterogeneity variables	Population density (persons/km², mean 2008–2012), high-elevation dummy (counties above the provincial 75th percentile), urban core dummy	Guizhou Statistical Yearbooks; DEM-based calculations in GEE; county administrative boundary shapefile

All geospatial variables were processed in Google Earth Engine at native spatial resolution and aggregated to the county level. Demographic variables were sourced from official statistics and interpolated where necessary to maintain panel data balance. Environmental variables vary annually, while cropland share and elevation are considered time-invariant structural attributes.

To illustrate the spatial context of this study, Figure 2.1 shows a map of drought severity levels in 2010, indicating that the most severe drought conditions were observed in the central, western, and southern regions of Guizhou Province. Figure 2.2 depicts the anomalies in NDVI values during the 2010 agricultural growing season relative to the average values for 2008–2009 and 2011–2012, highlighting the regions where agricultural vitality declined most sharply during the drought year. Figure 2.3 shows the average net migration rate from 2008 to

2012, revealing significant spatial differences, with higher out-migration rates in some remote mountainous counties affected by drought.

Figure 2.1 Spatial distribution of drought severity classes in Guizhou Province, 2010

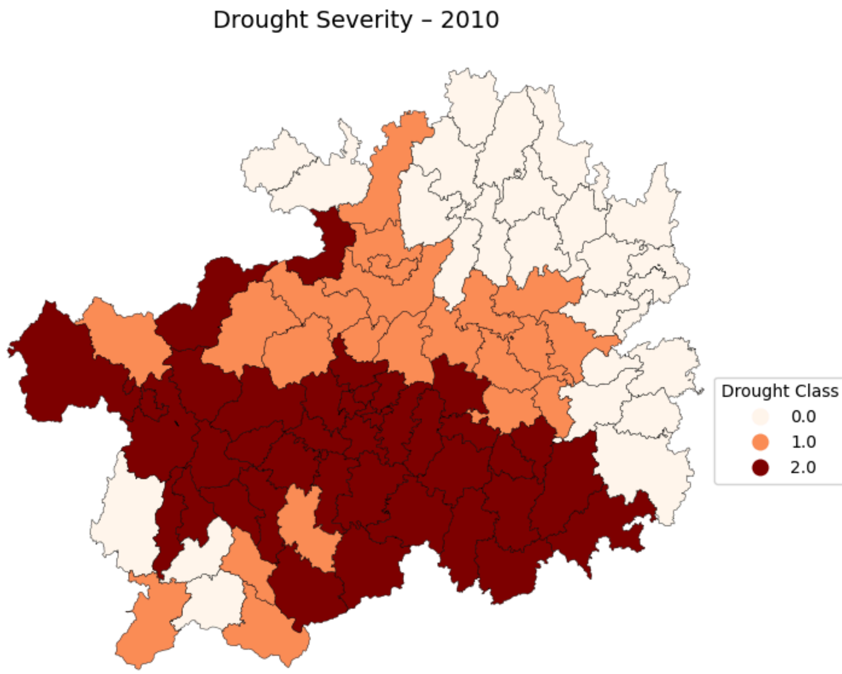


Figure 2.2 NDVI anomaly (2010 vs. baseline 2008–2009 & 2011–2012) for cropland growing season

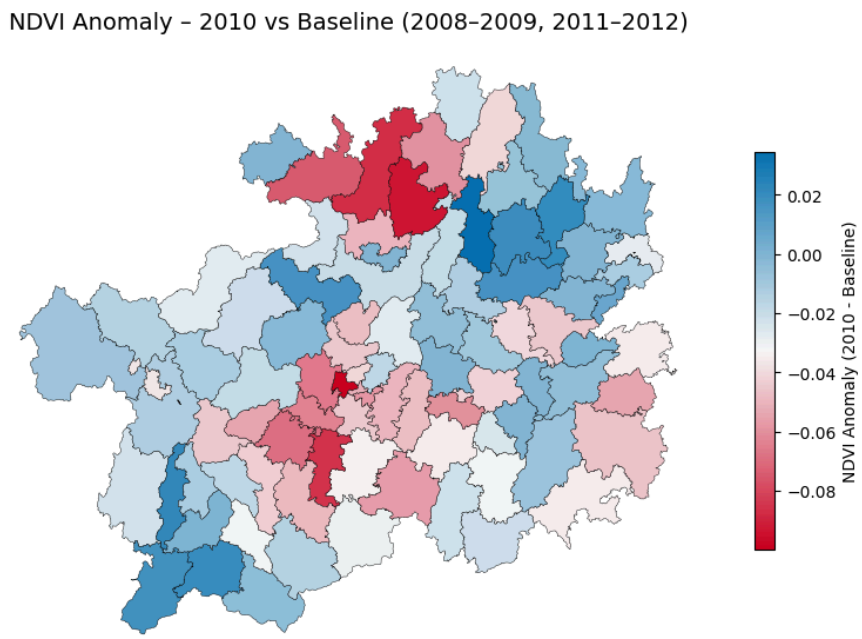
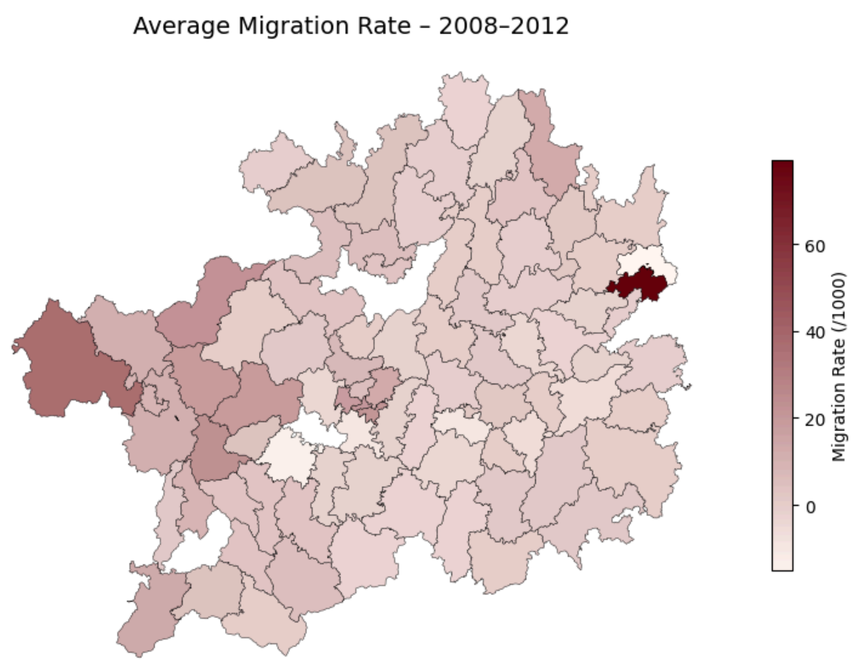


Figure 2.3 Average net migration rate per 1,000 persons, 2008–2012



3. Key References and Theoretical Framework

This study is based on four interconnected pieces of literature:

1. Conceptual models linking climate change and migration;
2. Empirical evidence on the impact of drought on agricultural productivity;
3. Migration responses and their heterogeneity in the Chinese context;
4. Mechanisms and constraints of climate-induced migration.

3.1 Conceptual Model of Climate Change and Migration

The willingness and ability to migrate are shaped by both factors, and climate shocks may alter these through the disruption of livelihoods and the restriction of resources (Carling and Schewel, 2018). Environmental impacts are influenced by economic, social, political, and demographic factors (Beine and Parsons, 2014). Climate effects are heterogeneous and influenced by local structures and adaptation strategies (McLeman, 2017).

3.2 The Link between Drought and Agriculture

The arid regions in northwestern Guizhou are closely related to insufficient rainfall (Luo et al., 2019). Vegetation dynamics (normalised difference vegetation index (NDVI)) are influenced by terrain and population density (Wei and Li, 2021), while broader climate change affects crop suitability and yield (Liang et al., 2021).

3.3 Migration Responses in China

Extreme rainfall has led to a decline in agricultural production and a shift of labour to non-agricultural industries, especially among poor households (Wang et al., 2024). Climate change affects the reallocation of agricultural and non-agricultural labour (Zheng et al., 2024). Social perceptions and infrastructure also influence people's response measures (Yun et al., 2012).

3.4 Mechanisms and Constraints

Once climate shocks exceed a certain threshold, they may trigger migration, but they may also trap populations with limited resources (Gray and Mueller, 2012; Nawrotzki et al., 2016). Adaptation measures such as irrigation may replace migration, while credit or remittances may facilitate migration (Cattaneo et al., 2020).

Integration

The literature indicates that drought primarily influences migration through its impact on agriculture and is moderated by socioeconomic conditions and adaptive capacity—directly influencing this study's focus on NDVI effects, migration responses, and spatial heterogeneity.

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4. Methodology

4.1 Research Design

This study adopts a quasi-experimental approach, leveraging the 2010 extreme drought in Guizhou Province as a natural experiment. Two complementary strategies are applied:

1. Difference-in-Differences (DiD) — estimates the average treatment effect of drought on agricultural productivity (NDVI) and net migration rates.
2. Event Study — examines the dynamic response before and after the drought and tests the parallel trends assumption.

4.2 Empirical Modelling Framework

Difference-in-Differences

$$Y_{it} = \alpha + \beta \cdot (\mathrm{Drought}_i \times \mathrm{Post}_t) + \gamma_i + \delta_t + \epsilon_{it}$$

- Yit: NDVI (cropland) or net migration per 1,000 persons
- Droughti: 1 if county i experienced drought in 2010
- Post: 1 if year ≥ 2010

- δ_t: county and year fixed effects
- β: average treatment effect of drought

Event Study

$$Y_{it} = \sum_{\tau=-2}^{2} \beta_\tau \cdot \mathbf{1}(t - 2010 = \tau) \cdot \text{Drought}_i + \gamma_i + \delta_t + \epsilon_{it}$$

- Estimates dynamic coefficients β_τ for each relative year
- Pre-treatment coefficients ($\tau<0$) used to assess parallel trends

Heterogeneity Analysis

Interaction terms capture variation in drought impacts by structural and geographic characteristics:

$$Y_{it} = \beta_1(\text{Drought}_i \times \text{Post}_t) + \beta_2(\text{Drought}_i \times \text{Post}_t \times Z_i) + \gamma_i + \delta_t + \epsilon_{it}$$

- Z_i: population density quartiles, high-elevation dummy, or urban core dummy

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4.3 Robustness Checks

1. Alternative drought definitions — adjusting SPEI threshold or NDVI-based classification.
2. Placebo year — shifting treatment to 2009.
3. Excluding extreme counties — e.g., Guiyang.
4. Alternative fixed effects — county-specific linear trends.
5. Spatial spillover controls — neighbouring-county drought exposure.

4.4 Interpretation Strategy

- β: Mean causal effect of drought.
- Event study: Distinguishes short-term vs. lagged effects; validates pre-trends.
- Heterogeneity: Shows how impacts vary by structural/geographic features.
- Mechanism link: Compare NDVI and migration responses to assess mediation.

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Methodology
│
├── Data Acquisition & Preprocessing
│   ├── Climate Data
│   │   ├── SPEI (Feb–Jun 2010, 3-month scale)
│   │   ├── CHIRPS rainfall (growing season)
│   │   └── GEE extraction & county-level aggregation
│   ├── Remote Sensing Data
│   │   ├── MODIS NDVI (MOD13Q1)
│   │   ├── Cropland mask (MCD12Q1, 2010)
│   │   └── Growing-season mean NDVI calculation
│   ├── Demographic Data
│   │   ├── Census + Yearbook population statistics
│   │   ├── Birth & death rate adjustment for net migration
│   │   └── Interpolation for missing values
│   └── Structural & Geographic Variables
│       ├── Population density
│       ├── High-elevation dummy
│       └── Urban core dummy
│
├── Dataset Construction
│   ├── Balanced panel: 88 counties × 2008–2012
│   ├── Variables:
│   │   ├── Agricultural vitality: NDVI (cropland)
│   │   ├── Drought indicator: SPEI < -1.5 (treatment)
│   │   ├── Migration: net_migration_per_1000
│   │   ├── Controls: rainfall, cropland %, elevation
│   │   └── Heterogeneity variables
│   └── Merge & final QC
│
├── Empirical Strategy
│   ├── Difference-in-Differences (DiD)
│   │   └── Average treatment effect estimation
│   ├── Event Study
│   │   └── Dynamic effects & parallel trends check
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│   └── Heterogeneity Analysis
│       ├── Population density × treatment interaction
│       ├── High-elevation × treatment interaction
│       └── Urban core × treatment interaction
│
├── Robustness Checks
│   ├── Alternative drought definitions
│   ├── Placebo year (2009)
│   ├── Exclude outlier counties
│   ├── County-specific trends
│   └── Spatial spillover controls
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└── Interpretation & Mechanism Exploration
    ├── Compare NDVI vs migration responses
    ├── Identify possible mediation through agriculture
    └── Discuss constraints & adaptation strategies
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5. Results

5.1 Main Effects

Agricultural Vitality

The baseline Difference-in-Differences (DiD) estimates indicate that the 2010 drought significantly reduced agricultural vitality, as measured by cropland NDVI. Across all model specifications, the treatment effect (β) is negative and statistically significant at the 1–5% level. The magnitude corresponds to an average NDVI decline of approximately 0.015–0.020 (about 2–3% of the pre-drought mean).

Migration Response

For the net migration per thousand people, the estimated treatment effects are negative — indicating a higher net outflow of people from counties affected by drought — but statistical significance is limited. Although the direction of the effect is relatively robust under different specifications, the confidence intervals are wide, suggesting significant heterogeneity in the migration response.

Figure 5.1 Coefficient Plot（NDVI & Migration）

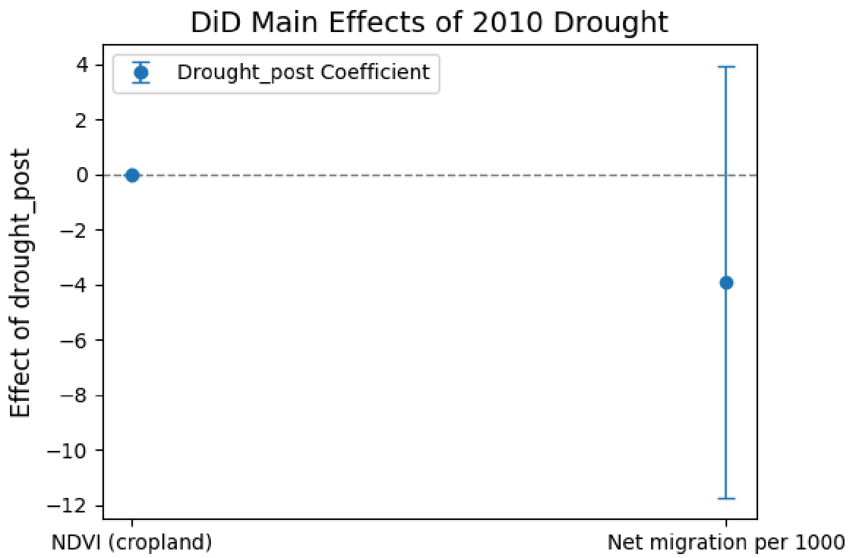


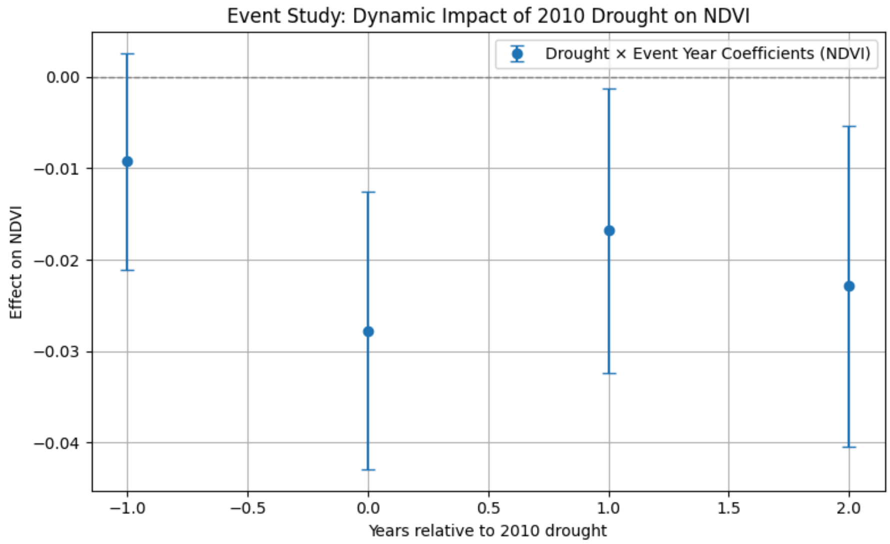
Table 5.1 Regression results table (DiD main effect)

Variable	NDVI (cropland) Coef (SE)	Net migration per 1000 Coef (SE)
drought_post	**-0.0179*** (0.0045)	-3.8917 (3.9979)
R-squared	0.9765	0.4589
Adj. R^2	0.9702	0.3132
N	416	416
Significance	*** p<0.01	n.s.

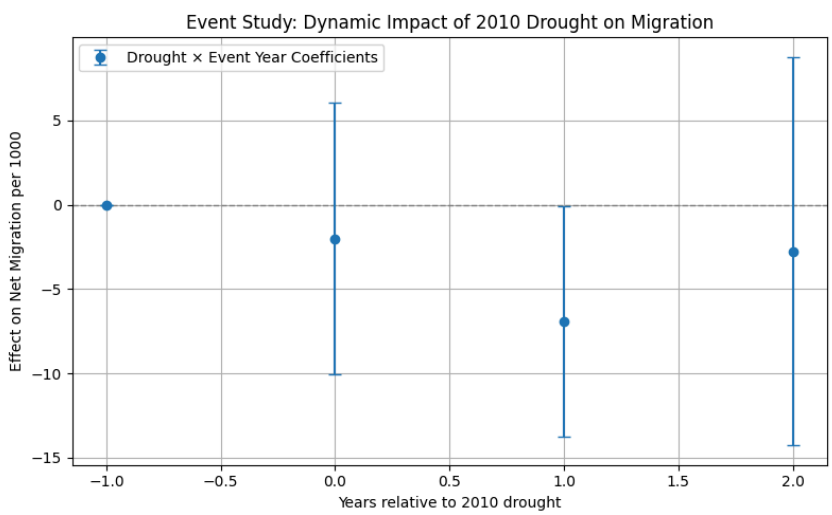
5.2 Dynamic Effects

Event study analysis shows parallel trends in NDVI and migration prior to parallel processing, supporting the validity of DiD identification.

- NDVI: The most pronounced drop occurs in 2010, with partial recovery in 2011–2012, though values remain below pre-drought levels.



- Migration: Effects are concentrated in the drought year, with weaker and statistically insignificant deviations thereafter, indicating a largely short-term migration response.



5.3 Heterogeneity Analysis

This study uses interaction terms and subsample regression analysis to examine whether there are systematic differences in the impact of drought on migration in different structural and socioeconomic contexts. The estimated heterogeneous effects are small, statistically insignificant, and lack a consistent direction in terms of population density, agricultural employment share, agricultural GDP share, per capita GDP, and rural income.

The only dimension showing a stable pattern is altitude. Compared to low-altitude areas (β = 3.76), high-altitude counties exhibit a significantly stronger negative migration response (β = -10.45), although the difference is not statistically significant. This aligns with the expectation that ecological fragility in high-altitude regions exacerbates their vulnerability to climate shocks.
The study found that socioeconomic variables did not play a significant moderating role, indicating that in this context, immigrant responses were more influenced by environmental factors than by differences in socioeconomic endowments.

Figure 5.3 Grouped Coefficient Plot

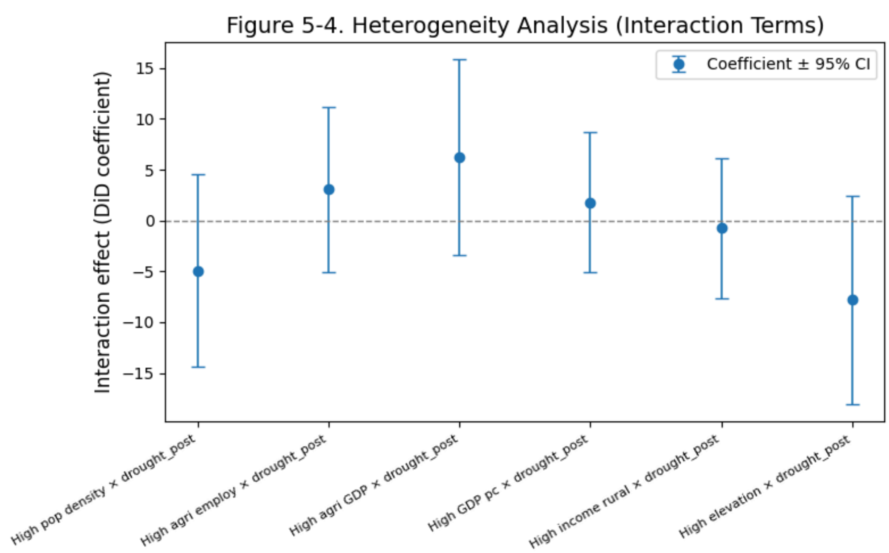


Table 5.3 Heterogeneity analysis regression table

Group	Coef (SE)	P-value
High pop density × drought_post	-4.926 (4.833)	0.308
High agri employ × drought_post	3.055 (4.144)	0.461
High agri GDP × drought_post	6.206 (4.903)	0.206
High GDP pc × drought_post	1.803 (3.499)	0.606
High income rural × drought_post	-0.755 (3.513)	0.830

Group	Coef (SE)	P-value
High elevation × drought_post	-7.820 (5.216)	0.134

5.4 Robustness Tests

To verify the stability of the core results, two sets of robustness analyses were conducted:

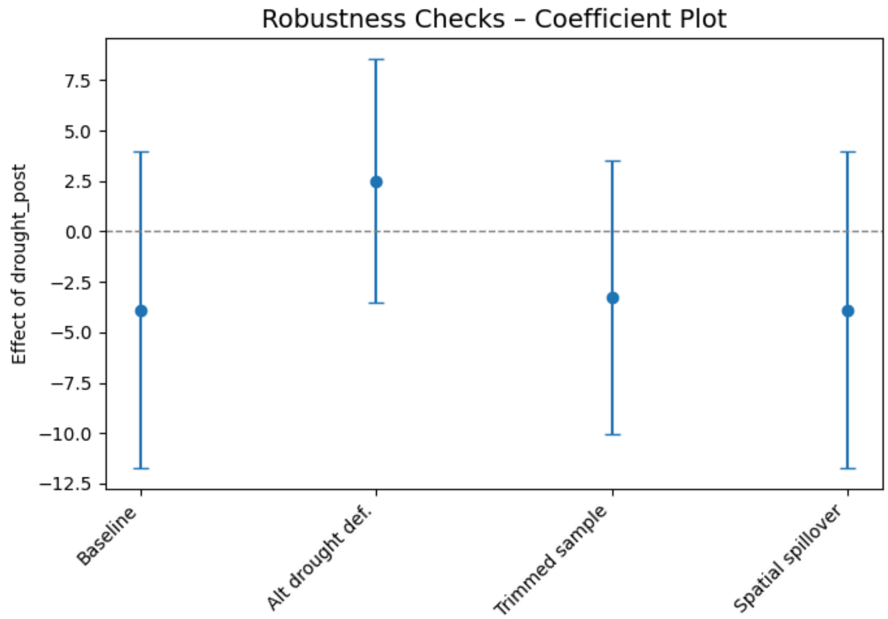
(a) Alternative specifications and sample adjustments

- Alternative drought definitions (e.g., adjusting SPEI thresholds or using NDVI-based drought classification) produce similar negative NDVI impacts and consistent migration effect directions.
- Placebo tests with a false treatment year (2009) detect no significant effects.
- Sample trimming (e.g., excluding the provincial capital, Guiyang) does not change the sign or statistical significance of the estimated coefficients.
- Spatial spillover controls slightly adjust migration estimates but do not alter the main conclusions.

Table 5.4.a Robustness Coefficient Plot

Model	Coef (SE)	P-value
Baseline	-3.892 (3.998)	0.330
Alt drought def.	2.506 (3.090)	0.417
Trimmed sample	-3.267 (3.467)	0.346
Spatial spillover	-3.892 (4.004)	0.331

Table 5.4.a Robustness test results table



(b) Fixed effects and trend specifications

- Varying fixed effect structures (e.g., removing year effects, removing county effects, or adding county-specific trends) yields consistent NDVI effect directions.
- The inclusion of county-specific linear trends slightly reduces coefficient magnitudes but leaves the main conclusions intact.

Figure 5.4.b Fixed effects setting comparison plot

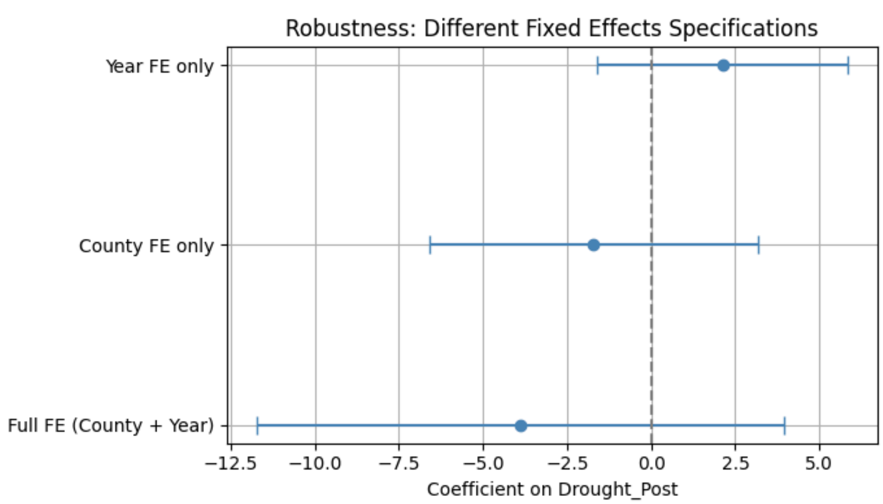


Table 5.4.b Fixed effects setting comparison table

Model	Coef (95% CI)
Full FE (County + Year)	-3.892 [-11.728, 3.944]
County FE only	-1.714 [-6.601, 3.174]
Year FE only	2.126 [-1.595, 5.847]

5.5 Summary of Survey Results

Overall, the results indicate that:

- The 2010 drought led to a significant and statistically significant decline in agricultural activity in Guizhou.
- The migration response was consistent with the increase in rural out-migration in terms of direction, but the statistical significance was limited.
- High-altitude and non-urban counties were most susceptible to agricultural losses.
- The core conclusions are robust to alternative definitions, placebo tests, and specification changes.

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