# Food Security at What Cost?

## Cropland Protection Policy under Climate Change in China

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# Motivations: Policy – Climate Tension

**Food security as a top national priority**

- Political mandate: "The rice bowl must be firmly held in our own hands."

**Area-based, location-specific cropland protection**

- Area-based control
- Spatial lock-in
- High rigidity

**Climate change as an external shock**

- Shifting climate conditions alter crop suitability zones
- **Crop migration** is a biophysical need

# Research Questions: A Moving Target on a Fixed Map

- **Policy mandates spatial rigidity**
  - Preserve designated cropland area and keep grain acreage stable in specific locations
- **Climate pushes for spatial reallocation**
  - Biophysically demands re-optimization of land use and crop mix

**Research Questions:**

- How do farmers make decisions in a constrained environment shaped by competing market, climate, and policy pressures?
- How costly is it to maintain static cropland protection policies in a dynamic, warming climate?

# Literature Review I: Gap Between Potential and Reality

## 1. The Adaptation Gap: Potential vs. Reality

*Prior Work:*

- **Frictionless Spatial Optimization (Theoretical Ceiling):**
  - *Hultgren et al. (2025); Xie et al. (2023); Rising & Devineni (2020)*
  - Comprehensive optimization of crop distributions to maximize welfare or minimize environmental footprints under frictionless condition
- **Reduced-Form Evidence (Empirical Floor):**
  - *Cui & Zhong (2024); Cui & Xie (2022); Sloat et al. (2020)*
  - Causal identification of land-use responses to long-run climate trends

**Our Contribution:**

- **Fill the "Missing Middle" Gap:** structurally quantify the **frictions** and **transition dynamics** to better illustrate the adaptation path

# Literature Review II: Gap in Land-Use Modeling

## 2. Structural Land-Use Modeling

*Prior Work:*

- **Land Conversion Models (Area Adjustment):**
  - *Scott (2013)*
  - Models the decision to convert land between agricultural and non-agricultural uses (entry/exit)
- **Crop Rotation Models (Crop Switching):**
  - *Pates & Hendricks (2021)*
  - Models the decision to switch crop types between corn and soybean

**Our Contribution:**

- **Methodological Refinement:** adapt the Arcidiacono & Miller (2011) framework into a **nested dynamic structure** to **jointly** model shifts in crop area and structure

# Institutional Background – How Cropland Protection Works in Practice

**1. Administrative Constraints: Spatial Lock-in**

- National “Red Line” quotas broken down to local zoning maps
    - Acreage targets assigned to local officials’, as a part of performance evaluations
- *Implication:* Land use becomes an administrative mandate, making conversion costly and difficult

**2. Economic Incentives: Distorted Returns**

- Minimum purchase prices and crop-specific subsidies
    - Policies raise returns for designated crops to maintain the status quo
- *Implication:* Financial incentives discourage **crop switching** even when climate suitability declines

# Institutional Background – How Farmers Make Adaptation Decisions

**1. Responses: Adaptation along Two Margins**

- **Extensive Margin (Land Conversion):** Farmers expand arable land in cold regions or abandon it in heat-stressed areas (Cui & Zhong, 2024).
- **Intensive Margin (Crop Switching):** Farmers adjust crop mix and rotations on existing land to mitigate yield losses (Cui & Xie, 2022).

**2. Determinants: Dynamic and Nested Decision-Making**

- **Intertemporal Trade-offs**
  - State-dependent soil conditions (Scott, 2013), rotation effects (Hendricks & Sumner, 2014), and crop-specific capital & experience (Song & Ren, 2022)
- **Unequal Switch Mode**
  - Switching *within* crops involves agronomic rotation and management adjustments
  - Switching *between* sectors involves land reclamation or abandonment

# Institutional Background – Transition Share Visualization

## 1. Study Region: Agriculture Frontier

- Defined as the **ever-cropped area** (cultivated in at least one year during the research period).
- *Assumption:* Only farmers within this frontier face active crop choices.
- **Non-crop:** Defined as land *within* this boundary but unplanted in a given year.

## 2. Definition of "Other Crops"

- Aggregates cash crops excluding staple grains and cotton.
  - Primarily consists of **Peanuts and Tubers**
  - Aggregated into a single choice due to small individual shares

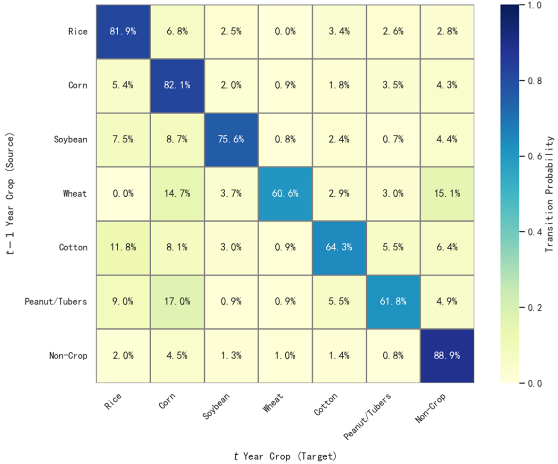


Figure 1: Crop Transition Probability Matrix

# Institutional Background – Example: Corn Expansion Pattern

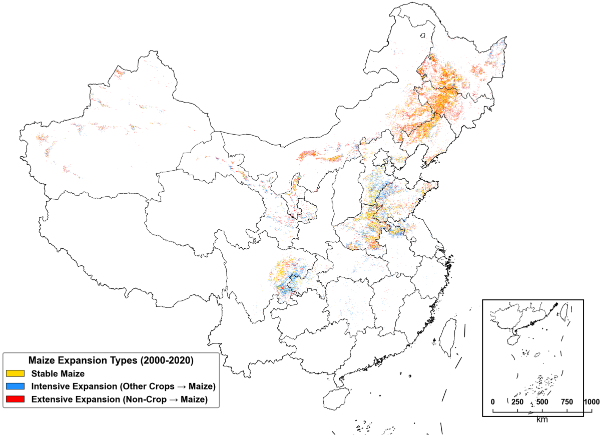


Figure 2: Spatiotemporal Changes in Corn Distribution (2000-2020)

**1. Spatially Distinct Patterns**

- **Northeast (Red):** Dominant **extensive expansion** in high latitudes.
- **North China Plain (Blue):** Widespread **intensive substitution** (e.g., cotton → corn) within existing farmland.

**2. Mixed Drivers: Climate & Policy**

- **Climate: Warming temperatures** unlocked previously cold land for corn
- **Policy: Price supports** (e.g., Temporary Reserve) incentivized corn production

# Model Setup

**1. Agent and decision unit**

- Individual small farmer located on grid-cell $i$ (field) in county $m$.
  - each period choose land use $j_{it} \in J$ to maximize expected discounted lifetime utility

**2. State variables**

- $w_{mt}$: exogenous market & climate state (crop prices, climate factors, etc)
- $k_{it}$: endogenous state (previous land use, $k_{it} = j_{i,t-1}$)
  - $k_{it}$ generates dynamics through switching costs and rotation benefits

**3. Nested choice structure**

- **Level 1 (extensive margin):** agriculture vs. non-agriculture
- **Level 2 (intensive margin):** conditional on $g_{it} = 1$ (agriculture), choose crop:

$$J_{\mathrm{Ag}} = \{\text{Rice, Corn, Soybean, Wheat, Cotton, Other (Cash crops)}\}.$$

# Payoff Function and Dynamic Optimization

**Flow payoff for choosing $j$:**

$$\pi_{ijmt}(j, k, w_{mt}) = r_j(w_{mt}) + \Phi_{jk} + \bar{\alpha}_j + \varepsilon_{ijt}.$$

- $r_j(w_{mt})$: expected net revenue from land use $j$

$$r_j(w_{mt}) = \text{Price}_{jmt} \times \text{Yield}_{jmt}(w_{mt}) - \text{Cost}_{jmt} + \xi_{jmt}$$

- $\bar{\alpha}_j$: crop-specific constant capturing average agronomic suitability and policy constraint
- $\Phi_{jk}$: transition cost when moving from last period's use $k$ to current use $j$
- $\varepsilon_{ijmt}$: idiosyncratic payoff shock (GEV), allowing within-nest correlation

**Bellman equation (finite-Markov process)**

$$V(k, w_{mt}) = \max_{j \in J} \left\{ \pi_{ijmt} + \beta \mathbb{E}\left[ V(j, w_{m,t+1}) \right] \right\}$$

# From Bellman to Probabilities

## 1. Nested Logit Probabilities (CCP)

$$P_{jk,t} = \underbrace{P_t(j|g,k)}_{\text{Within-Nest}} \times \underbrace{P_t(g|k)}_{\text{Nest Choice}}$$

- **Inclusive Value ($D_g$):** captures the aggregate attractiveness of nest $g$:

$$P_t(j|g,k) = \frac{\exp(v_j(k)/(1-\sigma))}{D_g(k)} \quad \text{where} \quad D_g(k) = \sum_{j' \in J_g} \exp\left(\frac{v_{j'}(k)}{1-\sigma}\right)$$

## 2. The Berry Inversion

- According to Arcidiacono & Miller (2011), to recover unobserved utility differences from observed shares:

$$v_j(k) - v_k(k) = \ln\left(\frac{P_{jk,t}}{P_{kk,t}}\right) - \sigma \ln\left(\frac{P_t(j|g,k)}{P_t(k|g',k)}\right)$$

- *Intuition:* Relative value = Log-odds ratio corrected by **within-nest substitution** ($\sigma$).

# Handling the Dynamics

**3. Finite Dependence (Handling the Future)**

- **Problem:** $E[V]$ involves an infinite sum.
- **Solution:** Construct two paths (Switch $k \to j \to j$ vs. Stay $k \to k \to j$) that lead to the same state at $t+2$. Future terms cancel out, expressing future value difference as:

$$\beta \Delta E[V_{t+1}] = \beta \left[ \ln \left( \frac{P_{jj,t+1}}{P_{jk,t+1}} \right) - \sigma \ln \left( \frac{P_{t+1}(j|g,j)}{P_{t+1}(j|g,k)} \right) \right]$$

# Final Linear Estimating Equation

**Combining Inversion and Finite Dependence**, we derive the linear estimating equation:

$$\underbrace{\ln\left(\frac{P_{jk,mt}}{P_{kk,mt}}\right)-\beta\ln\left(\frac{P_{jk,m,t+1}}{P_{jj,m,t+1}}\right)}_{\text{Y: Dynamic Log-Odds}}=\tau_{jk}+\alpha\Delta R_{jmt}+\sigma\underbrace{\left[\ln\frac{P_{mt}(j|g,k)}{P_{mt}(k|g',k)}-\beta\ln\frac{P_{m,t+1}(j|g,k)}{P_{m,t+1}(j|g,j)}\right]}_{\text{X}_{\sigma}\text{:Nested Correction}}+\eta_{jmt}$$

- LHS ($Y$): Dynamic Relative Probability
- $\tau_{jk}$ **(Intercepts): Structural Frictions & Heterogeneity**
  - transition-specific **switching costs** ($\Phi_{jk}$)
  - crop-specific **policy bias/suitability** ($\bar{\alpha}_j$)
- $\alpha\Delta R_{jmt}$**: Profit Incentives**
  - $\alpha$ represents the *marginal utility of income.*
- $\sigma[\ldots]$**: The Nested Logit Correction**
  - $\sigma \in [0,1)$ measures substitution similarity within the nest.
  - crops within the AG nest are closer substitutes both now and in the future

# Estimation Strategy: A Two-Step Structural Approach

**Step 1: First-Difference Estimation**

- **Objective:** Eliminate location-specific, time-invariant unobservables (e.g., soil quality, topography, static policy zones)
- **Method:** Estimate parameters using time-differenced equations:

$$\Delta Y_{jk,mt} = \alpha \Delta R_{diff,mt} + \sigma \Delta X_{\sigma,jk,mt} + \Delta \eta_{jmt}$$

- *Result:* estimates of $\hat{\alpha}$ (marginal utility) and $\hat{\sigma}$ (nesting parameter)

**Step 2: Recovering Structural Parameters**

- **Objective:** Recover the “constants” (Intercepts) lost in Step 1.
- **Method:** Calculate residuals using $\hat{\alpha}, \hat{\sigma}$ and average them over time:

$$\hat{\tau}_{jk} = \frac{1}{T} \sum_{t} \left( Y_{jk,mt} - \hat{\alpha} \Delta R_{diff,mt} - \hat{\sigma} \Delta X_{\sigma,jk,mt} \right)$$

- **Decomposition:** Unpack $\hat{\tau}_{jk}$ to separate **Switching Costs** ($\Phi_{jk}$) from **Crop Fixed Effects** ($\bar{\alpha}_j$)

## Identification Strategy: Constructing Instruments

**1. Within-Nest Endogeneity**

- *Source:* The term $X_\sigma$ correlated with current unobserved shocks $\xi_{jmt}$
- **Instrument:** Sum of **potential revenues** of *competing crops* in the same nest

$$Z_{j,mt}^{BLP} = \sum_{k \in g, k \neq j} (\text{GAEZ Yield}_{k,m} \times \text{Price}_{k,mt})$$

- *Logic:* Exogenous variation in competitors' suitability (GAEZ potential) shifts $j$'s share without directly affecting $j$'s unobserved utility

**2. Dynamic Endogeneity**

- *Source:* The future terms correlates with differenced (current) errors $\Delta\eta_{jmt}$
- **Instrument:** Twice-lagged revenue differences

$$Z_{j,mt}^{Lag} = \Delta\text{Revenue}_{j,m,t-2}$$

- *Logic:* Revenue from $t-2$ are **predetermined**

# Baseline I: Estimation of Structural Parameters

## Table 1: First-Step Estimates

| Parameter | Estimate | Std. Err. | t-stat | Interpretation |
|---|---|---|---|---|
| **Nesting Parameter** ($\sigma$) | **0.823** | 0.011 | 75.17 | High substitution within Ag |
| **Marginal Utility** ($\alpha$) | **0.747** | 0.066 | 11.27 | Price responsiveness |

- **High Nesting Correlation** ($\hat{\sigma} \approx 0.82$)**:**
  - crops within the agriculture nest are close substitutes but distinct from non-crop.
- **Price Responsiveness** ($\hat{\alpha} \approx 0.75$)**:**
  - The unit of revenue is **10,000 CNY/ha**.
  - *Meaning:* A revenue advantage of **10,000 CNY** for crop $j$ relative to (current) crop $k$ increases the dynamic **log-odds** of switching to crop $j$ (in the next year) by **0.75**.

# Table 2: Recovered Structural Primitives (Utility Units)

**Switching Costs ($\phi$)**

| Type | Value ($\phi$) |
|---|---|
| Exit Cost (Avg Ag $\rightarrow$ Non) | -3.920 |
| Entry Cost (Avg Non $\rightarrow$ Ag) | -0.759 |
| Rotation Cost (Crop $\leftrightarrow$ Crop) | -0.532 |

- **Negative Signs:** switching land use causes utility losses
- **Asymmetric Frictions** ($\phi_{exit} \gg \phi_{entry} > \phi_{rot}$) :
  - **Exit Cost is Massive (-3.92):** The cost to abandon cropland is **7x higher** than rotating crops.
  - *Insight:* This quantifies the **"Red Line" policy rigidity**.
    - Administrative bans on abandoning farmland act as a massive shadow tax on exiting agriculture.

## Elasticity Definitions & Framework

### 1. Definition

- simulate a permanent **+10% revenue shock** and measure the % change in area shares

$$\text{Elasticity} = \frac{\%\Delta\text{Share}}{\%\Delta\text{Price}}$$

### 2. Temporal Dimensions

- **Short-Run (SR):** The immediate response in year $t+1$
- **Long-Run (LR):** The response at a new **steady-state** ($t \to \infty$) when the system converges

### 3. Structural Dimensions (Nesting)

- **Unconditional Elasticity:** The total change in absolute area
- **Conditional (Within-Nest) Elasticity:** The change in share *within the cropland nest* (ignoring land abandonment)

# Elasticities I: Own-Price Elasticities & Rotation Dynamics

## Own-Price Responsiveness

| Crop | Short-Run (SR) | Long-Run (LR) | Pattern |
|---|---|---|---|
| **Rice** | **0.65** | 0.58 | SR > LR |
| Cotton | 0.55 | 0.44 | SR > LR |
| Other Crops | 0.68 | 0.53 | SR > LR |
| Corn | 0.36 | **0.31** | SR > LR |
| Wheat | 0.34 | 0.32 | SR > LR |
| Soybean | 0.30 | 0.26 | SR > LR |

- A **1% increase** in Rice revenue leads to a **0.65% increase** in Rice area in the short run, while **0.58%** in the long run.

**Mechanism: The "Rotation Effect" (SR > LR)**

- continuous cropping penalty (such as yield drag) weakens the total response

# Elasticities II: Decomposing Adaptation Margins

## 1. Intensive Margin: Within-Nest Substitution

- **Cross-Elasticity:** A 1% rise in Corn price reduces Soybean area by $\sim 0.06\%$
  - the decline in Soybean's share within cropland (0.067%) is sharper than its absolute area decline (0.063%)
- **The "Squeeze" Effect:**
  - Conditional Cross-Elas $(-0.067) >$ Unconditional Cross-Elas $(-0.063)$
  - *Insight:* Adaptation is mainly driven by **internal crop switching** (Within-Nest), not land abandonment.

## 2. Extensive Margin: High Barriers to Entry

- **Single Shock vs. All-Crop Shock:**
  - Corn Price $\uparrow$ 1% $\rightarrow$ Total Cropland $\uparrow$ **0.004%** (Negligible).
  - All Crop Prices $\uparrow$ 1% $\rightarrow$ Total Cropland $\uparrow$ **0.055%** (13x larger).
- *Insight:* Single-crop incentives are insufficient to overcome land conversion costs; only a systemic boom drives extensive expansion.

# Elasticities III: Regional Heterogeneity in Own-Price Elasticities

**Regional Own-Price Elasticities (Long Run)**

| Region | Corn | Rice | Wheat | Soybean | Cotton | Other |
|---|---|---|---|---|---|---|
| Huang-Huai-Hai Plain | **2.27** | **3.06** | **2.54** | 2.68 | 2.22 | 1.24 |
| Sichuan Basin | 1.68 | 1.46 | 1.44 | 0.42 | 0.34 | 0.89 |
| Northern Arid & Semiarid | 0.14 | 0.32 | 0.11 | 0.02 | 0.02 | 0.21 |
| Middle–Lower Yangtze Plain | 0.08 | 0.21 | 0.07 | 0.05 | 0.23 | 0.13 |

- Heterogeneity: Huang–Huai–Hai Plain & Sichuan Basin (high) v.s. Northern Arid & Semiarid region & the Middle–Lower Yangtze Plain (low)

# Policy Counterfactual I: Modeling Climate Damage

## 1. The Damage Function Specification

- counterfactual yields under warming scenarios:

$$Y_{jmt}^{CF} = Y_{jmt}^{Base} \cdot \exp\left( \sum_{k \in \mathcal{K}} \hat{\beta}_{j,k} \cdot (\text{Days}_{mt}^{k,CF} - \text{Days}_{mt}^{k,Base}) \right)$$

- *Where:* $K$ denotes high-temperature bins (e.g., $\geq 35°$C).

## 2. Parameter Calibration

- **Crop-Specific vs. Overall:** While the model allows for crop-specific $\beta_{j,k}$, our baseline uses a robust overall estimate from recent literature (Chen et al., 2024).
- **Current Parameter:**
  - *Value:* Each additional day with temperature $\geq 35°$C reduces overall agricultural TFP by approximately **0.5%**.

# Policy Counterfactual II: The Cost of Rigidity

## 1. The Impact: Yield & Calorie Loss

- **Scenario:** Under a 2050 moderate warming scenario (SSP2-4.5), if land use remains fixed (No Adaptation):
  - **Yield Loss:** Average crop yield drops by $\sim 0.21\%$
  - **Calorie Loss:** Total caloric production decreases by $50,750$ kcal per hectare

## 2. The Price Tag: Subsidy Required

- subsidy budget would need to increase by roughly 733 CNY per hectare to keep farmers in agriculture despite the lower returns

## 3. Mitigation: Reducing Frictions

- *Hypothesis:* Lowering **switching costs** (e.g., via better extension services or land transfer markets) facilitates climate adaptation
- *Ongoing Analysis:* Map these channels into reductions in estimated transition costs $(\phi_{\text{entry}}, \phi_{\text{rot}})$

## Takeaways

- **Tension:**
  - China's food-security regime is built on *area-based, location-specific* cropland protection
  - while climate change is shifting where crops can be productively grown
- **Approach:**
  - a **nested dynamic discrete-choice model** jointly capture **switching costs** and **adaptation elasticities** on both **extensive** (ag vs. non-ag) and **intensive** (crop switching) margins
- **Key Findings:**
  - Large **exit costs** make cropland abandonment very difficult, thus most climate and price responses operate through **within-cropland switching**.
  - Own-price elasticities are moderate overall but highly heterogeneous across regions.
- **Policy Implication:** Under a moderate future warming scenario, keeping current cropland targets requires an around 700 CNY increase in subsidy per hectare.

Thank you for listening!

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