The Effect of Climate on Insurance: Measuring the Impact of El Nino Southern Oscillation on U.S. Crop Insurance

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Motivation

- The drought conditions of 2012 materialized following a La Niña episode of the El Niño Southern Oscillation (ENSO) cycle
- This linkage has long been documented in the literature (e.g. Handler 1990; Solow et al 1998; Adams et al 1999; Chen et al 2002)
- Some studies suggest frequency and intensity of ENSO anomalies will increase parallel to climatic change
    - Subject of ongoing debate, literature still evolving

Motivation

- Better understanding of ENSO dynamics have improved forecasts of this phenomenon (e.g. Kirtman and Schopf 1998; Hall et al 2001; Ubilava and Helmers 2013)
  - Presents opportunities for crop producers to mitigate adverse climatic conditions and/or take advantage of more favorable ones
  - Value of improved forecasts has been well recognized, studies report positive impacts in both developing and developed regions of the world
- Impacts of climate forecasts on production decision-making has been well studied, more work needs to be done to address the issue from the insurance standpoint (Carriquiry and Osgood 2011)

Research Questions

- What factors can sabotage actuarially fair crop insurance premium rates, and how might ENSO events be linked to these deficiencies?
- Moreover, what opportunities could these effects create for crop insurers?

Suggestive Evidence

- Goodwin and Ker (1998) note that area-specific idiosyncrasies such as floods and/or extreme hail likely affect localized yield distributions
- ENSO's established linkage with hazardous weather conditions in turn suggests a linkage with the overall shape of these distributions
  - ENSO linked to damaging storms, drought, wildfires, and flooding (Handler 1990; Bove et al 1998; Saunders et al 2000; Legler et al 1999)
- Goodwin (2001) finds that spatial correlation of crop yields strengthens during extreme weather events
  - Premium rates that ignore ENSO-driven impacts suggests an overall program vulnerability similar in spirit to the "formula that felled Wall St" criticism that has been (at least) partially linked to the 2008-2009 global financial crisis

Important Timing of Events

- Chronology of events for insurance rate-setting and producer purchase-decisions creates interesting economic dynamic
- ENSO conditions establish in May-December
  - After RMA sets premium rates
  - Before deadline for crop insurance enrollments, and perhaps more importantly, before deadline for private insurance companies to decide to retain policies or cede some of them back to FCIC
- Reasonable to presume that these private companies can exploit ENSO-driven information asymmetry to identify pricing inaccuracies in RMA rates, and capitalize on this in an economically meaningful way

Objective of this Research

- Utilize historical data on yield and weather outcomes to evaluate ENSO's effect on yield distribution
- Evaluate if these effects provide an opportunity for private insurance companies to accrue economic rents through reinsurance decisions
- Focus on Southeastern cotton production
  - Southeast an attractive venue for analyzing ENSO impacts on agriculture due to the numerous hazardous weather conditions it may cause (Hansen et al 1998; Jones 1999; Solis and Letson 2013)
  - Cotton a major Southeastern crop

Main Findings

Use large panel of county-level yield and weather data to measure ENSO effects on rates for the Group Risk Plan (GRP)

- Find that extreme ENSO events alter cotton yield distributions in the Southeastern U.S.
- Impacts translate into economically meaningful effects on crop insurance premium rates
- Demonstrate that commercial insurers can use publicly available information to extract economic rents via the cede/retain decision

Model Overview

- The moment based maximum entropy (MBME) model has two components
- First component utilizes moment equations in the spirit of Antle's Linear Moments Model to condition moments of the crop yield distribution on weather
- Second component utilizes these conditioned moments in a maximum entropy framework to estimate the corresponding conditional probability density function

Moment Model

- System of $j = 1, .., J$ equations that link moments to conditioning variables

$$\phi_j(y) = g(x; \beta) + \varepsilon$$

where $\phi_j(y)$ is a transformation of yield y, and $g(x; \beta)$ is a parameterized function of conditioning variables x. Under $E(\varepsilon \mid x) = 0$, it follows that $E\left[\phi_j(y) \mid x\right] = g(x; \beta)$ which effectively links different types of moments to x

Maximum Entropy

- A finite set of moments alone are not sufficient to identify the entire density (and thus premium rates)
- Well-known moments problem: there might exist an infinite number of densities satisfying the given moment conditions
- Jaynes' Principle of Maximum Entropy suggests selecting the density, among all candidates satisfying the moment conditions, that maximizes the entropy
- The maximum entropy density is uniquely determined as the one which agrees with what is known, but expresses maximum uncertainty with respect to all other matters

Maximum Entropy

- Solution is of the form

$$f^*(y) = \exp\left[\lambda_0 + \sum_{j=1}^{J} \lambda_j g_j(y)\right]$$

  which is the pdf for the exponential family
- We assume densities can be approximated using $g_j(y) = y^j$, $j = 1, 2, 3$
  - Nests the normal distribution ($g_1(y) = y$, $g_2(y) = y^2$)
  - Including the third moment allows for an arbitrary pattern of skewness
- Implies that the log-density is being approximated by a third order polynomial

$$\ln f^*(y) = \lambda_0 + \lambda_1 y + \lambda_2 y^2 + \lambda_3 y^3$$

Model Flow Chart

Historical Data

y, x

↓

Linear Moment Model

$$\phi_j(y) = g(x;\beta) + \varepsilon$$

↓

Predicted Moments

$$\widehat{\phi_j(y)} = g(\bar{x};\hat{\beta})$$

Maximum Entropy Lagrangian

$$L = -\int f(y)\ln f(y)dy$$
$$-\left[\lambda_0 \int f(y)dy - 1\right]$$
$$-\sum_{j=1}^{J} \lambda_j \left[\int \phi_j(y) f(y)dy - \widehat{\phi_j(y)}\right]$$

↓

Maximum Entropy Density

$$f^*(y \mid \bar{x}) = \exp\left[-\hat{\lambda}_0 - \sum_{j=1}^{J} \hat{\lambda}_j \phi_j(y)\right]$$

ENSO Impact Vectors

- El Niño and La Niña can impact U.S. agriculture through multiple vectors
  - ENSO linkages with precipitation and temperature provide a straightforward causal connection with crop production
  - Extreme ENSO events are likely to amplify hazardous weather conditions, resulting in damaging storms, drought, and flooding
  - Climate conditions during ENSO events are correlated with pest damage as extreme conditions can generate large changes in development rates for insects and germination rates for bacteria, fungi, and nematodes

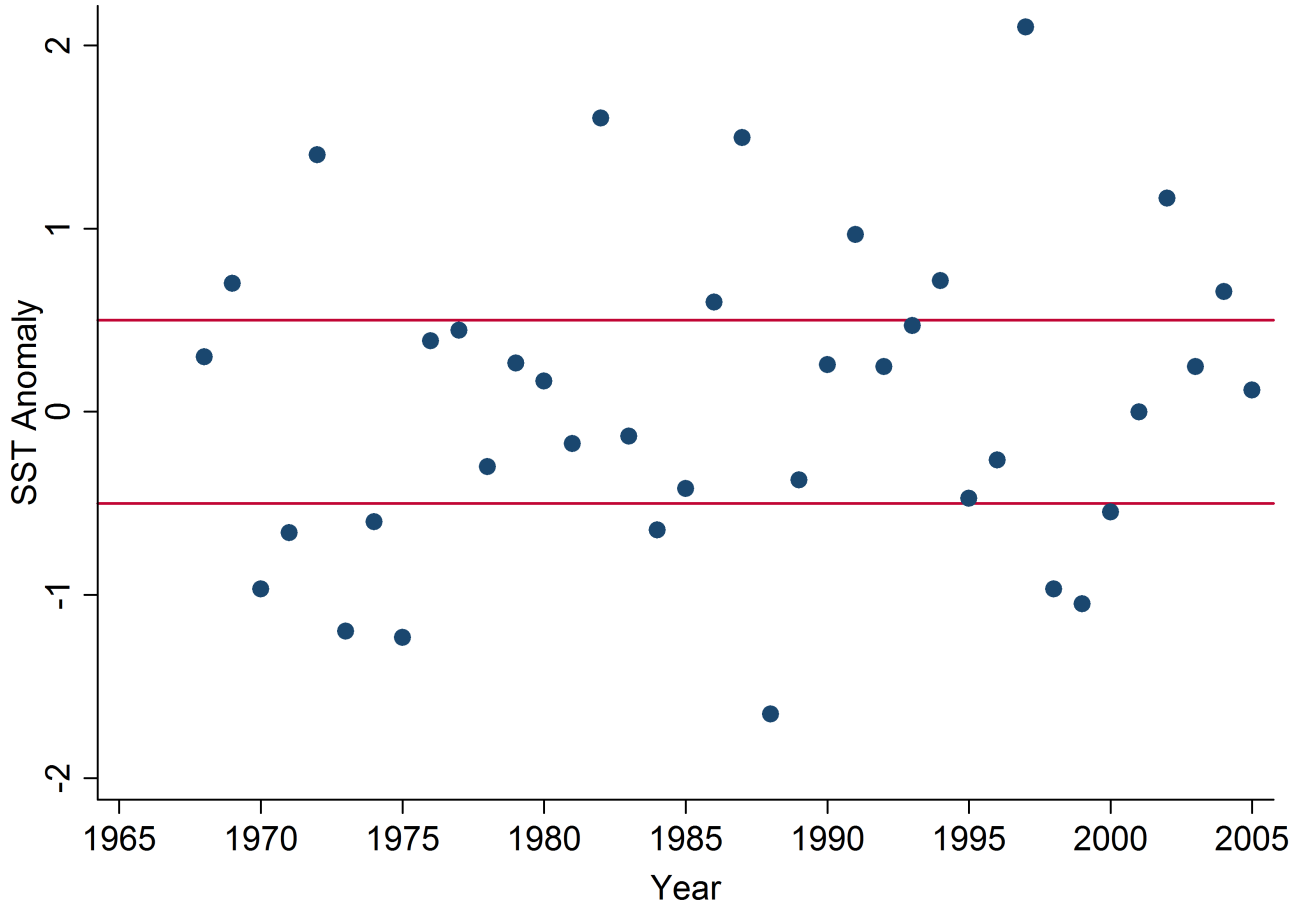
$$\mathbf{x}_t = \begin{bmatrix} low_t & med_t & high_t & p_t & p_t^2 & trend_t & nino_t & nina_t \end{bmatrix}$$

Data Overview

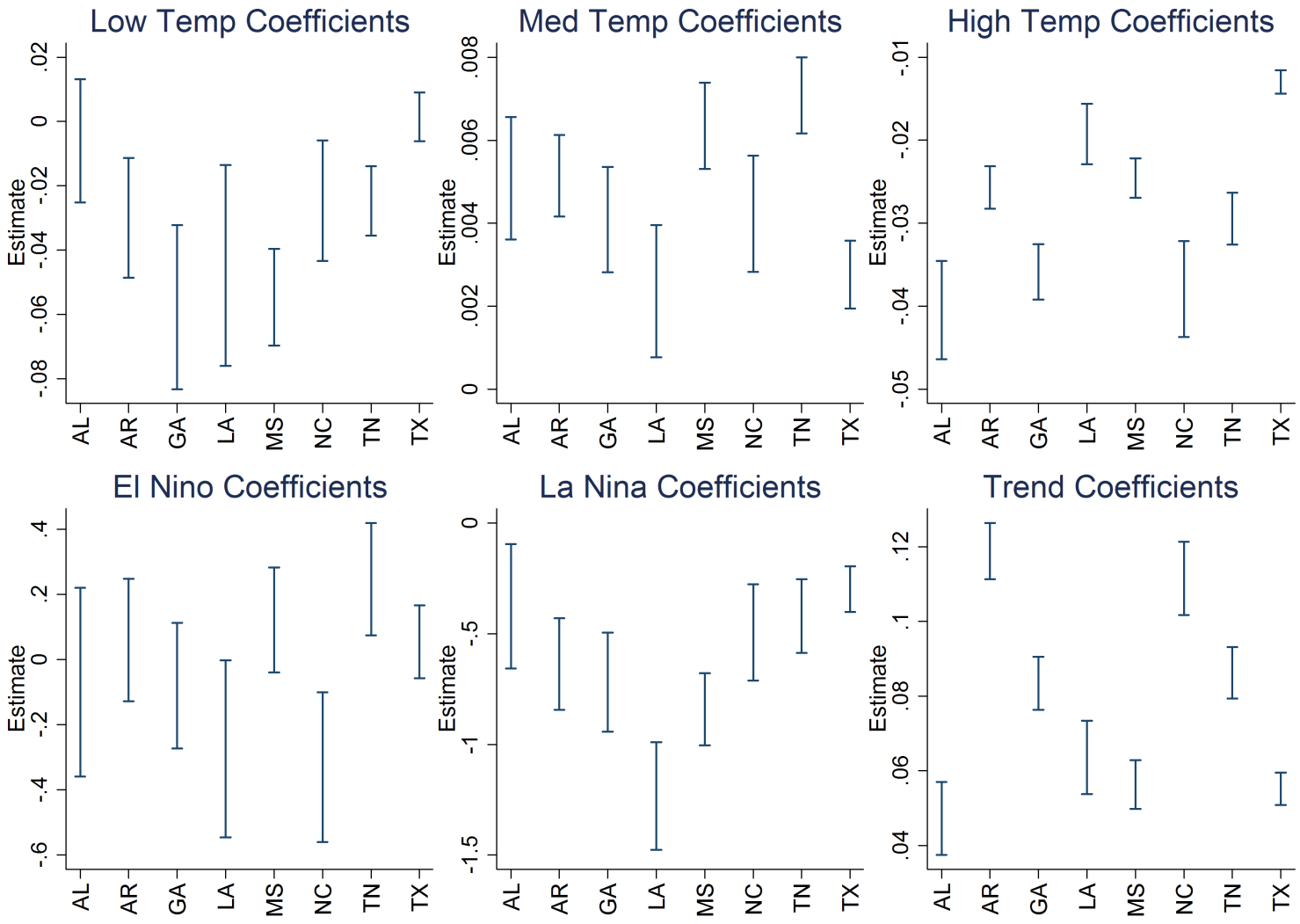
- County-level yield data are collected from the National Agricultural Statistics Service and are measured in 10 lb units per acre ($8,512$ observations representing 224 counties in 8 states, 1968-2005)
- ENSO measures are derived from monthly time series of the ENSO anomaly, Niño 3.4, tabulated by the Climate Prediction Center at NOAA
- Temperature (degree days) and precipitation data are the same as in Schlenker and Roberts (2009)

ENSO Events

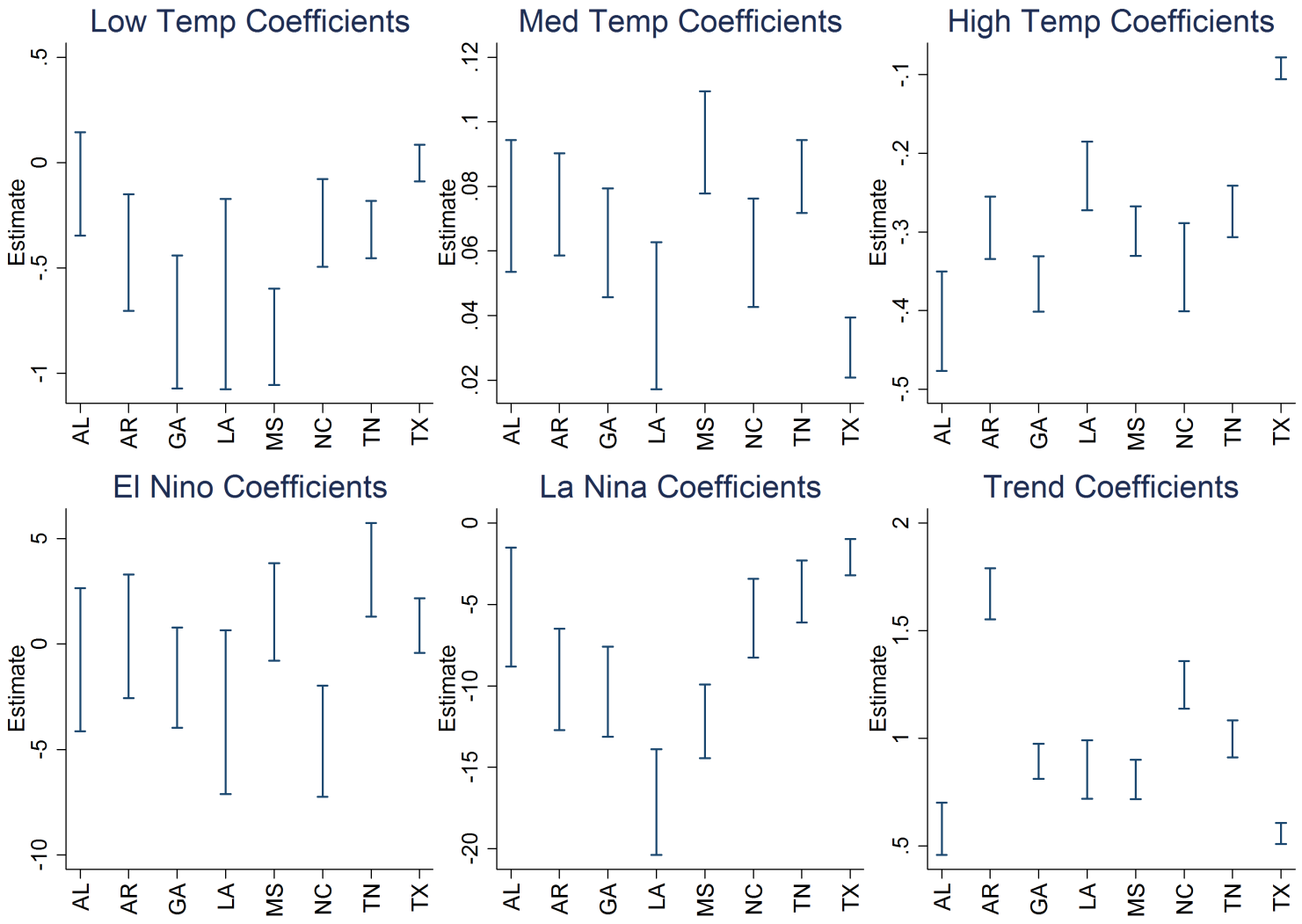
Average sea surface temperature anomaly, preceding May-Dec



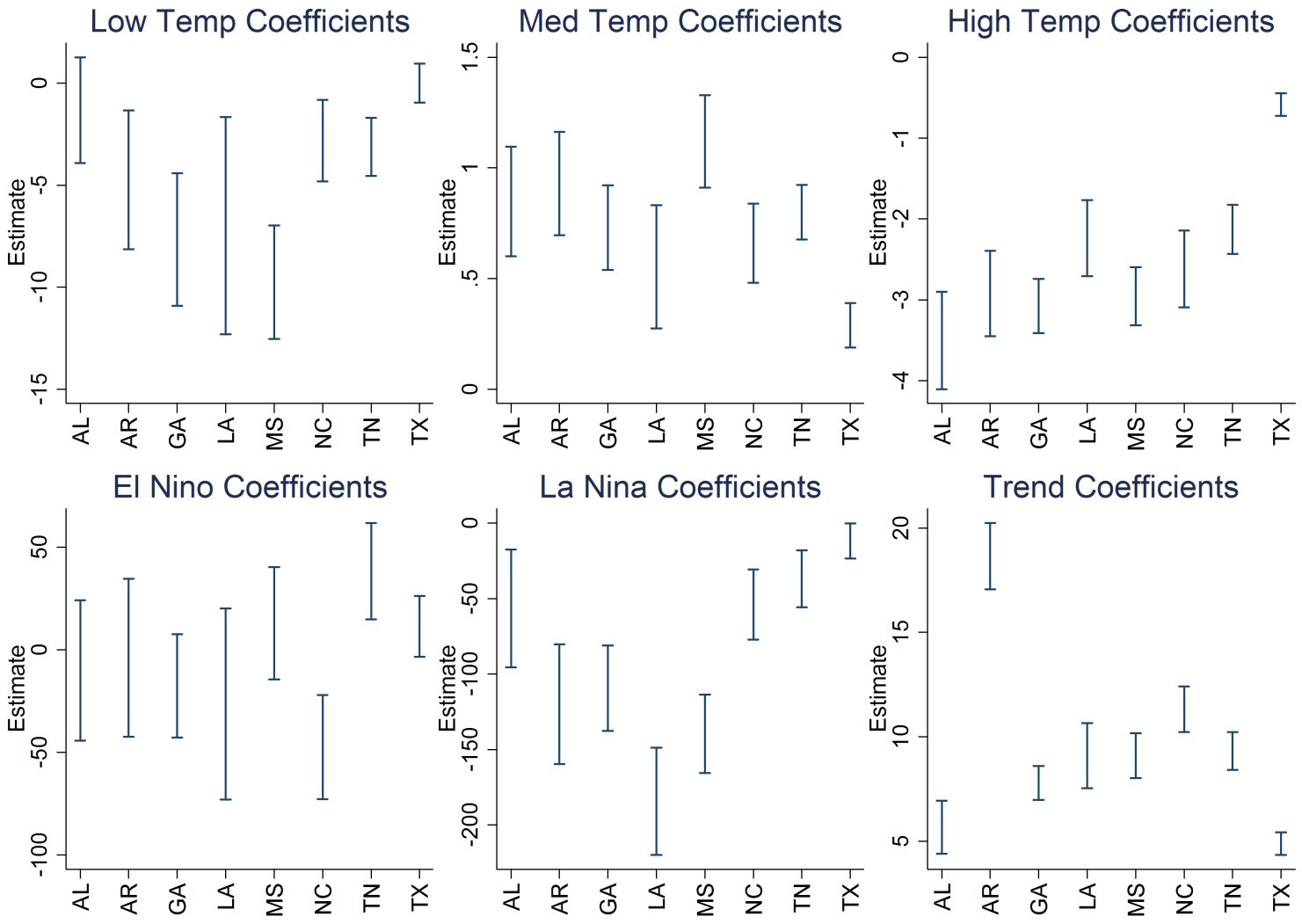
Parameter Estimates, Mean Equation



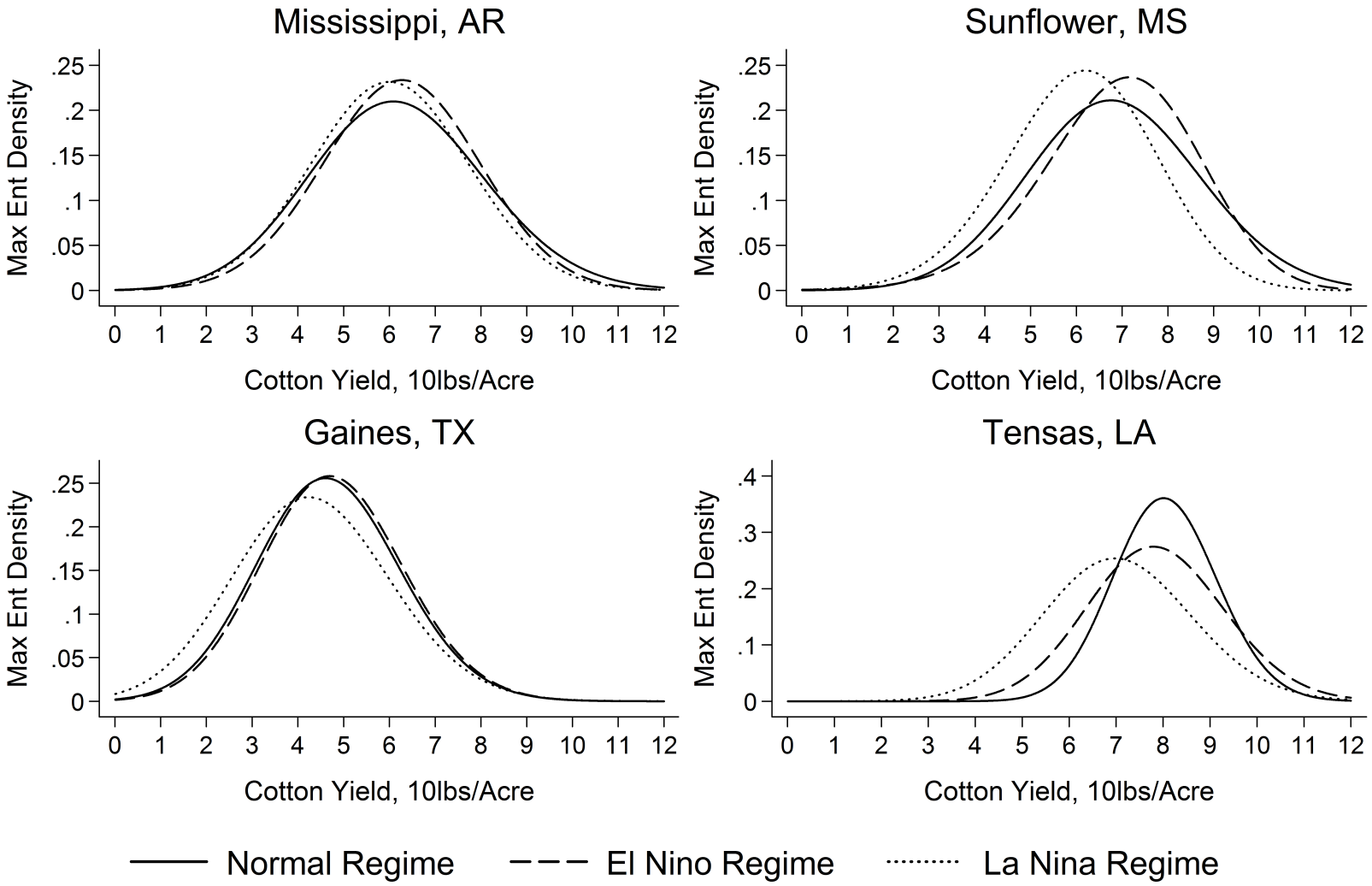
Parameter Estimates, Second Moment



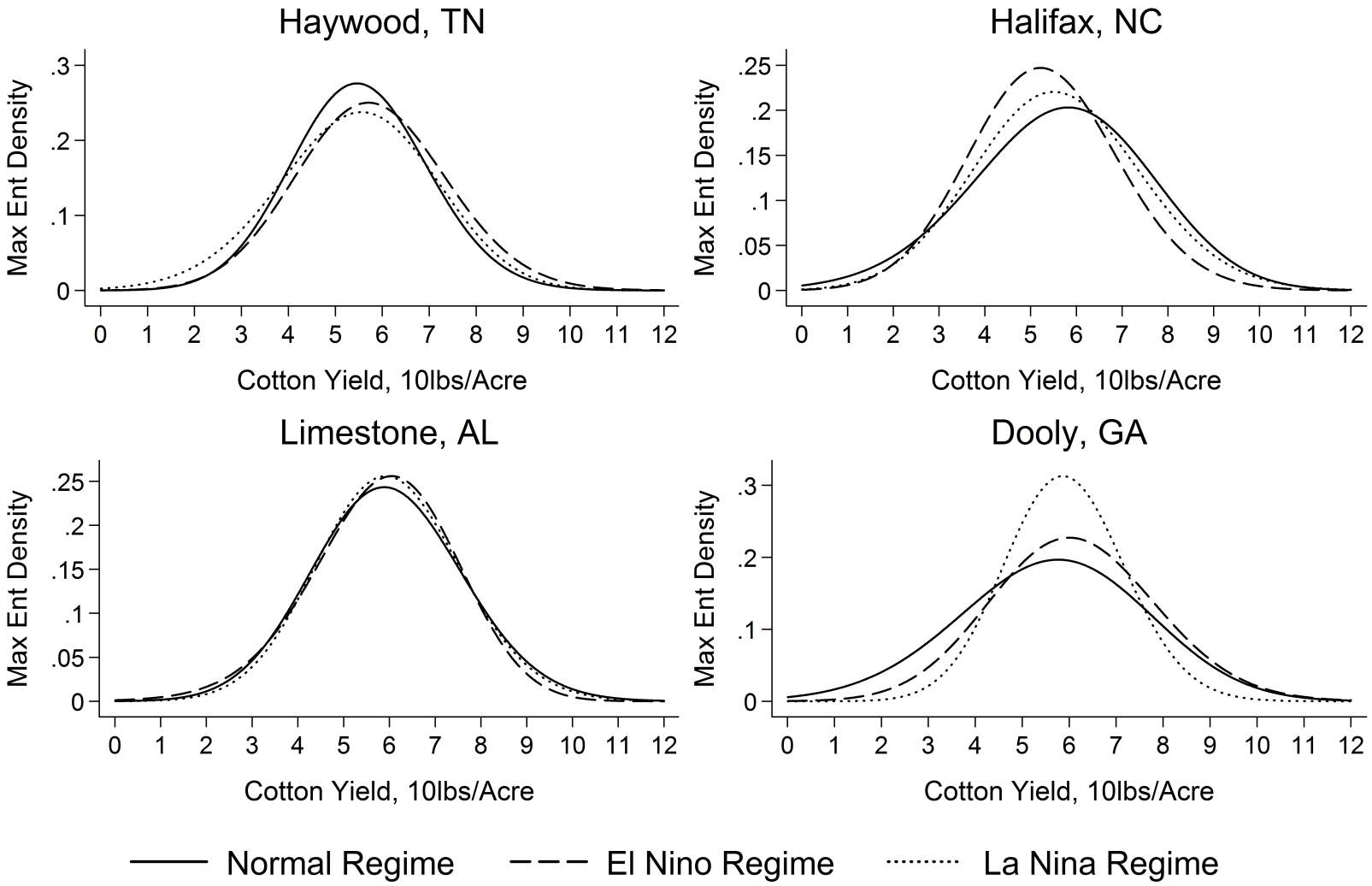
Parameter Estimates, Third Moment



Regime Densities

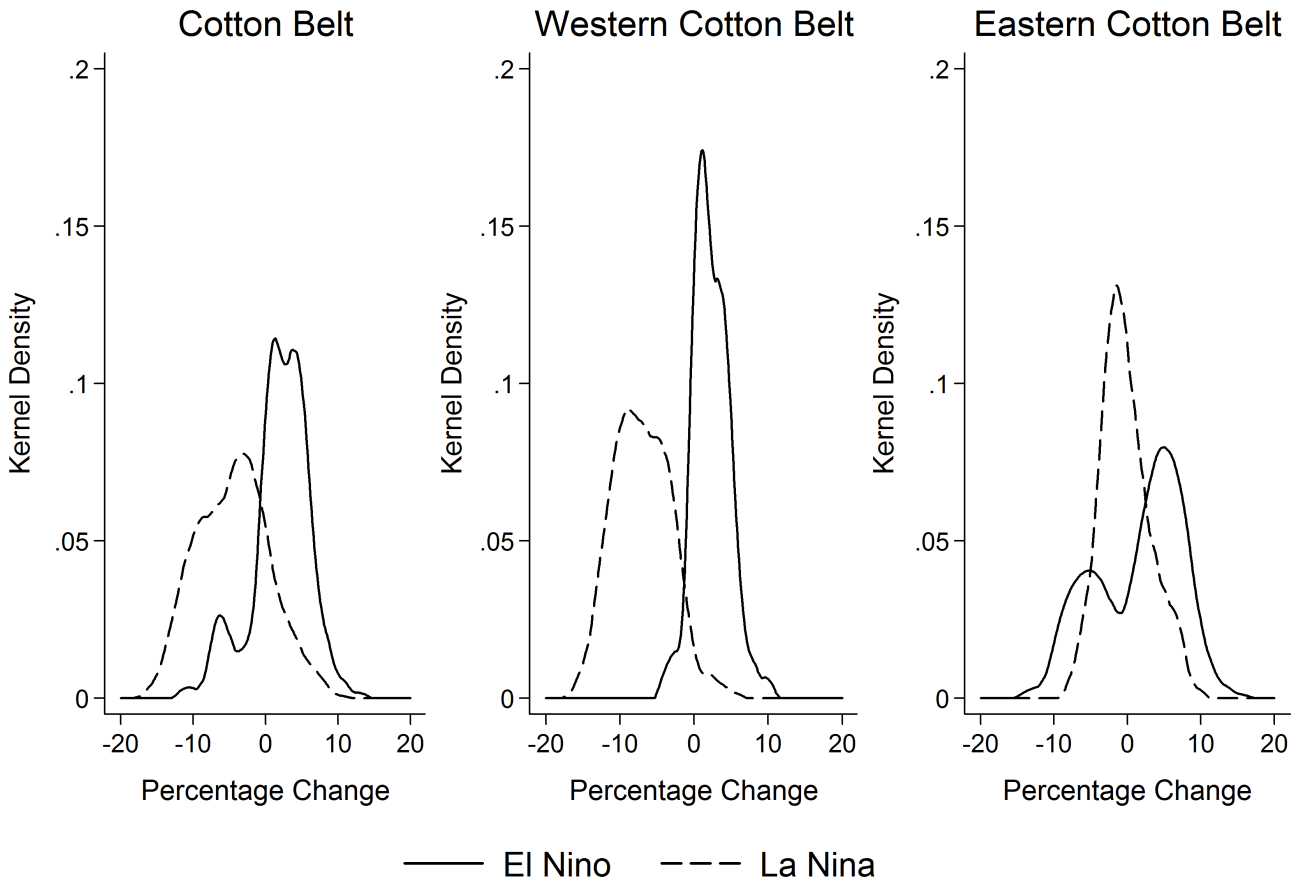


Regime Densities



Mean Effects

Calculated as the percentage change relative to Normal Regime



Calculating GRP Rates

Densities are used to calculate county-level rates for each ENSO regime ($i = nino, nina, normal$) at coverage levels $c \in [.5, .9]$ according to

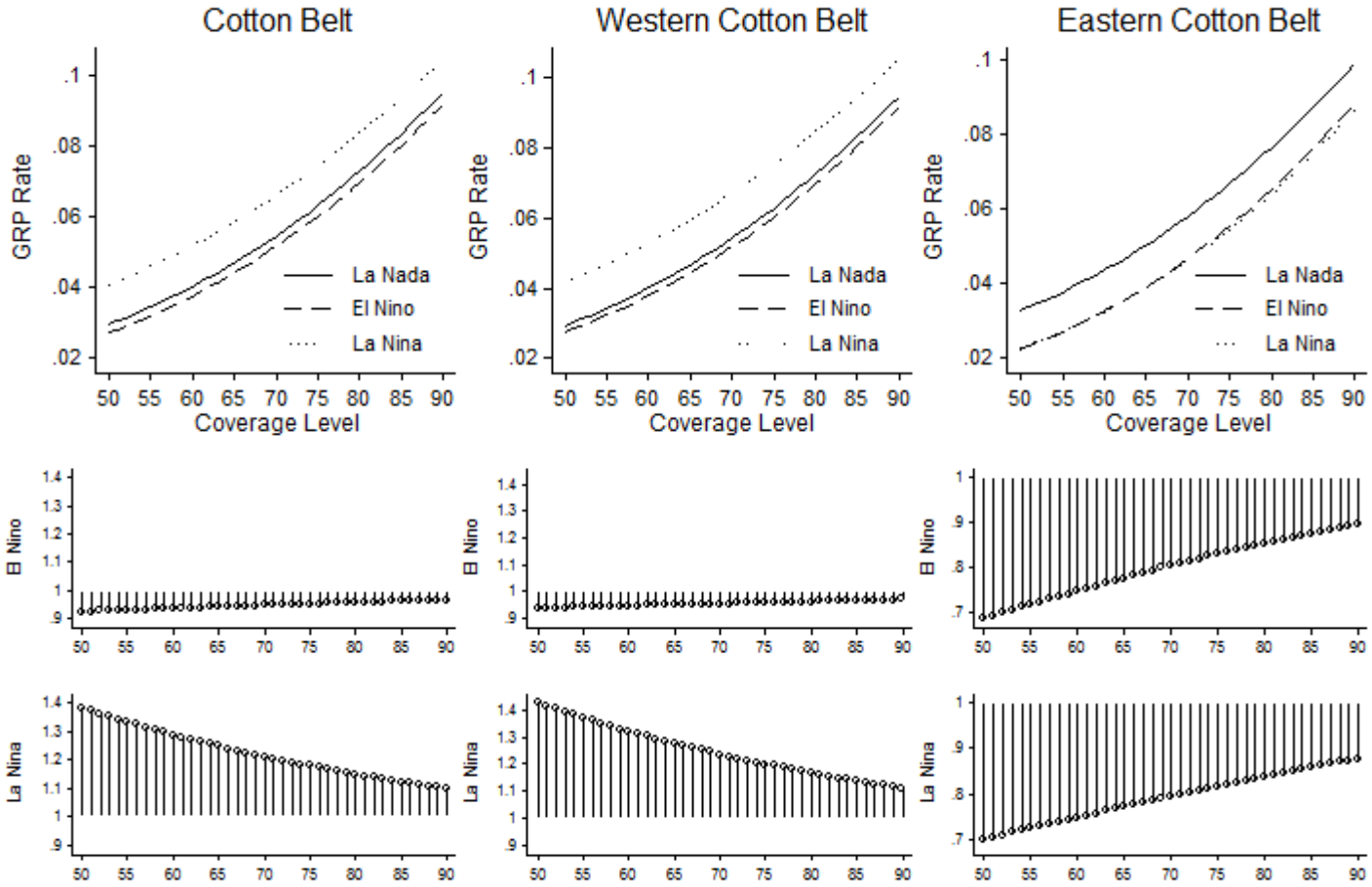
$$rate_c^i = E\left(indemnity_c^i\right) / liability_c^i$$

where

$$\begin{aligned} E\left(indemnity_c^i\right) &= \int_0^{y_c^i} \left[\left(y_c^i - y\right) / c\right] f\left(y|\overline{\mathbf{x}}_i\right) dy, \\ liability_c^i &= y_c^i = cE\left(y|\overline{\mathbf{x}}_i\right) = c\int_0^{\infty} y f\left(y|\overline{\mathbf{x}}_i\right) dy \end{aligned}$$

Regional GRP Rate Impacts

Acreage-weighted rates: full sample, western, and eastern



Economic Significance of Rate Effects

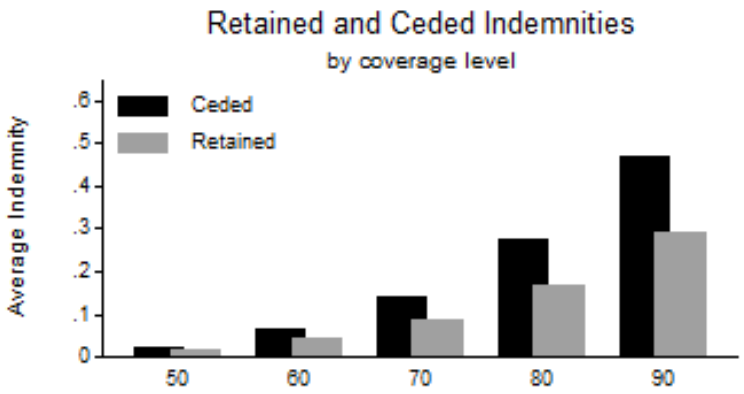
- Demonstrate that these effects are economically significant by conducting a repeated game of insurance selection similar to Harri et al (2011)
  - Timing of knowledge regarding ENSO events is key. ENSO conditions establish between May-Dec. RMA cannot make use of this information, private crop insurance companies can
- Infrequency of ENSO events and relatively short time series of data implies cannot conduct out-of-sample exercise
- We use an in-sample counterpart

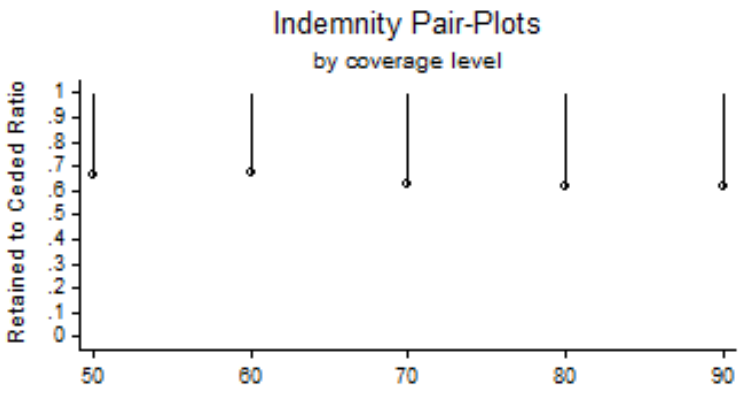
In-sample Game of Insurance Selection

- Entire time series used to derive actuarially fair premium rates while ignoring the influence of ENSO (RMA rates)
- Assume the role of a private insurance company and compare these rates to El Niño and La Niña rates
- Time-invariant decision rule: if RMA rate is lower than El Niño (La Niña) rate then we cede the policy in every El Niño (La Niña) year as we believe them to be under-priced. Retain policies otherwise
- Calculate actual indemnities for all county-year observations in the data using realized yield observations

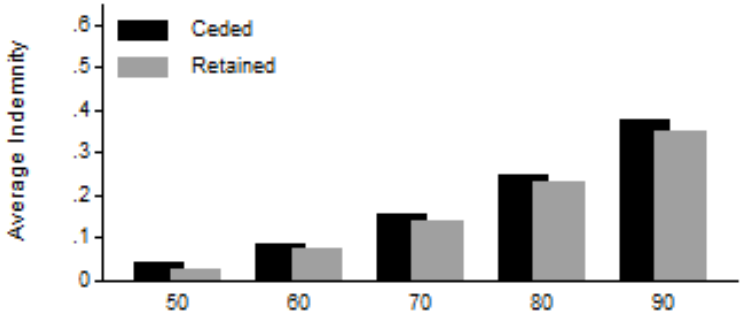
Expected Indemnities for Ceded/Retained Policies, Full

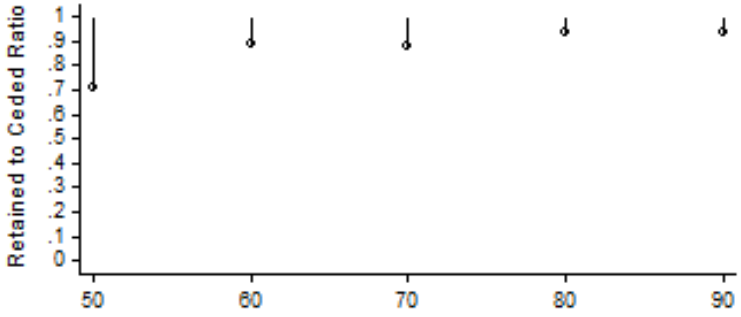
La Nina





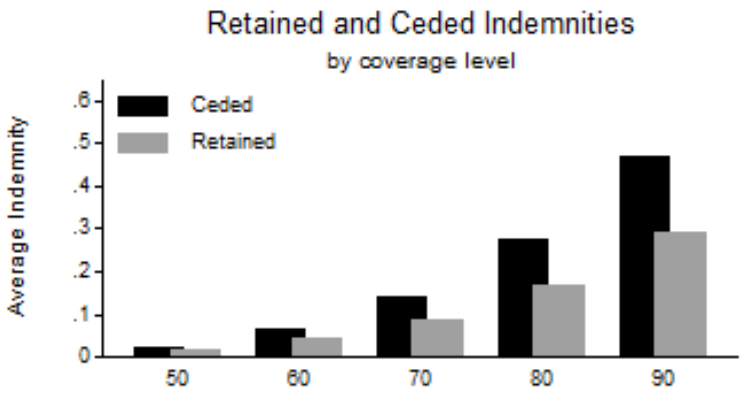
El Nino

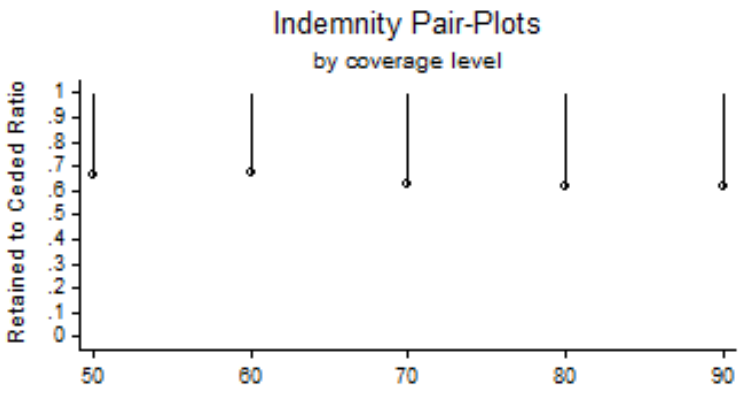




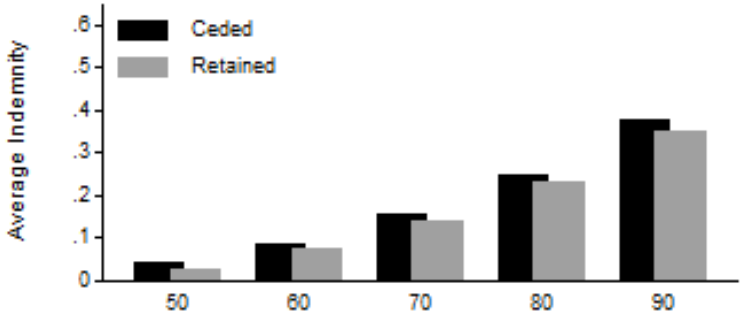
Expected Indemnities for Ceded/Retained Policies, Western

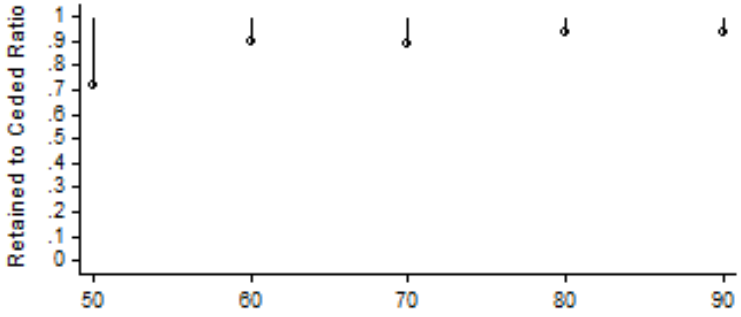
La Nina





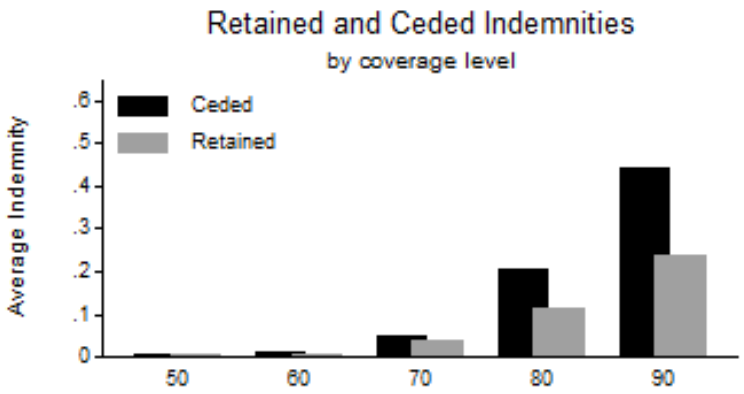
El Nino

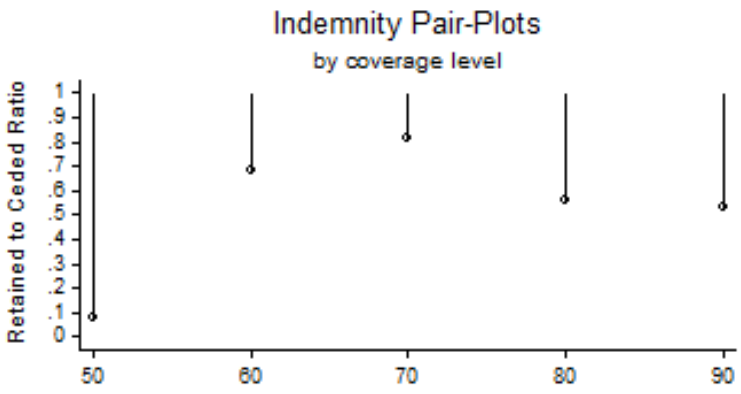




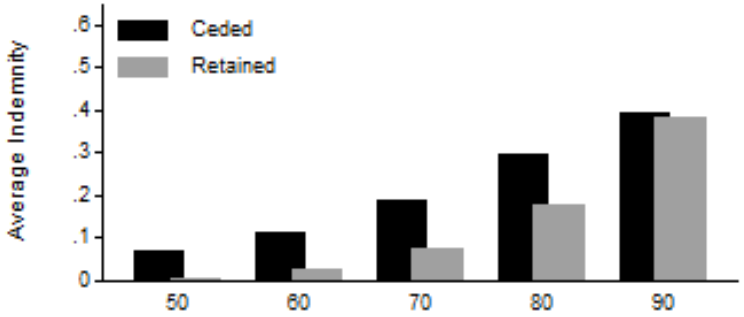
Expected Indemnities for Ceded/Retained Policies, Eastern

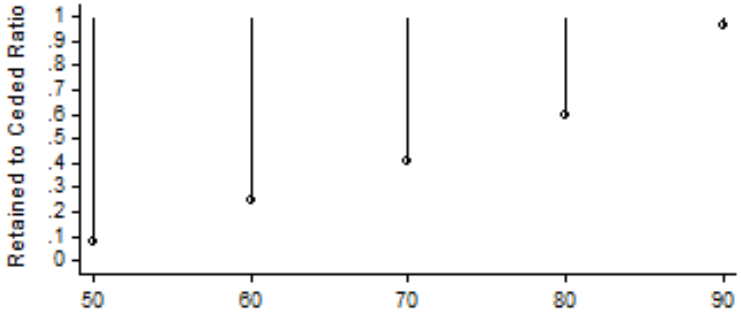
La Nina





El Nino





Average County-Level Indemnities for Repeated Insurance Game

	All Years		El Niño Years		La Niña Years	
Cov	All Pol	Ret Pol	All Pol	Ret Pol	All Pol	Ret Pol
50	0.013	0.011	0.014	0.005	0.011	0.004
60	0.039	0.034	0.028	0.013	0.041	0.017
70	0.090	0.078	0.056	0.032	0.108	0.070
80	0.185	0.162	0.126	0.095	0.245	0.194
90	0.334	0.298	0.250	0.220	0.455	0.398

Conclusions

- An emerging literature shows that predictive models of climatic phenomena can aid in insurance program-design and decision-making
- Extreme weather outcomes have been linked to ENSO, which globally impacts agricultural production
- We find that extreme ENSO events alter cotton yield distributions in the Southeastern U.S., and these impacts translate into economically meaningful effects on crop insurance premium rates
- We demonstrate that commercial insurers can use publicly available information to determine if government-set premium rates are mis-priced, and in turn extract economic rents via the federally mandated Standard Reinsurance Agreement