Cotton Premium Rate Heterogeneities and Implications under Climate Change

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Introduction

Weather is a major factor influencing crop production. Year-to-year variation in crop yields is largely driven by annual weather fluctuations, but one specific fluctuation may not affect all varieties of a crop equally as some varieties may be more drought/heat tolerant than others. This in turn implies that some varieties are potentially more "risky" to produce than others. Much work has focused on yield risk heterogeneities in the literature, however very few studies have looked at how actuarially-fair crop insurance premium rates might vary across (i) varieties grown under the same climate and (ii) different climates for the same variety.

Crop insurance is the dominant agricultural policy instrument and thus could potentially play an important role as producers begin to adapt to climate change. For example, if a newly bred variety provides improved heat resistance relative to others but this difference is not reflected in the premium rate, then producers might be less likely to adopt this new variety as the climate warms. Currently, the Risk Management Agency (RMA) does not offer alternative premium rates across varieties, nor is there any indication that it plans to adjust rates in anticipation of climate change. This is likely because the warming impacts of climate change on the performance of the U.S. Federal crop insurance program (FCIP) is an evolving research focus in the literature. Relevant literature includes studies estimating the impacts of climate change on agriculture (e.g Tack, Harri and Coble 2012; Tack, Barkley, and Nalley 2014, 2015; Lobell, Schlenker and Costa-Roberts 2011; Schlenker and Lobell 2010; Schlenker and Roberts 2006, 2009; Mendelsohn, Nordhaus and Shaw 1994; Schlenker, Hanneman and Fisher 2005, 2006, 2007; Urban et al 2012; Fisher et al 2012; Deschenes and Greenstone 2007; Lobell and Asner 2003; Pongratz et al 2012). Studies identifying important linkages between crop insurance and climate include Beach et al (2010) and Di Falco et al (2014), however neither of these studies consider variety specific premium rates nor the influence of climate change on these rates.

Empirical Model

We focus here on cotton yields and estimate the empirical model using Mississippi Cotton Variety Trial data from 1998-2013. The yield data is matched to weather outcomes at the location/year level. The moment-based regression model of Antle (1983, 2010) was utilized to link weather outcomes to the first (mean) and second (variance) moment of yield. The mean and variance equations are given by;

$$y_{ikt} = \alpha_i + \alpha_k + \beta_1 low_{kt} + \beta_2 med_{kt} + \beta_3 high_{kt} + \beta_4 p_{kt} + \beta_5 p_{kt}^2 + \varepsilon_{ikt}$$
$$\varepsilon_{ikt}^2 = \delta_i + \delta_k + \gamma_1 low_{kt} + \gamma_2 med_{kt} + \gamma_3 high_{kt} + \gamma_4 p_{kt} + \gamma_5 p_{kt}^2 + v_{ikt}$$

where y_{ikt} is log yield for seed variety i at location k in year t. The (α_i, α_k) and (δ_i, δ_k) are variety and location fixed effects while the $\boldsymbol{\beta}$ and $\boldsymbol{\gamma}$ capture the nonlinear effects of temperature and precipitation on cotton yields. The three temperature variables *(low, med, high)* and cumulative precipitation *(p)* are defined as in the piecewise linear approach of Schlenker and Roberts (2009).

Using $\mathbf{x}_{kt}$ to denote the weather variables, the variety-specific conditional mean and variance are defined by $\mu_{ikt} = E(y_i | x_{kt})$ and $\sigma_{ikt}^2 = E(\varepsilon_i^2 | x_{kt})$. We estimate the parameters of the moments model using ordinary least squares and then predict the conditional mean and variance for each variety-location-year *ikt*, which are denoted $\hat{\mu}_{ikt}$ and $\hat{\sigma}_{ikt}^2$. Under the assumption that each of these conditional distributions is distributed lognormal, i.e. $y_i | x_{kt}, \square\ LN(\hat{\mu}_{ikt}, \hat{\sigma}_{ikt}^2)$, we then model the unconditional distribution for each variety/location as a mixture of the conditional lognormals:

$$f_{ik}(y) = \frac{1}{T} \sum_{t=1}^{T} f(y | \hat{\mu}_{ikt}, \hat{\sigma}_{ikt}^2).$$

Data

The field trial yield data was provided by the Mississippi Agricultural and Forestry Experiment Station (MAFES). These trials are mainly held at the Delta Research and Extension Center in Stoneville and a few other locations within the state. The observations for the cotton yield data are for dryland (non-irrigated, rain-fed). Yields are measured in pounds per acre, and we utilize 1,249 observations across 105 varieties and 3 locations (Clarksdale, Rolling Fork and Verona).

The weather data is obtained from the PRISM climate group and is based on a rectangular grid cell with a standard prism of 4km that covers each of our three locations. Daily minimum and maximum temperature as well as total precipitation were collected. We observed both the planting and harvest date for each location/year combination. We interpolate temperature exposure between daily minimum and maximums and use these to construct growing day variables that accumulate exposure over the entire growing season. We use the same piecewise linear knots as Schlenker and Roberts (2009), 14°C and 32°C. Precipitation is measured as a cumulative rainfall in centimeters.

Descriptive statistics for the data are reported in Tables 1, 2 and Figure 1. Years span 1998 to 2013 with some missing values for some locations in some years. Verona has the highest number of observations followed by Clarksdale and Rolling Fork (Table 1). Cotton yields across varieties and weather variables observed for each location-year combination shows there is considerable variation in the data (Figure 1). The average yield across varieties matched with corresponding average precipitation and average daily minimum and maximum temperature, are

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presented in Table 2. Clarksdale has the highest average yield and there is a slight difference between the average yields of Verona and Rolling Fork.

Results

RMA currently reports 19 different insurance policies covering more than 100 crops. Here we focus on yield protection (YP) contracts for cotton. While these contracts are less popular than their revenue counterparts, any finding of premium rate heterogeneity for yield contracts will likely extend to revenue contracts since the price-risk component of revenue contracts is independent of the variety produced.

The parameter estimates for the moments model are reported in Table 3. We cluster standard errors by year to control for heteroskedasticity and spatial correlation. The r-squared for the mean equation suggests a reasonable level of fit. The lower value for the variance equation suggests that there are likely other drivers of yield variation that are not considered here. Overall, we find strong evidence of mean and variance heterogeneity across varieties as nested tests suggested rejection of the common intercept model at standard significance levels (Table 4).

As discussed above the parameter estimates are used to construct location-variety specific yield distributions. Figure 2 displays kernel density plots for the mean, skewness and coefficient of variation (CV) across varieties and show that there is considerable distributional heterogeneity. Next we use these distributions to calculate actuarially fair premium rates for 70 and 75% coverage levels, which provide further evidence heterogeneity across varieties for all three locations (Figure 3 and 4). The estimated YP rates were calculated as the ratio of expected indemnity over liability.

The next phase of this research will simulate the effect of warming temperatures on premium rates to evaluate whether some varieties might provide more risk protection than others. This work is in progress.

Conclusions

The primary aim of this study is to examine whether actuarially fair crop insurance premium rates vary across different seed varieties and the likely effect of warming temperature on these rates. At this stage, we are only able to provide results on the variation in premium rates across seed varieties, and these findings are considered very preliminary.

Our results identified heterogeneities for both the mean and variance of cotton yields across varieties. These differences extended to the coefficient of variation – a commonly used measure of yield risk – as well as actuarially fair premium rates, which capture a producer's exposure to downside risk. Our findings provide evidence of yield risk heterogeneity across varieties.

The finding of heterogeneous premium rates across varieties presents an interesting problem for the FCIP. By not conditioning on rates across varieties, as is currently the case, the program potentially suffers from a lack of actuarial soundness which in turn can lead to adverse selection. However, these issues might be small relative to the administrative burden required to condition rates on varieties. New varieties are always being introduced into the market and it is not clear how long field trials must be conducted in order to get a credible estimate of yield risk for any one variety. In addition, if the rate differentials happen to be incorrect, they can create perverse incentives for adoption among producers.

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Tables

Table 1. Characteristics of study sites in Mississippi: location and observations included in sample

Site	Abbreviation	Lattitude/longitutde	Num of Years	Min/Max of Years	Num of Varieties	Observations
Clarksdale, Coahoma County	CLC	34.20°N/90.57°W	15	1998/2013	105	405
Verona, Lee County	VNL	34.19°N/88.72°W	15	1998/2013	105	466
Rolling Fork, Sharkey County	RFS	32.91°N/90.88°W	13	1998/2012	105	378
Total	--	--	15	1998/2013	105	1249

Table 2. Characteristics of study sites in Mississippi: means (SDs) of yield, temperature, and precipitation

Site	Yield (lb/acre)	T_{min} (°C)	T_{max} (°C)	Cummulative Precipitation (cm)
CLC	1518.1	19.1	30.6	48.7
	(341.0)	(1.0)	(1.3)	(21.6)
VNL	1262.6	19.0	31.3	52.0
	(289.0)	(0.7)	(1.3)	(19.4)
RFS	1228.5	19.6	32.0	55.2
	(293.6)	(0.8)	(1.1)	(23.5)

Notes: Values of yield were calculated across all years from 1998 to 2013 (except year 2000) and values of temperature and precipitaion were calculated using the growing season (April-November).

Table 3. Regression Results for Mean and Variance of Corn Yields

| Variables	(1) Mean	(2) Variance
Low Temperature	-0.00036	0.00024
	(0.00034)	(0.0017)
Medium Temperature	0.00067*	0.00064
	(0.00036)	(0.0021)
High Temperature	-0.0024	-0.0093
	(0.002)	(0.0083)
Precipitation	0.0288***	0.0833**
	(0.0053)	(0.0279)
Precipitation Squared	-0.0002***	-0.0006**
	(0.00003)	(0.0002)
R-squared	0.5706	0.2120
Observations	1249	1249
Locations	3	3
Varieties	105	105
Years	15	15

Notes: All models include fixed effects for trial site location and seed variety. Standard errors clustered by year are reported in parenthesis. *, **, and *** denote statistical significance at the 10, 5 and 1 percent significance levels.

**Table 4. Equality tests for regression parameters within models**

Null Hypothesis	P values	
	Mean	**Variance**
Equality of temperature varibales		
lowdday = medday = hghdday = 0	0.2922	0.5283
Equality of precipitation variables		
prec = prec2 = 0	0.0000	0.0306
Equality of Fixed Effects		
All location effects equal	0.0007	0.2795
All variety effects equal	0.0076	0.0005

Notes: Hypothesis were tested using *F-tests* with standard errors clustered by year.
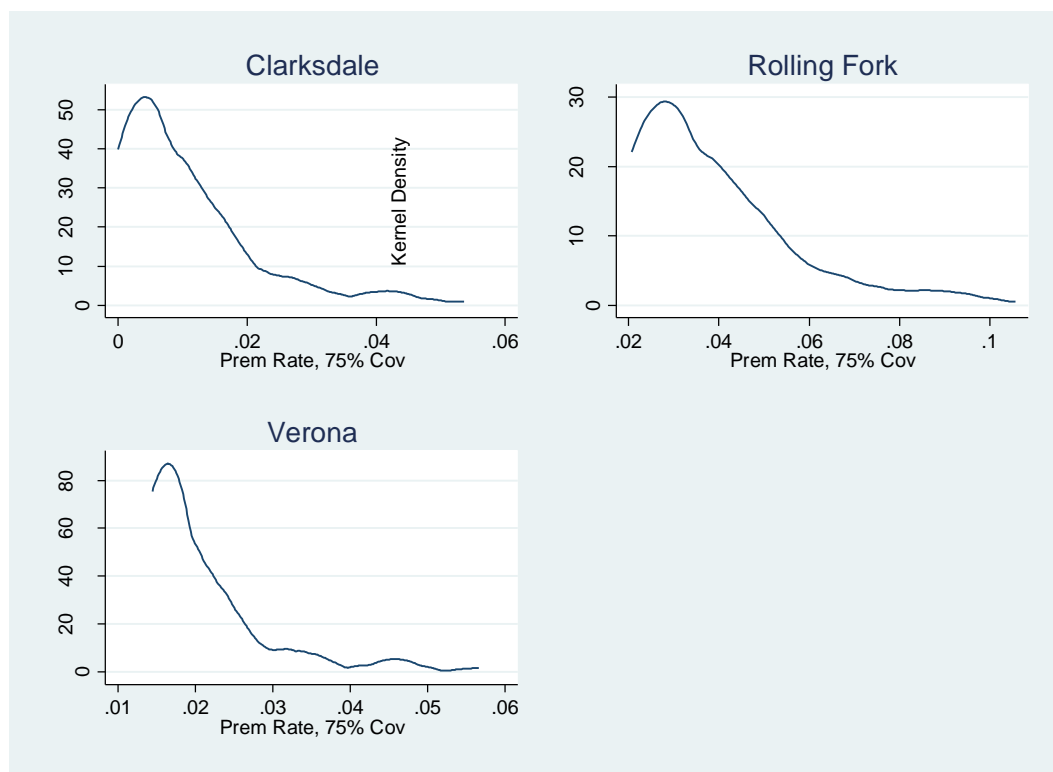
Figures
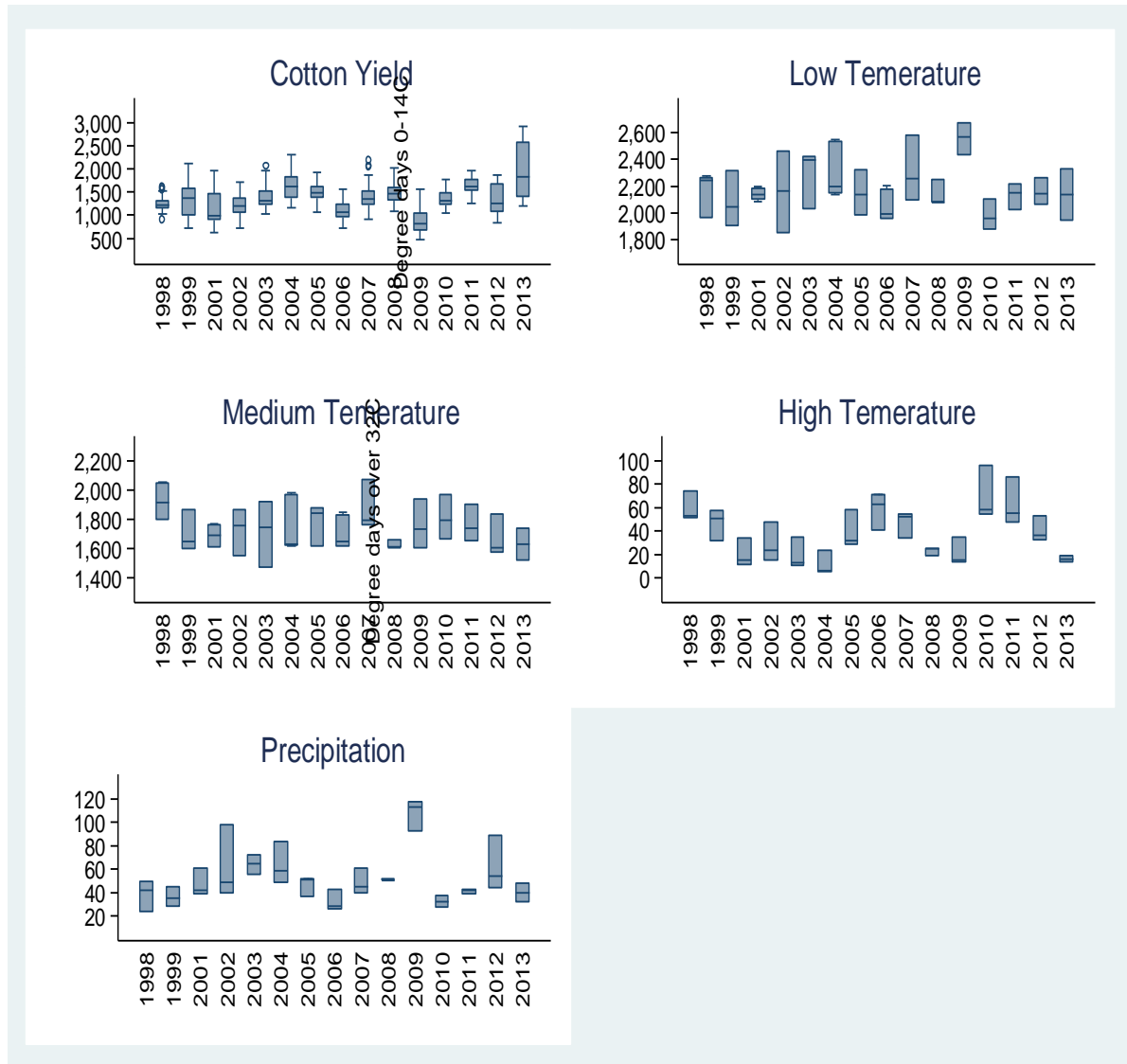
Figure 1: Annual box plots for location level cotton yield data across varieties and weather sample data. Each box is defined by the upper and lower quartile, with the median depicted as a horizontal line within the box. The endpoints for the whiskers are the upper and lower adjacent values, which are defined as the relevant quartile +/- three-halves of the interquartile range, and circles represent data points outside of the adjacent values.
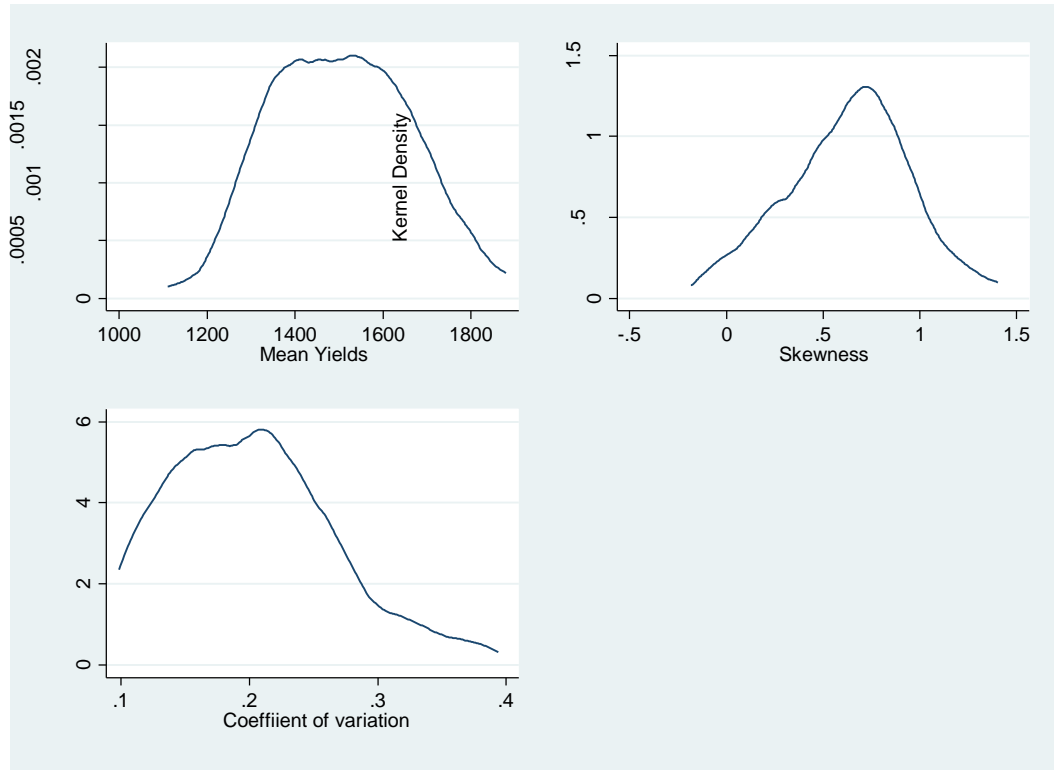
Figure 2: Heterogeneity of distributional moments for the unconditional yield distributions across varieties. The location-specific mean yields, coefficient of variation, and skewness estimates are summarized across varieties by a kernel density plot. This is specifically for Clarksdale location.
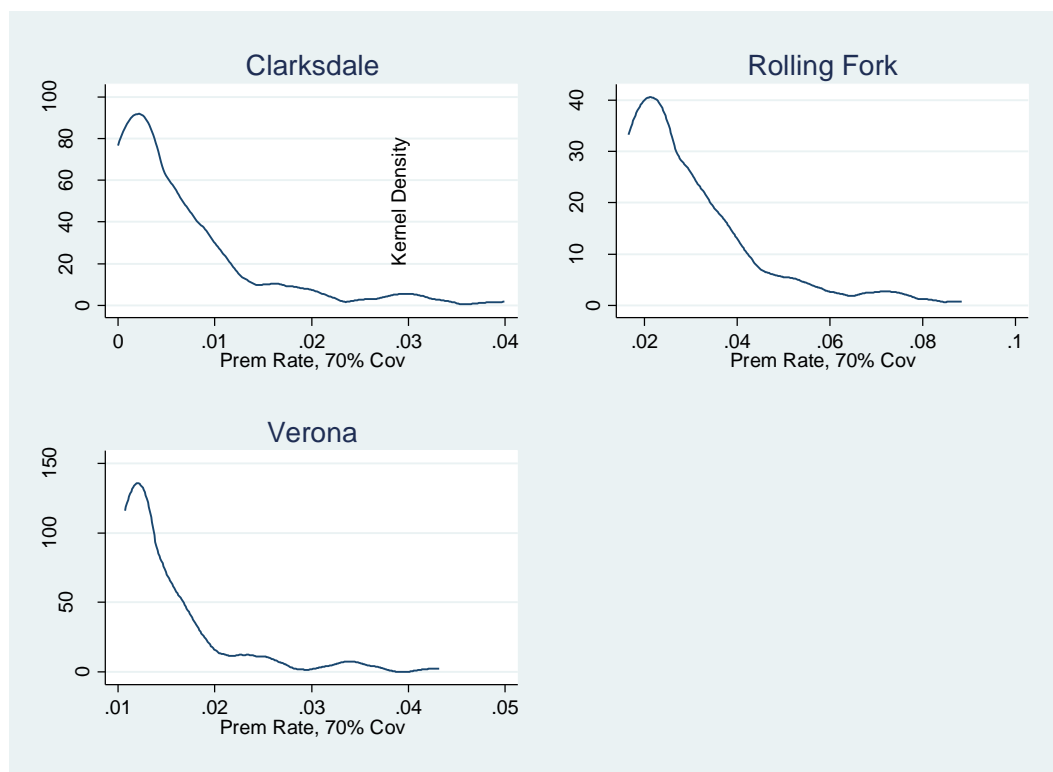
Figure 3: Heterogeneity of premium rates for the unconditional yield distributions across varieties for each location. We estimated separate yield densities for each variety-location-year combination in the data. The kernel density plots summarized the variety-specific premium rates estimates for each location with a coverage level of 70%.

Figure 4: Heterogeneity of premium rates for the unconditional yield distributions across varieties for each location. We estimated separate yield densities for each variety-location-year combination in the data. The kernel density plots summarized the variety-specific premium rates estimates for each location with a coverage level of 75%.