

# The Economic Response to Weather Shocks and Climate Change in the Farm Sector: The United States 1895-1969

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## **Abstract**

This paper uses a 75 year panel of states to identify the effect of weather fluctuations on different types of agricultural commodities. Using information from the USDA and National Climatic Data Center, we estimate these effects for corn, a crop with high transport costs and used in other local productive activities and cotton, a crop with relatively low transport costs and few local uses. Results indicate that for crops such as cotton that are sold primarily in international markets, changes in local weather have little effect on farmgate prices. However, crops with strong local markets such as corn are much more sensitive to changes in state-level temperature, precipitation and drought conditions. Attempts to control for farmer expectations did not substantially affect the coefficient estimates, suggesting that while long-term crop mix adjustment may still affect the plausibility of the estimates, short-term crop mix adjustments do not.

## **1 Introduction**

Recently much attention has been given to studying the effects from human activities in generating a warmer, wetter and more variable climate. Given that the climate change scenarios are correct, it is important to determine the economic effects of not only global increases in temperature and precipitation, but also how regional variation in weather may affect productive activities. Increases in regional variation will be of particular importance

to those activities where weather is a direct input into production and the good is relatively difficult to trade.<sup>1</sup>

Although increases in temperature, precipitation and weather variability are expected to affect many different industries, they have a direct and readily measurable effect on agriculture. Droughts, floods, heat waves, blizzards, cold spells, and a variety of other weather crises have direct effects on crop yields and the vitality of farm animals. These weather events may affect the prices that farmers receive for their products, and thus also farm incomes and land values. However, these effects may differ across types of farm commodities. For crops sold in international markets, fluctuations in local weather may not influence farmgate prices significantly whereas for crops primarily used and sold at the local level, such disasters may lead to significant local price responses.

Our goal is to examine the sensitivity of agricultural prices and output to local and non-local weather fluctuations over a large span of time in the United States. In this paper, we limit the analysis to two important staple crops. The first is cotton, a crop with a very high value-to-weight ratio and one that is not used in other agricultural productive activities. The second, corn, is used as feed for livestock and has a value-to-weight ratio about a  $\frac{1}{10}$  of cotton's. As such corn is primarily used and sold at the local level; at the beginning of our period of consideration, over 77% of corn was retained and consumed in the county where it was grown.

We expect that when agricultural commodities have high transportation costs and are used in productive activities at the local level, prices will be sensitive to changes in local weather. Conversely, for commodities sold in non-local markets, prices will be robust to changes in local weather, but sensitive to weather conditions affecting the aggregate market. Thus, the analysis also examines how globalization and reducing transactions costs across

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<sup>1</sup>This could be due to tariffs or other trade barriers, or alternatively is simply a result of the inherent properties of the good (i.e. the good is heavy, bulky, or does not store well)

countries could potentially alter the effects of localized weather shocks. As markets become less centralized, the effect on consumers from these localized dramatic weather events should be mitigated. Additionally, because this paper uses a 75 year panel, we can examine the effects of different United States' policy regimes. Prior to the New Deal legislation, little effort was made by the federal government to stabilize farm incomes and prices. However, with the Agricultural Adjustment Act came an era of farm subsidies and price supports. Since the panel spans about 37 years in each period, we can look at whether the sensitivity of prices to changes in weather changed from one period to the other. Below we explain how adverse weather is measured.

## 2 Measuring Local Weather and the Palmer Drought Indices

Standard practice in the agronomic literature is to measure weather through a combination of both linear and non-linear effects on crop yields. Because both very low and very high levels of precipitation and temperature adversely affect crop yield, assuming a simple linear relationship between weather and prices or profit would be a misspecification. Generally, the non-linearity introduced is a quadratic in precipitation and temperature.

We choose a similar path, but also include measures for drought and wetness conditions developed by Palmer (1965) in his creation of the Palmer Drought Severity Index (PDSI).<sup>2</sup> Specifically, these drought measures are functions of monthly indices called “Z indexes” that Palmer calculated and accumulated to create his drought severity index. These Z indexes measure departures of precipitation levels from some baseline level, weighted by some factor<sup>3</sup>

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<sup>2</sup>We define the term “drought” as a prolonged and abnormal moisture deficiency.

<sup>3</sup>In Palmer’s paper, these weights were developed in relation to the 12 months of driest weather on record for northwestern North Dakota, Western Kansas, Central Iowa, the Texas high plains, Edwards Plateau of Texas, Southern Texas, Western Tennessee, West Central Ohio and Northeastern Pennsylvania.

determined from the climate record in the relevant area before the actual model calculations begin. The weighting is used to ensure comparability across both regions and months (assuming that regional differences show variation similar to the monthly differences). After plotting a series of accumulated Z values against the length of drought for the thirteen driest intervals in central Iowa and western Kansas, Palmer defined these as “extreme drought,” and then used this baseline to further subdivide the drought index into five more drought sections of “severe,” “moderate,” “mild,” “incipient,” and “near normal.” Palmer calculated periods of wetness by reversing signs in the Z index.

### 3 Data and Summary Statistics

To study the effects of state-level weather fluctuations on farmgate prices, we combine two existing datasets; one containing historical crop information, the other historical weather information. State-level information on yield, harvests, and prices<sup>4</sup> for commodities produced and sold across the United States was taken from the Agricultural Time Series-Cross Section Dataset (ATICS), compiled from USDA records by Thomas Cooley, Stephen DeCanio and M. Scott Matthews.<sup>5</sup> This dataset covers the contiguous United States from 1866 to 1969, although due to data constraints, we limit to those years after 1895.

To adjust for inflation, commodity prices are adjusted to reflect 1982-1984 dollars using the CPI series developed by Lawrence Officer. Table 1 gives summary statistics on output and prices in 1982-1984 dollars for both the selected farm commodities, as well as the different weather variables used in estimation.

The two most important things to take from the cotton and corn summary statistics are that first, there is great temporal and spatial variation in both output and prices for both

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<sup>4</sup>Prior to 1930, crop prices represent the farm gate price on December 1st, and afterwards are the yearly average.

<sup>5</sup>The data are fully available at the National Agricultural Statistics Service

cotton and corn, and second, there is also large variation between the two commodities. This is likely a function of corn being more difficult than cotton to transport across regions and the extensive use of corn as animal feed on the farm and in local markets. Cotton is much easier to transport and is used primarily as an input in manufacturing, with only a small share of cotton withheld for use in household production. Therefore cotton prices display much less regional variation, with the observed variation being primarily temporal. Corn prices vary much more across regions, and likely fluctuate much more with local weather shocks.

Map 1 shows the distribution of production across the contiguous United States for cotton and corn in 1929, a year relatively free of inclement weather. Both the cotton and corn belts are clearly visible. Also evident is that corn production is more widely distributed across the country, consistent with the existence of local markets for corn. Every state in the Union engages in at least some level of corn production, whereas cotton was limited to the more southern latitudes.

Monthly data on temperature, precipitation and the Palmer drought measures were compiled by the National Climatic Data Center. To correct for biases in raw weather data that arose from different measurement times across the stations, we adjusted monthly mean temperature and precipitation using a model suggested by Karl et. al (1986).

Because the agricultural data are measured annually and the planting and harvesting dates differ among states, for simplicity we convert all weather variables to yearly averages. Summary statistics for average temperature, average precipitation, months of extreme or severe drought, months of extreme or severe wetness and the standard deviation of the Palmer Z Index in cotton and corn producing states are given in the lower portion of Table 1. For the period under consideration, these series are stationary.<sup>6</sup>

Most states producing cotton tend to be warmer and wetter than states producing corn,

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<sup>6</sup>Stationarity is tested using the Fisher test suggested by Maddala and Wu (1999)

and aside from precipitation, have slightly less variable weather.<sup>7</sup> For both cotton and corn producing states, average yearly precipitation, which is an average of average monthly precipitation from January to December, ranges from about a third of an inch per month to just over 6 inches per month. Temperature is averaged similarly to precipitation, and also represents a twelve month average of the January to December monthly averages. In our sample, this ranges from about 35° Fahrenheit to about 74° Fahrenheit in the corn producing states and from about 50° Fahrenheit to about 74° Fahrenheit in the cotton producing states. Months of extreme or severe drought and extreme or severe wetness are calculated using a form of the Palmer Drought Severity Index, the Palmer Hydrological Drought Index (PHDI).<sup>8</sup> In both cotton and corn producing states, some states experienced serious drought conditions for all twelve months of the year, while other states enjoyed an entire year's worth of normal moisture levels. The number of months of extreme or severe wetness ranged similarly.

## 4 Price Effects and Transportation Costs

State level price effects from state level supply shocks will be mitigated for more tradable goods sold in international markets because individual states play too small a role to affect prices significantly. At the extreme, if a farm commodity is perfectly tradable, the observed state average farmgate (local) price is a function only of non-local, or international supply and demand and farmgate prices vary only with changes affecting the aggregate market. After controlling for weather that affects producers as a whole, prices would then be robust to state-level weather shocks. Conversely, for perfectly non-tradable commodities with prohibitively high transportation or storage costs, the observed state farmgate price is a function only of supply and demand in the local market. If a severe drought hits, local traders do not import

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<sup>7</sup>During the period under consideration arid western states began producing cotton using irrigation

<sup>8</sup>The PHDI represents about a year's worth of abnormal moisture conditions, while the PDSI represents about nine months worth

goods from other states or countries to mitigate the effects of the shock. Additionally, weather affecting producers outside of the local area will not affect local prices.

Commodities generally do not fit either of these two extreme cases, but instead fall somewhere in between. Assuming tradability is only a function of the specific properties for a specific crop and does not vary temporally or spatially, we follow the setup of Mundlak and Larson (1992) and write the observed logged price of commodity  $c$  in state  $s$  during year  $t$  as function of the both international and local supply and demand:

$$\ln(P_{s,c,t}^{obs}) = \tau_c \ln(P_{c,t}^{int}) + (1 - \tau_c) \ln(P_{s,c,t}^{loc}) \quad (1)$$

where  $\tau_c$  is an index of the strength of the local market (itself a function of transaction costs and local uses for the crop) for crop  $c$ . Crops such as cotton that are easy to store, easy to transport, have a high value-to-weight ratio and have few local uses have a  $\tau_c$  closer to one, while crops such as corn that are used in other areas of agricultural production and have higher transport costs have a stronger local market and a  $\tau_c$  much closer to zero.

Figures 1 and 2 show the differential effects of positive and negative local supply shocks for goods with relatively high and low transport costs. In each of these figures, local supply is upward sloping and relatively inelastic and given by S1 and S2. Also present in each is the internationally determined price  $P_{buy}^{int}$  as well as  $P_{sell}^{int}$ , the effective price received by commodity producers after taking out the marginal<sup>9</sup> cost of bringing the commodity to the international market. The distance between  $P_{buy}^{int}$  and  $P_{sell}^{int}$  is  $C_i^{int}$ , or the size of the marginal cost to bring commodity  $i$  to the international market.

Figures 1a and 1b represent local markets for commodities such as corn that have higher transport costs and strong local markets. Because the cost of bringing these goods to international market is high compared to a good such as cotton, fluctuations in the local market

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<sup>9</sup>If we assume constant marginal transaction costs, this is also the average cost

play a larger role, while fluctuations in the international market play a relatively smaller role. In Figure 1a, an adverse weather shock would cause supply to fall from  $S_1$  to  $S_2$ . This drives the quantity produced from  $Q_a$  to  $Q_b$  and the price to rise from  $P_a$  to  $P_b$ . The price is not driven high enough as to generate imports into the local market. If the supply shift were drastic enough, then goods from the outside market could potentially be imported, but it would take a particularly severe shock for that to occur. The same is true if there is a bumper year as in Figure 1b; supply shifts out from  $S_1$  to  $S_2$ , expanding output to  $Q_b$  from  $Q_a$  and pushing local prices down to  $P_b$ . However, local prices do not fall by enough to make exporting to the outside market worth it to local producers. Local prices would need to fall past  $P_{sell}^{int}$  before producers began exporting to other markets. The effect of the international market on the local market is also mitigated. Changes in price determined by the international market, or  $P_{buy}^{int}$ , will affect local market prices if it pulls the “band” in Figures 1a and 1b above or below the local equilibrium price. Goods with higher transport costs have wider bands, so have local prices less susceptible to changes in the international market.

Figures 2a and 2b represent local markets for commodities such as cotton that have low transportation costs and are not generally used and sold at the local level. In this case, the costs associated with bringing the good to international market are low, so the distance  $C_i^{int}$  is small. Here the international market plays a relatively larger role in determining local prices than do the local supply and demand interactions. Because of the lower costs, it is easier for producers and consumers to mitigate the effects of positive or negative supply shocks through importing and exporting. In Figure 2a, an adverse supply shock occurs, shifting supply from  $S_1$  to  $S_2$  and pushing the locally produced quantity down. However, in this situation, consumers import  $Q_d - Q_c$  at a price of  $P_{buy}^{int}$  to mitigate the local price effects. Although the local supply shifts in substantially, the quantity sold in the local market only falls to  $Q_d$  and the observed price rises to  $P_c$ , below the price  $P_b$  that would be observed

were the outside market not present.

In Figure 2b, a positive supply shock occurs, shifting supply from  $S_1$  out to  $S_2$ . In this case, the local supply expands by a large amount, but local producers choose to take some of that surplus to international market. Whereas price would have fallen from  $P_a$  to  $P_b$ , in this case the observed price only falls to  $P_c$ .

Considering a simplified version for cotton or corn prices where weather is the only input, then

$$\ln(P_{s,c,t}) = \tau_c \ln(P(Q_{c,t}^{int}(OPW_{s,t}))) + (1 - \tau_c) \ln(P(Q_{s,c,t}(w_{s,t}))) \quad (2)$$

where  $Q^{int}$  is the international level of the commodity sold,  $w_{s,t}$  is a measure of weather conditions in state  $s$  and year  $t$ , and  $OPW$  is a set of averaged of weather variables across states other than  $s$  producing commodity  $c$ , weighted by each state's share of the national production.<sup>10</sup>

## 5 Model Setup

To test the significance and magnitude of the relationship between farm commodity prices and adverse weather, we use the year-to-year variations in both weather and commodity prices to specify a regression model including state and year fixed effects. Including these fixed effects will net out much of the unobserved variable bias that seems to plague the cross-sectional models present in much of the agronomic literature (Deschenes and Greenstone 2007). In this way, we can look at the entire United States, instead of, for instance, limiting our scope to non-irrigated counties, to the time period before the large scale crop subsidies began in the 1930s, or to states that were net exporters of the different crops.

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<sup>10</sup>Each state's share of the national production was calculated for 1929 and assumed constant for the rest of the panel. 1929 was chosen since it was a year relatively free of inclement weather

Local weather is measured using time-bias corrected temperature and precipitation, their squared terms, the number of months of extreme or severe drought, the number of months of extreme or severe wetness, and moisture variation. The last three variables are derived from the Palmer Z Index. The weather in the rest of the crop production area is measured as a weighted average of weather in other areas where the weights are state's share of output in 1929.

## 5.1 The New Deal and the Changing Agricultural Price Structure

Because our data spans the period of the large scale New Deal programs, it is necessary to test for the potential effects of the New Deal's agricultural policies. To test this, we estimated basic pooled and non-pooled models for each commodity, including the variables temperature, precipitation and their squared terms. Performing Chow tests for both cotton and corn, we reject each of the nulls that a pooled model is appropriate, suggesting that prices responded differently between the two policy regimes. We account for this structural change by estimating separate models for the period before 1933 and then also for 1933 and after.

## 5.2 Reduced Form Models

For each time period, we estimate the following reduced form models for price and quantity:

$$\ln(P_{s,c,t}) = \alpha_s + \gamma_t + W_{s,t}\beta_c + OPW_{s,c,t}\omega_c + \epsilon_{1,s,c,t} \quad (3)$$

$$\ln(Q_{s,c,t}) = \alpha_s + \gamma_t + W_{s,t}\beta_c + OPW_{s,c,t}\omega_c + \epsilon_{2,s,c,t} \quad (4)$$

where  $\ln(P_{s,c,t})$  is the logged real price for commodity  $c$  in year  $t$  and state  $s$ ,  $\ln(Q_{s,c,t})$  is the logged quantity,<sup>11</sup>  $\alpha_s$  is a set of state fixed effects that net out time invariant determinants of the farmgate price,  $\gamma_t$  is a set of year indicators that control for annual shocks common to all states,  $W_{s,t}$  is a vector of weather variables in year  $t$  and state  $s$  that could potentially affect local prices, and  $OPW_{s,c,t}$  is the vector of weather variables in year  $t$  for other producers of commodity  $c$  than state  $s$ . As usual, the disturbance terms  $\epsilon_{1,s,c,t}$  and  $\epsilon_{2,s,c,t}$  are assumed to have conditional mean zero and defined as the other factors influencing farmgate prices and output besides weather.

Although there are certainly other factors that could potentially affect farm commodity prices, it is not likely that these unobserved effects will cause the local weather variables to be correlated with the error term. And while the variables that proxy for weather fluctuations in other producing states are weighted by that state's share of national production, because we calculate this for 1929 and fix that value over time, it is also unlikely that after including state and year fixed effects, these variables are correlated with the error term.

As stated earlier, the dependent variables in the analysis are the logged value of the real prices and quantities for cotton and corn. Since corn has relatively high transport costs and is used in agricultural production, it is expected that an adverse local weather shock will reduce the local corn supply, thereby raising the farmgate price. This would imply a positive correlation between commodity prices and variables controlling for drought and wetness conditions, as well as with the squared terms in temperature and precipitation. A negative correlation should exist between corn prices and temperature and precipitation. Cotton is sold at the international level and as such should see analogous relationships between price and weather shocks, but instead of local weather shocks, should be sensitive to the weighted averages of the other producer's weather.

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<sup>11</sup>After examination of the different output distributions, we concluded that they were all closer to a log-normal distribution than a normal distribution

## 6 Results

Tables 2a and 2b give regression results with the logged prices of cotton and corn as the dependent variables (a-cotton, b-corn) and Tables 3a and 3b give regression results with logged quantity as the dependent variable. Both tables contain six columns of regression results, representing three sets of models: one basic model without any of the *OPW* variables, and two with the *OPW* variables included.

All of the models present in Tables 2 and 3 include state and year fixed effects.<sup>12</sup> Columns 1 and 2 in each table give results based on controlling for weather using just temperature, precipitation and their squared terms. Including this basic model allows comparison to prior work using only variables for temperature and precipitation, as well as a robustness check to see how including additional weather variables affects the coefficient estimates for temperature and precipitation.

Columns 3-6 represent the different models that include the *OPW* variables. Columns 3 and 4 include just temperature, precipitation and their squared terms, so are comparable to columns 1 and 2. Columns 5 and 6 add in the number of months of extreme or severe drought and wetness, as well as the standard deviation of the Palmer Z index to control for effects of changes in weather variability. Tables 3a and 3b are identical to Tables 2a and 2b, but with logged quantity as the dependent variable.

In general, cotton and corn prices exhibited different sensitivities to local and non-local weather events, although there were some commonalities across the tables. The coefficient estimates tended to be similar across the different model specifications, and both including the *OPW* variables as well as the additional weather variables had little effect on the coefficient estimates. Also common to both the cotton and corn price regressions were the differences in price responses before and after the New Deal (ND) structural break. This is

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<sup>12</sup>It is the inclusion of the fixed effects that is causing the  $R^2$  to be so close to one. Without the fixed effects, the coefficient of determination ranges from about 0.15 to 0.3 depending on the model

likely due to the New Deal agricultural policies, as these included price supports and subsidies for many of the different crops, although these differences could also be a function of how prices were reported by the USDA before and after 1930.<sup>13</sup>

Figures 3a-3d take the last two columns of statistically significant estimates (columns 5 and 6) from Table 2a and plots the cotton price elasticities against changes in temperature and precipitation for both the local weather and the weather in other producing states. Figures 4a-4d plot the different corn elasticities based off the coefficient estimates in Table 2b. Below we describe these figures and the coefficient estimates for cotton and corn.

## 6.1 Cotton - Table 2a, Table 3a

Cotton output was sensitive to fluctuations in local temperature, extreme or severe drought and wetness and changes in weather variability both before and after the New Deal. However, cotton prices do not follow the same story, and show different sensitivities in the pre and post New Deal periods. Prior to the New Deal, cotton prices were most sensitive to changes in non-local weather. Increases in local weather variability tended to decrease the state farmgate price of cotton, but it was changes in precipitation and drought conditions in other producing states to which the state level prices for cotton were most sensitive. After the New Deal, state farmgate prices showed much more sensitivity to local temperature changes than they were to changes affecting other producers.

Figures 3a through 3d plot the price responsiveness of changes in temperature and precipitation in both local and non-local areas, regardless of whether the coefficient estimates were statistically significant. The statistically significant coefficient estimates included those for local temperature in the post-New Deal period and non-local precipitation in both the pre and post New Deal periods. As seen in Figure 3a, cotton price elasticity to changes in temperature is increasing as temperature increases. At about 60° F, a 1% rise in average

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<sup>13</sup>Prior to 1930, crop prices are recorded at December 1st, and afterwards are the yearly average.

temperature is associated with very little changes in price. However, at very low and very average temperature measurements, state-level cotton prices are very responsive (about -3.5 for temperatures below 35° F and about 3% for average temperature levels about 72° F.)

The sensitivity of cotton prices to local weather in the post-New Deal period is likely a function of Mississippi taking market share from other cotton producers and a greater concentration of production in Mississippi and Texas compared to the prior period.

## 6.2 Corn - Table 3b, Table 3b

Both before and after the New Deal, corn prices were sensitive to both local and non-local weather conditions. In both periods the coefficients on nearly all of the weather variables were statistically significant, although only the coefficients for temperature, precipitation and their squared terms were economically significant.

As with the local weather, nearly all of the *OPW* variables had statistically significant coefficients, although only temperature and precipitation before the New Deal and precipitation after the New Deal had economically significant coefficients.

Looking at Figures 4a through 4d, it is clear that with perhaps the exception of local temperature, before the New Deal agricultural policies, prices were much more responsive to changes in both local weather fluctuations and fluctuations in weather affecting the aggregate market. So these policies seemed to be successful in dampening the price volatility caused by changes in weather.

## 7 Controlling for Farmer Expectations

To control for producer expectations, we estimate an alternative model including acres planted on the right hand side. Previously we estimated equation 3, which presumably estimated the price effect from changes in supply caused by fluctuations in weather. How-

ever, if farmers are good at predicting weather, this could either understate or overstate the price effects for farm commodities. Producers of multiple commodities likely adjust their output mix based on their weather expectations. If they expect weather to be unfavorable to corn, but favorable to cotton, they may adjust away from corn and the price effect would be overstated for corn, but understated for cotton. Producers of a single commodity face a similar choice. If they expect weather to be unfavorable leading to decreased output and high prices, they may choose to plant more and the price effect would be attenuated.

Including the number acres planted gives a summary measure of these expectations. Although the model will still not control for long term adjustments in crop mix, adding this variable will help control for the short term adjustments to changes in farmer expectations.

We estimate the revised model using state-level farmgate prices for cotton and corn, but only for the period after 1932 as these were the years for which acres planted data existed.

Results from the model are given in Table 4. Although including acres planted did not change the weather variable coefficients much, the coefficient on acres planted was statistically significant and positive for both cotton and corn. However, these were not economically significant, as the elasticities for cotton and corn 0.0184 and 0.023, respectively. Size-wise, the temperature and precipitation coefficients in the cotton regressions are slightly smaller once the number of acres planted is included. In the corn regressions they are slightly larger. However, in both cases the difference is marginal.

From the results above, short term expectations do not appear economically important in affecting farmgate prices, and excluding them does not seem to significantly bias the weather variable coefficients for cotton and corn.

## 8 Concluding Remarks

In this paper we estimate the price sensitivity of two different agricultural commodities to changes in both local and non-local weather fluctuations over a 75 year period. In the case of cotton in the period prior to the New Deal, changes in weather at both the local and national level had little effect on farmgate prices, while prices became much more sensitive to local weather fluctuations after 1933. Corn had prices more responsive to changes in temperature, precipitation and drought conditions. For both commodities, rises in temperature were negatively correlated with farmgate prices, suggesting the supply-side effects dominated any demand-side effects.

The effects differed between the periods prior to and after the New Deal, suggesting that changes in government policy have the ability to affect price responsiveness to local weather fluctuations. Both cotton and corn had cases where prices were sensitive to changes in a weather variable during one period, while showing little or different price sensitivity in the other. This is potentially due to the effects of the New Deal agricultural subsidies, or perhaps from changes in U.S. trade policy for these commodities.

Both the locally traded crop (corn) and the internationally traded crop (cotton) showed sensitivity to weather affecting the outside market. This finding supports the results found in Mundlak and Larson (1992) that international markets play a dominant role in determining local prices. And in the cases of both cotton and corn, attempts to control for farmer expectations did not substantially affect the coefficient estimates.

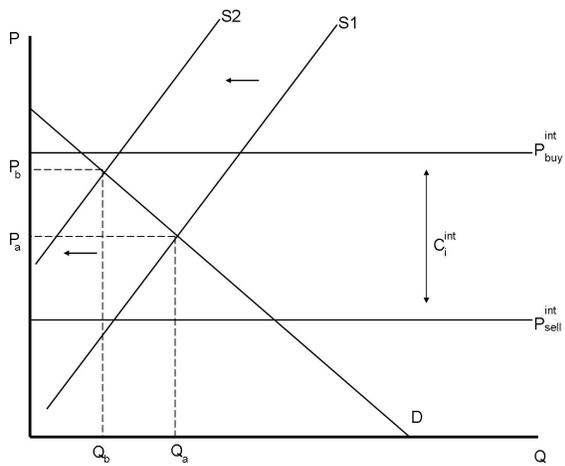
In many cases, the estimated size of the price responsiveness to weather fluctuations was small. This could be due to using yearly averages of temperature and precipitation instead of the monthly averages during the growing season, or perhaps due to weather affecting both demand and supply and the interaction between the two competing effects. However with regards to this last possibility, comparison of Tables 2a and 2b to Tables 3a and 3b suggests

that the supply side effects tend to dominate any demand side effects present.

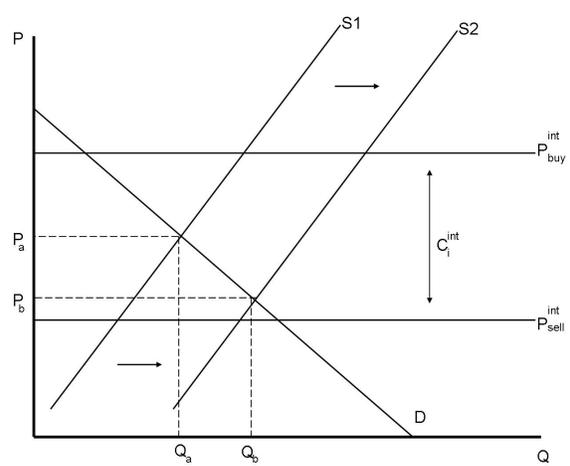
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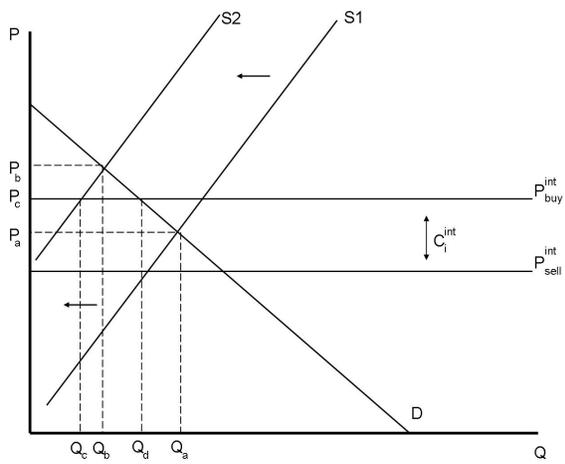


(a) Adverse supply shock

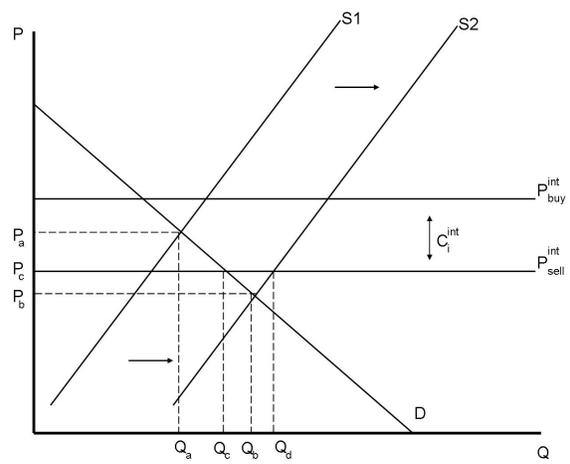


(b) Positive supply shock

Figure 1: Effects for a good with high transport costs



(a) Adverse supply shock



(b) Positive supply shock

Figure 2: Effects for a good with low transport costs

Figure 3a: Cotton Price Elasticity to Local Temperature

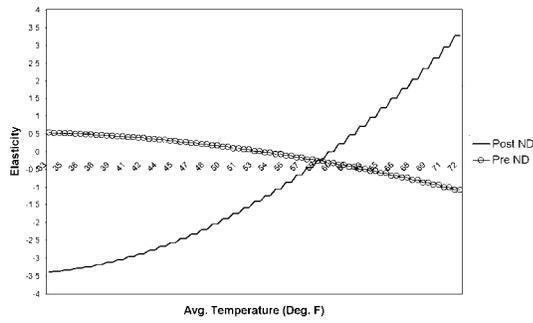


Figure 3b: Cotton Price Elasticity to Other Producer's Temperature

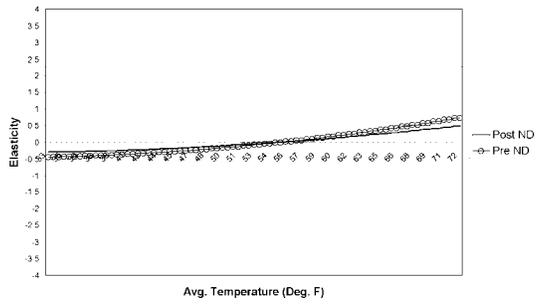


Figure 3c: Cotton Price Elasticity to Local Precipitation

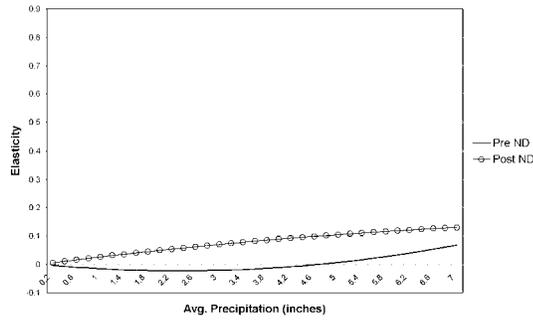


Figure 3d: Cotton Price Elasticity to Other Producer's Precipitation

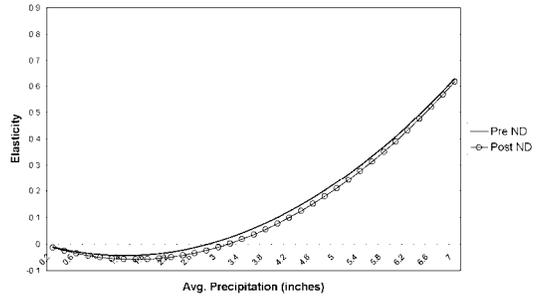


Figure 4a: Corn Price Elasticity to Local Temperature

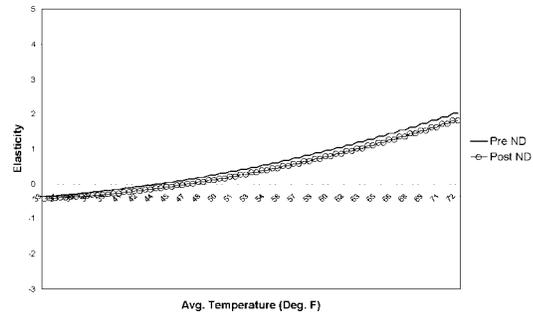


Figure 4b: Corn Price Elasticity to Other Producer's Temperature

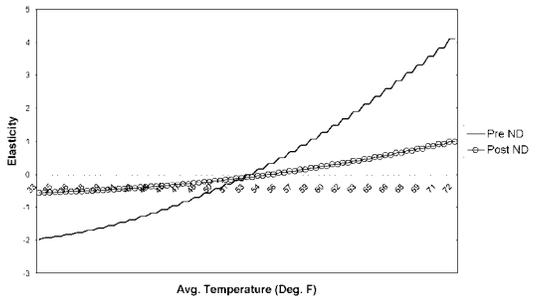


Figure 4d: Corn Price Elasticity to Other producer's Precipitation

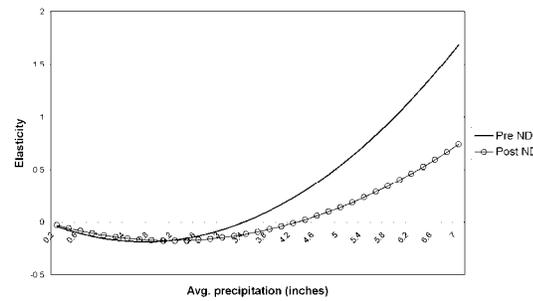
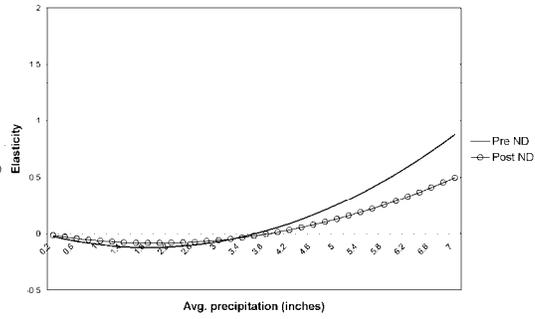
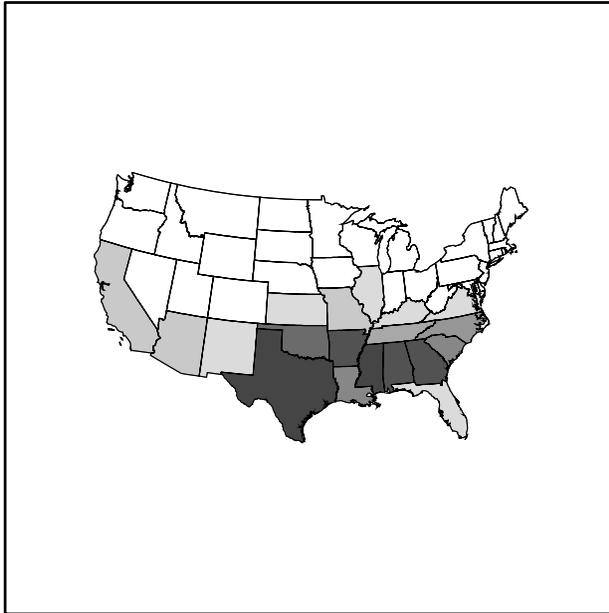


Figure 4c: Corn Price Elasticity to Local Precipitation

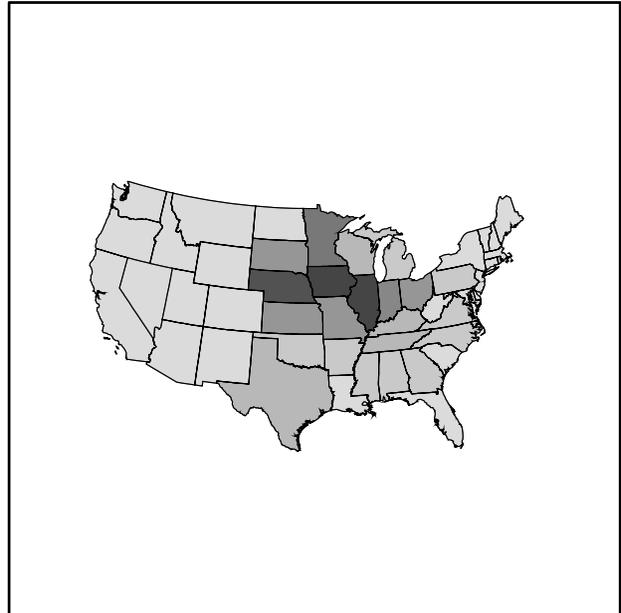


# Map 1 - Crop Shares

## Cotton



## Corn



### Legend

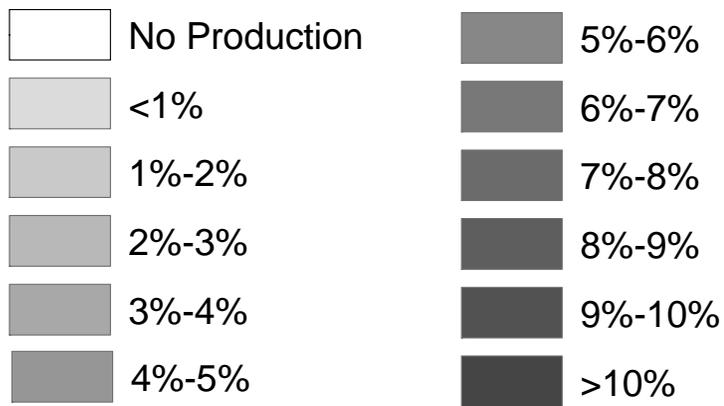


Table 1  
Summary statistics for farm commodities and climate variables

<u>Crop Prices</u>	<u>Mean</u>	<u>Std. Dev.</u>	<u>Min</u>	<u>Max</u>
Cotton	114.65	42.43	31.71	763.77
Corn	622.95	215.48	145.25	1,840.87
<u>Crop Output</u>				
Cotton	126,895.10	311,783.10	0.00	2,897,100
Corn	51,282.21	93,885.47	0.00	815,360
<u>Climate Variables</u>				
Cotton states				
Average yearly temperature	60.445	5.221	50.206	73.763
Average yearly precipitation	3.459	1.225	0.394	6.193
Months of extreme or severe drought	1.111	2.073	0	12
Months of extreme or severe wet	0.802	1.621	0	10.286
Moisture index std. dev.	1.693	0.382	0.754	4.021
Corn states				
Average yearly temperature	52.077	7.952	35.044	73.763
Average yearly precipitation	2.932	1.168	0.366	6.193
Months of extreme or severe drought	1.178	2.183	0	12
Months of extreme or severe wet	1.081	2.066	0	12
Moisture index std. dev.	1.690	0.402	0.643	4.293

Table 2a  
 Dependent variable: ln(price of cotton in \$1982-3)

Variables	(1)	(2)	(3)	(4)	(5)	(6)
	<u>Pre ND</u>	<u>Post ND</u>	<u>Pre ND</u>	<u>Post ND</u>	<u>Pre ND</u>	<u>Post ND</u>
Avg. Temperature	0.0185 (0.36)	-0.2646 (3.36)***	0.0491 (0.77)	-0.2233 (2.89)***	0.0427 (0.67)	-0.2281 (2.90)***
Avg. Temperature Sq.	-0.0002 (0.45)	0.0022 (3.35)***	-0.0004 (0.84)	0.0019 (2.86)***	-0.0004 (0.72)	0.0019 (2.90)***
Avg. Precipitation	-0.0142 (0.62)	0.0024 (0.10)	-0.0319 (1.36)	0.0007 (0.03)	-0.0197 (0.71)	0.0269 (0.81)
Avg. Precipitation Sq	0.0016 (0.55)	0.0004 (0.13)	0.0037 (1.26)	0.0005 (0.19)	0.0021 (0.66)	-0.0006 (0.19)
Months of XS wetness					0.0047 (1.43)	-0.0029 (0.90)
Months of XS drought					-0.0001 (0.05)	-0.0006 (0.23)
Palmer Z Index Std. Dev.					-0.0182 (1.68)*	-0.0293 (1.64)
<u>Other Producer's Weather</u>						
Avg. Temperature			-0.0186 (0.87)	-0.0338 (1.66)*	-0.0331 (1.56)	-0.0220 (1.09)
Avg. Temperature Sq.			0.0002 (1.03)	0.0004 (1.77)*	0.0003 (1.61)	0.0002 (1.26)
Avg. Precipitation			-0.0854 (3.08)***	-0.0302 (0.90)	-0.0614 (2.07)**	-0.0729 (1.44)
Avg. Precipitation Sq			0.0130 (3.22)***	0.0063 (1.35)	0.0108 (2.57)**	0.0115 (1.70)*
Months of XS wetness					-0.0007 (0.33)	0.0064 (1.41)
Months of XS drought					0.0043 (2.25)**	0.0001 (0.12)
Palmer Z Index Std. Dev.					-0.0038 (0.45)	-0.0066 (0.47)
Constant	4.1852 (2.70)***	12.6839 (5.46)***	5.3998 (2.03)**	14.8559 (4.44)***	7.1733 (2.73)***	14.0625 (4.46)***
Observations	559	708	559	708	559	708
R-squared	0.97	0.85	0.98	0.86	0.98	0.86

Robust t statistics in parentheses

\* significant at 10%; \*\* significant at 5%; \*\*\* significant at 1%

Table 2b  
 Dependent variable: ln(price of corn in \$1982-3)

Variables	(1)	(2)	(3)	(4)	(5)	(6)
	<u>Pre ND</u>	<u>Post ND</u>	<u>Pre ND</u>	<u>Post ND</u>	<u>Pre ND</u>	<u>Post ND</u>
Avg. Temperature	-0.0411 (2.31)**	-0.0431 (2.79)***	-0.0435 (2.41)**	-0.0455 (2.92)***	-0.0441 (2.42)**	-0.0469 (3.00)***
Avg. Temperature Sq.	0.0005 (2.85)***	0.0004 (2.98)***	0.0005 (3.10)***	0.0005 (3.07)***	0.0005 (3.05)***	0.0005 (3.01)***
Avg. Precipitation	-0.1306 (4.19)***	-0.1160 (5.47)***	-0.1277 (4.10)***	-0.1109 (5.19)***	-0.1349 (3.84)***	-0.0870 (3.74)***
Avg. Precipitation Sq	0.0180 (4.35)***	0.0145 (4.99)***	0.0179 (4.32)***	0.0140 (4.79)***	0.0186 (4.28)***	0.0113 (3.81)***
Months of XS wetness					-0.0022 (1.09)	-0.0007 (0.43)
Months of XS drought					0.0012 (0.69)	0.0032 (2.39)**
Palmer Z Index Std. Dev.					0.0164 (1.82)*	0.0074 (1.01)
<u>Other Producer's Weather</u>						
Avg. Temperature			-0.1357 (3.61)***	-0.0330 (1.23)	-0.1589 (4.65)***	-0.0438 (1.61)
Avg. Temperature Sq.			0.0013 (3.41)***	0.0003 (1.27)	0.0015 (4.49)***	0.0004 (1.64)
Avg. Precipitation			-0.1154 (1.89)*	-0.0759 (2.25)**	-0.2240 (3.38)***	-0.1658 (4.04)***
Avg. Precipitation Sq			0.0186 (2.06)**	0.0088 (1.77)*	0.0332 (3.46)***	0.0194 (3.61)***
Months of XS wetness					0.0159 (2.93)***	0.0166 (5.74)***
Months of XS drought					0.0088 (2.35)**	0.0047 (2.91)***
Palmer Z Index Std. Dev.					0.0295 (1.31)	0.0365 (2.99)***
Constant	7.0815 (14.93)***	7.4973 (19.01)***	9.6347 (11.32)***	8.5289 (13.57)***	10.1610 (12.60)***	8.8258 (13.95)***
Observations	1796	1344	1796	1344	1796	1344
R-squared	0.91	0.93	0.91	0.93	0.91	0.93

Robust t statistics in parentheses

\* significant at 10%; \*\* significant at 5%; \*\*\* significant at 1%

Table 3a  
 Dependent variable: ln(total cotton output)

Variables	(1)	(2)	(3)	(4)	(5)	(6)
	<u>Pre ND</u>	<u>Post ND</u>	<u>Pre ND</u>	<u>Post ND</u>	<u>Pre ND</u>	<u>Post ND</u>
Avg. Temperature	1.2643 (5.42)***	1.2799 (4.49)***	1.4058 (5.29)***	1.2719 (4.07)***	1.3143 (5.12)***	1.1637 (3.67)***
Avg. Temperature Sq.	-0.0106 (5.57)***	-0.0091 (3.90)***	-0.0118 (5.45)***	-0.0091 (3.53)***	-0.0110 (5.26)***	-0.0083 (3.21)***
Avg. Precipitation	-0.1255 (0.55)	0.2238 (1.05)	-0.1119 (0.49)	0.2306 (1.08)	0.1281 (0.58)	0.2831 (1.17)
Avg. Precipitation Sq	-0.0077 (0.29)	-0.0294 (1.22)	-0.0100 (0.38)	-0.0299 (1.23)	-0.0271 (1.07)	-0.0346 (1.36)
Months of XS wetness					-0.0417 (2.53)**	-0.0289 (1.60)
Months of XS drought					-0.0216 (1.84)*	0.0268 (1.74)*
Palmer Z Index Std. Dev.					-0.1780 (2.86)***	0.1807 (2.34)**
<u>Other Producer's Weather</u>						
Avg. Temperature			0.0247 (0.29)	-0.1231 (1.05)	0.0658 (0.74)	-0.1714 (1.42)
Avg. Temperature Sq.			-0.0002 (0.19)	0.0011 (1.03)	-0.0005 (0.63)	0.0016 (1.41)
Avg. Precipitation			0.2369 (1.75)*	-0.0199 (0.14)	0.3005 (1.92)*	-0.0817 (0.42)
Avg. Precipitation Sq			-0.0307 (1.60)	0.0065 (0.31)	-0.0428 (2.07)**	0.0113 (0.43)
Months of XS wetness					-0.0281 (2.57)**	-0.0062 (0.43)
Months of XS drought					-0.0254 (3.54)***	-0.0123 (1.87)*
Palmer Z Index Std. Dev.					0.0744 (1.59)	0.0221 (0.41)
Constant	-24.4308 (3.31)***	-32.2468 (3.60)***	-34.0117 (2.99)***	-17.4355 (1.04)	-36.9132 (3.39)***	-8.6891 -0.51
Observations	559	708	559	708	559	708
R-squared	0.95	0.96	0.95	0.96	0.96	0.96

Robust t statistics in parentheses

\* significant at 10%; \*\* significant at 5%; \*\*\* significant at 1%

Table 3b  
 Dependent variable: ln(total corn output)

Variables	(1)	(2)	(3)	(4)	(5)	(6)
	<u>Pre ND</u>	<u>Post ND</u>	<u>Pre ND</u>	<u>Post ND</u>	<u>Pre ND</u>	<u>Post ND</u>
Avg. Temperature	0.2142 (3.05)***	-0.0450 (0.67)	0.2203 (3.08)***	-0.0379 (0.56)	0.2233 (3.19)***	-0.0329 (0.52)
Avg. Temperature Sq.	-0.0027 (4.26)***	0.0004 (0.65)	-0.0028 (4.32)***	0.0004 (0.61)	-0.0028 (4.43)***	0.0006 (0.90)
Avg. Precipitation	0.2934 (2.77)***	0.6697 (5.74)***	0.2877 (2.68)***	0.6484 (5.52)***	0.3501 (2.98)***	0.3816 (3.05)***
Avg. Precipitation Sq	-0.0396 (2.97)***	-0.0771 (5.08)***	-0.0390 (2.87)***	-0.0747 (4.90)***	-0.0442 (3.13)***	-0.0425 (2.75)***
Months of XS wetness					0.0014 (0.15)	-0.0140 (1.79)*
Months of XS drought					-0.0001 (0.01)	-0.0495 (7.59)***
Palmer Z Index Std. Dev.					-0.0641 (1.84)*	-0.0891 (2.83)***
<u>Other Producer's Weather</u>						
Avg. Temperature			0.2039 (2.59)***	0.0135 (0.12)	0.1895 (2.34)**	0.0182 (0.17)
Avg. Temperature Sq.			-0.0020 (2.58)***	-0.0001 (0.13)	-0.0019 (2.33)**	-0.0001 (0.10)
Avg. Precipitation			0.2138 (1.52)	0.2043 (1.25)	0.1232 (0.76)	0.0111 (0.07)
Avg. Precipitation Sq			-0.0301 (1.47)	-0.0171 (0.76)	-0.0186 (0.81)	0.0071 (0.32)
Months of XS wetness					0.0003 (0.03)	-0.0014 (0.14)
Months of XS drought					-0.0006 (0.08)	-0.0193 (3.01)***
Palmer Z Index Std. Dev.					0.0631 (1.30)	-0.1920 (3.35)***
Constant	6.8718 (3.45)***	10.3341 (6.36)***	2.9457 (1.17)	9.5722 (3.60)***	2.9937 -1.17	9.4286 (3.74)***
Observations	1806	1344	1806	1344	1806	1344
R-squared	0.96	0.97	0.96	0.97	0.96	0.98

Robust t statistics in parentheses

\* significant at 10%; \*\* significant at 5%; \*\*\* significant at 1%

Table 4  
Including Acres Planted

Dependent var: logged real price	(1)	(2)	(3)	(4)
	Cotton		Corn	
Avg. temp.	-0.2275 (2.89)***	-0.2312 (2.93)***	-0.0454 (2.90)***	-0.0420 (2.67)***
Avg. temp. squared	0.0019 (2.88)***	0.0019 (2.92)***	0.0004 (2.95)***	0.0004 (2.64)***
Avg. precipitation	0.0055 (0.18)	0.0065 (0.21)	-0.0881 (3.90)***	-0.0864 (3.83)***
Avg. pcp. squared	0.0008 (0.25)	0.0006 (0.19)	0.0117 (3.95)***	0.0116 (3.91)***
Months of XS wet	-0.0042 (1.21)	-0.0038 (1.09)	-0.0005 (0.31)	-0.0005 (0.30)
Months of XS drought	-0.0012 (0.45)	-0.0012 (0.46)	0.0032 (2.37)**	0.0038 (2.79)***
Acres planted		0.000017 (2.15)**		0.000013 (1.74)*
<u>Other producer's weather</u>				
Avg. temp.	-0.0241 (1.20)	-0.0031 (0.13)	-0.0331 (1.28)	-0.0296 (1.14)
Avg. temp. squared	0.0003 (1.35)	0.0000 (0.19)	0.0003 (1.35)	0.0003 (1.20)
Avg. precipitation	-0.0747 (1.33)	-0.0738 (1.38)	-0.1538 (3.84)***	-0.1467 (3.61)***
Avg. pcp. squared	0.0115 (1.57)	0.0111 (1.61)	0.0188 (3.55)***	0.0177 (3.28)***
Months of XS wet	0.0063 (1.37)	0.0071 (1.55)	0.0165 (5.88)***	0.0178 (6.08)***
Months of XS drought	0.0000 (0.03)	0.0001 (0.06)	0.0048 (2.96)***	0.0055 (3.40)***
Constant	14.32 (4.48)***	12.32 (3.85)***	8.59 (13.93)***	8.43 (13.66)***
Observations				
R-squared	708	708	1344	1344
Robust t statistics in parentheses	0.86	0.86	0.93	0.93

\* significant at 10%; \*\* significant at 5%; \*\*\* significant at 1%