The Effects of Weather Shocks on Crop Prices in Unfettered Markets: The United States Prior to the Farm Programs, 1895-1932

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Abstract

This paper uses a 37-year panel of state information to identify the effects of weather fluctuations on different types of agricultural commodities. Using information from the United States Department of Agriculture and National Climatic Data Center, we estimate these effects for the staple crops cotton, corn, and wheat. We also analyze the effects for hay, an important crop in local agronomic production. Corn and hay are crops with high transport costs and are used in local productive activities, while cotton and wheat are crops with relatively low transport costs and are primarily exported to non-local markets. The results indicate that for crops sold primarily in international markets, changes in local weather have little effect on farm-gate prices, while changes in weather affecting the aggregate market play an important role. Crops with strong local markets such as corn and hay are much more sensitive to changes in state-level temperature, precipitation, and drought conditions.

1 Introduction

Recently much attention has been given to studying the effects of human contributions toward an increasingly warmer, wetter and more variable climate. If we assume that the climate change scenarios are correct, it is important to determine the economic implications of not only global increases in temperature and precipitation, but also how local variation in weather may affect productive activities. Changes in temperature and precipitation, and weather disasters like droughts, floods, heat waves, and blizzards, 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, thus also farm incomes and land values. The price effects of localized supply shocks at the farm-gate level will differ across types of farm commodities. Local weather shocks may have minimal influence on the local prices of crops sold in international markets. However, for crops primarily used and sold at the local level, such disasters may lead to significant local price responses.[1]

During the World Trade Organization negotiations, the rest of the world has been pressuring the United States and Europe to cease interfering with agricultural markets while trying to support their domestic farmers. Most modern studies of agricultural price responses to weather shocks have been focused on these heavily regulated markets, but such studies provide little information on how unfettered markets, which might arise out of the trade negotiations, will operate.

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 prior to 1932, when markets were relatively unfettered by farm programs. In this paper, we examine the United States' three great staple crops (cotton, corn and wheat), as well as hay. Cotton and wheat are crops with high value-to-weight ratios, and ones that are not heavily used in other agricultural productive activities. During the period of consideration, cotton prices, adjusted to 1982-84 dollars, averaged about $113 per pound. Wheat prices averaged about $15 per pound in 1982-84 dollars. Corn and hay, on the other hand, are both used as feed for livestock and have value-to-weight ratios less than that of cotton or wheat. For comparison, between 1895 and 1932, corn averaged about $9 per pound in 1982-84 dollars, and hay about $5 per pound in the same denomination. Both corn and hay are primarily used and sold at the local level. For example, at the beginning of our period of consideration, over 77 percent of corn was retained and consumed

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[1] 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).

in the county of production, whereas only about 40 percent of wheat, and only a negligible fraction of cotton was consumed in the locality where it was grown.

We expect that when agricultural commodities have high transportation costs and are heavily 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 affected much less by changes in local weather but will be sensitive to geographically broad changes in weather conditions. While we do not explicitly estimate the relationship between transportation costs and price volatility, by looking at the differences between two crops with relatively high value-to-weight ratios and two crops with relatively low value-to-weight ratios, we can explore how the reduction of transactions costs through globalization might potentially mitigate the effects of localized weather shocks.

2 Local Weather and Drought

Between 1895 and 1932 there was a great deal of variation in weather conditions, yields on different harvests, and commodity prices. In his 1926 *Business Annals*, published for the National Bureau of Economic Research, Willard Thorp assembled narrative information from commercial sources on the success or failures of the cotton, corn and wheat harvests over the previous century, as well as data on crop prices. Within our period, he reported multiple instances of record crop harvests, as well as several years of failures. For example, 1921 witnessed poor harvests of both corn and wheat, and a failure of the cotton harvest, leading to price increases even in the midst of a recession (Thorp 1926, pp. 144). As predicted from a supply-driven equilibrium model, good harvests generally led to lower prices and bad harvests to higher prices. Some crops hewed more closely to this relationship than others. Inspection of Thorp's annals reveals that when the cotton harvest was poor, short or failed, cotton prices were always listed as rising or being high. This relationship was only generally true for corn and wheat.

Many different reasons contributed to the good and bad harvests reported by Thorp in his business annals. Defective seed, pests, and disease played a small role in reducing yields. As has been well documented, the boll weevil, which entered the United States around 1892, was particularly devastating to cotton harvests in the South (Lange, Olmstead, Rhode, 2009). Table 1 reports USDA estimates of reduction of cotton yield by cause between 1909 and 1932. As was often the case with plant diseases and other insect and animal pests, the effects of the weevil was tied to weather conditions. Specifically, weevil damage was worse in wet, warm years.

Even though most people have focused on the destruction wrought by the boll weevil, drought and other weather fluctuations caused more crop losses than did that nasty pest (USDA Yearbook 1922, Kramer 1983). Droughts, floods, hot winds and other climatic shocks destroyed numerous harvests across the United States. Heavy rain led to multiple devastating floods on the Ohio, Missouri and Mississippi basins, ruining harvests and destroying farmland that sometimes took several years to recover. In the Mississippi Basin, there were twelve separate instances of major flooding, culminating in 1927 with the famous flood that led to the Flood Control Act of 1928 (Trotter et. al 1998).[2]

Drought was also a major problem. According to the USDA estimates, drought conditions in 1911 destroyed a quarter of the corn, wheat and hay harvests. The drought eliminated 35 pounds per acre of the cotton harvest, a loss that is 50 percent higher than the amount of cotton destroyed by the boll weevil in any of the surrounding four years (USDA Yearbook 1922). Deficient moisture conditions severely curtailed the corn harvests again in 1916 and 1918, and in 1917 frost reduced the corn and wheat yields by nearly 14 and 12 percent, respectively (USDA Yearbook 1922). The droughts in the late 1910s also contributed to an outbreak of stem rust which devastated the spring wheat crop in Northern Plains. The Great Drought of 1930, which USDA Secretary Arthur M. Hyde called "the worst drought ever recorded in this country," served as a prelude to the infamous Dust Bowl conditions of the 1930s (Hamilton 1982, p. 850).

Given the importance of weather in determining the strength of the cotton, corn and wheat harvests, it is not surprising that so many studies have been devoted to determining the relationship between temperature, precipitation and crop yields. Just within our sample years, Annie Hannan counted over 2,000 studies that examined the influence of weather on crops (Hannan 1932).

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 and subsequently profit, would be a misspecification. Generally, the non-linearity introduced is a quadratic in precipitation and

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[2] These were 1903, 1907, 1908, 1912, 1913, 1916, 1920, 1922, 1923, 1927, 1929, and 1932.

temperature. We choose a similar path, but also include measures for drought and wetness conditions using the Palmer Drought Severity Index (PDSI).[3]

3 Data and Summary Statistics

To study the effects of state-level weather fluctuations on farm-gate prices, we combine two existing datasets; one containing historical crop information, the other historical weather information. State-level information on yield, harvests, and prices 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.[4] This dataset covers the contiguous United States from 1866 to 1969, although the limited availability of weather data constrained the analysis to the period after 1895. After 1932, the federal government intervened heavily in many agricultural markets, with payments to limit acreage under production, price supports for some agricultural commodities, and the formation of federal crop insurance in 1938. This new legislation, changes in technology, increases in the use of fertilizer, and other factors affecting the relationship between weather and crop yields, caused a variety of effects that have yet to be sorted out. To isolate the activities of relatively unregulated markets, we limit the analysis to the 37 years between 1895 and 1932.

To adjust for inflation, commodity prices are adjusted to reflect 1982-1984 dollars using the CPI series developed by Lawrence Officer. Table 2a gives summary statistics on output and prices per pound in 1982-1984 dollars for the selected farm commodities, and Table 2b the summary statistics for the different weather variables used in estimation.

There was great temporal and spatial variation in both output and prices for all four of the crops; second, there is also large variation between the commodities. Within any one year cotton and wheat prices displayed much less regional variation than prices for corn and hay. This is likely a function of two key differences. Corn and hay were used as animal feed on the farm and in local markets, while cotton was used primarily as an input for manufacturing in U.S. and English cities and wheat was marketed internationally. Further, cotton was much less costly to transport than the other crops. The differences in markets lead us to believe that state level corn and hay prices will fluctuate more with state level weather shocks than will wheat and cotton prices.

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[3] We define the term “drought” as a prolonged and abnormal moisture deficiency.

[4] Crop prices represent the farm gate price on December 1st.. The data are freely available from the National Agricultural Statistics Service

Map 1 shows the distribution of production across the contiguous United States for the four crops in 1929, a year relatively free of inclement weather. Both the cotton, corn and wheat belts are clearly visible. Also evident is that corn and hay production is more widely distributed across the country, consistent with the existence of local markets for these commodities. Every state engaged in at least some production of corn and hay, whereas cotton was limited to the more southern latitudes. Wheat was concentrated in the Midwest, with no production occurring in Florida, Mississippi, Alabama, New Hampshire, Massachusetts, Rhode Island or Connecticut.

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, the average temperature and precipitation data are adjusted for time of day using the 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 Palmer Z standard deviation are given in Table 2b. For the period under consideration, these series are stationary in the time series sense.[5]

The weather in most states producing cotton tended to be warmer and wetter than in states producing corn, hay and wheat. Temperatures also displayed less variability in the cotton states.[6] In all of the 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, hay and wheat 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).[7] Between 1895 and 1932, some states endured years with serious drought conditions for all twelve months, while other states enjoyed years with twelve months straight of normal moisture levels. The number of months of extreme or severe wetness ranged similarly.

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[5] This is tested using the Fisher test suggested by Maddala and Wu (1999).

[6] During the period under consideration, arid western states began producing cotton using irrigation.

[7] The PHDI represents about a year's worth of abnormal moisture conditions, while the PDSI represents about nine months worth.

4 Price Effects and Transportation Costs

State-level price responses from state-level supply shocks will be mitigated for tradable goods sold in an international market because individual states will play too small a role to affect prices significantly. At the extreme, if a farm commodity is perfectly tradable internationally, the observed state average farm-gate (local) price is a function only of non-local, or international supply and demand and farm-gate prices vary only with changes affecting the aggregate market.[8] Conditional on weather that affects producers as a whole, state farm-gate commodity prices would not be influenced much by state-level weather shocks. Conversely, for perfectly non-tradable commodities with prohibitively high transportation or storage costs, the observed state farm-gate price is a function only of supply and demand in the local market. If a severe drought hits, local traders do not import goods from other states or countries to mitigate the price shock. Additionally, weather affecting producers outside of the local area will not affect local prices.

Commodities generally fall in between these two extreme cases. Assuming tradability is only a function of the specific properties for a certain crop and it 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 a function of both the international and local supply and demand:

$$\ln(P^{obs}_{s,c,t}) = \tau_c \ln(P^{\text{int}}_{c,t}) + (1-\tau_c)\ln(P^{loc}_{s,c,t}) \qquad (1)$$

where τ_c is an index of the strength of the local market for crop c. The strength of the market itself is a function of transaction costs and local uses for the crop. Crops such as cotton and wheat, which are easy to store, easy to transport, have a relatively high value-to-weight ratio and few local uses, have a τ_c closer to one. On the other hand, crops such as corn and hay, which are used in other areas of agricultural production, have higher transport costs, and stronger local markets, have a τ_c much closer to zero.

Figures 1 and 2 show the differential effects of negative local supply shocks for goods with relatively high and low transport costs. In each of these figures, local supply is upward sloping, relatively inelastic and given by S1 and S2. Also present in each is the internationally determined prices P^{int}_{buy}, the price paid by international buyers and P^{int}_{sell},the effective price

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[8] This statement assumes that transport costs between the farm-gate and markets stay constant over time.

received by commodity producers after subtracting their marginal cost of bringing the commodity to the international market.[9] The distance between P_{buy}^{int} and P_{sell}^{int} is C_i^{int}, the size of the marginal cost to bring commodity i to the international market. Within each of the figures, the bolded line represents the effective market demand curve faced by suppliers in the local area, and the bolded dashed line represents the relevant areas of the market supply curves for local suppliers.

Figure 1 represents the local market for commodities such as corn and hay that have higher transport costs and strong local markets. Because the cost of bringing these types of goods to international market is high compared to a good such as cotton, fluctuations in the local market play a larger role. Additionally, fluctuations in the international market will play a relatively smaller role. In Figure 1, producers begin in an exporting situation on supply curve $S1_L$, where the market quantity Q_b is the amount sold at the local level, and the quantity $Q_a - Q_b$ is exported to the outside market. Because the marginal transport cost C_i^{int} is large, very little of the good is exported, and a relatively small supply shock would cause local producers to sell exclusively to the local market. For example, an adverse weather shock that causes supply to fall from $S1_L$ to $S2_L$ drives the quantity produced from Q_a to Q_c and causes the price at which the farmers sell to rise from P_a to P_b. If the supply reduction were particularly severe, it could potentially drive the local market price above P_{buy}^{int} and cause local markets to import from the outside market.

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" between P_{buy}^{int} and P_{sell}^{int} in Figure 1 above or below the local equilibrium price. Local prices tend to be less susceptible to changes in the international market for goods with higher transport costs and wider bands.

Figure 2 represents a local market 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 the international market, C_i^{int}, are small. We again begin in an exporting situation with a local market price at P_a, total production of Q_a, local purchases of

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[9] If we assume constant marginal transaction costs, this is also the average cost

Q_c. In this situation, however, the production exported to outside markets ($Q_a - Q_b$) is much larger. It takes a much larger adverse supply shock to force the local market to rely exclusively on local production. In the event of a supply shock that moves the local supply curve to $S2_L$, the price shock is much lower than in Figure 1, as the price rises much less from P_a to P_b. Because of the lower transport costs, a local supply shock would be more likely to lead to a situation where local consumers pay the international price paid by buyers.

Considering a simplified version for farm commodity prices where weather is the only input, then

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

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 measure of weather conditions across all other states producing the commodity, defined in section 5.1 below.

5 Empirical Model

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 or to states that were net exporters of the different crops. Additionally, we can conduct the analysis without worry that states in different climate zones may have different levels of transportation structure.

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. In addition to the effect of local weather on local prices, we are also interested in the effect of weather fluctuations by other producers who are competing in the national and international market. For this reason, we construct a set of “Other Producer's Weather” (OPW) variables.

5.1 Other Producer's Weather

For goods with weak local markets and sold primarily as exports, geographically broad changes in weather conditions affecting the aggregate market play the dominant role in determining local prices. To capture the effect of weather-driven supply shocks in the outside market, we create a set of variables that measure changes in weather affecting all other producing states in the U.S.

If the United States economy was completely closed and trade occurred only between the different states, including these variables would completely capture the effect of an international market. However, while the U.S. was not a closed economy and cotton and wheat were being bought and sold in a true international market, we argue that including aggregate measures of weather affecting domestic producers will proxy well for shocks to the entire market outside the local state market. This proxy works well because the United States is a sufficiently large portion of the overall international supply for each of the different crops.

We construct these OPW variables for each of the four commodities. These weather variables are weighted by each state's relative share of national production in 1929, which is chosen as the weighting reference year due to its near absence of inclement weather. These variables control for the effect on local farm-gate prices from weather shocks affecting other producers of the commodity.

To create the weights, we first calculate the national share of production within in state s for commodity c in 1929. This is represented by $\eta_{s,c}$ and defined as:

$$\eta_{s,c} = \frac{Q_{s,c}}{\sum_{j=1}^{S} Q_{j,c}} \tag{3}$$

where $Q_{s,c}$ is the total output of commodity c produced by state s in 1929.

We then use this to construct the weighted averages of the different weather variables (OPW). For weather variable W, OPW is defined as:

$$OPW_{s,c,t}^{W} = \frac{1}{1-\eta_{s,c}} \sum_{j \neq s}^{S} \eta_{j,c} * W_{j,t} \tag{4}$$

In the above equation, W could be average annual precipitation in state j and year t, average annual temperature in state j and year t, or one of the other weather variables included in the analysis.

5.2 Reduced Form Models

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

$$\ln(P_{s,c,t}) = \alpha_s + \gamma_t + W_{s,t}\beta_c + OPW_{s,c,t}\omega_c + \varepsilon_{1,s,c,t} \qquad (5)$$

$$\ln(Q_{s,c,t}) = \alpha_s + \gamma_t + W_{s,t}\beta_c + \varepsilon_{2,s,c,t} \qquad (6)$$

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,[10] α_s is a set of state fixed effects that control for unmeasured time-invariant determinants of the farm-gate price, γ_t is a set of year indicators that control for unmeasured 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 outside state s. The disturbance terms $\varepsilon_{1,s,c,t}$ and $\varepsilon_{2,s,c,t}$ are assumed to have conditional mean zero, and defined as the other factors influencing farm-gate prices and output besides weather.

Although there are certainly other factors that could potentially affect farm commodity prices, after controlling for fixed effects, it is not likely that these unobserved effects will cause the local weather variables to be correlated with the error term. While the variables that proxy for weather fluctuations in other producing states are weighted by that state's share of national production, it is also unlikely that the OPW variables will be correlated with the error term. The share of production used to weight the weather in the other states is fixed in 1929, and thus cannot vary over time in response to weather shocks. Any influence of the production share in 1929 on the error term will be controlled with the state fixed effects.

The dependent variables in the analysis are the logged values of the real prices and quantities for the different commodities. Corn and hay had higher transport costs and were more commonly used in agricultural production than cotton and wheat. Therefore, we expect that the state farm-gate prices of corn and hay were more responsive to adverse local weather shocks than were the state farm-gate prices of cotton and wheat. We might expect all of these commodities to experience changes in prices due to fluctuations in the weather in the rest of the nation. Such fluctuations will influence the placement of the upper and lower prices in the price

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[10] After examination of the different output distributions, we concluded that they were all closer to a log-normal distribution than a normal distribution

band created by transportation and transactions costs. How much the weather outside the state will matter is an empirical question.

6 Results

Tables 3a-d show regression results with the logged prices of cotton and corn as the dependent variables (a-cotton, b-corn, c-hay, and d-wheat) and Tables 4a-d give regression results with logged quantity as the dependent variable. All of the models present in Tables 3 and 4 include state and year fixed effects.[11] Column 1 in each table presents results from measuring weather using just temperature, precipitation and their squared terms. Including this basic model allows comparison to the prior work that used only measures of temperature and precipitation and sets a baseline for comparison when the additional weather variables are included. Column 2 includes the variables controlling for the number of months of extreme or severe wetness and extreme or severe drought. For all of the different crops, including the extreme or severe wetness and drought measures did not affect the coefficients on average yearly temperature or its squared term. Their inclusion tended to slightly attenuate the coefficients for precipitation and its squared term because these variables are measures of the extreme parts of the distribution of drought and wetness that arises from changes in current and prior precipitation.

Columns 3-5 represent the different models that include the OPW variables. Column 3 includes just temperature, precipitation, and their squared terms. Column 4 adds in the number of months of extreme or severe drought and wetness, and Column 5 includes the standard deviation of the Palmer Z index to control for effects of changes in weather variability. Tables 4a-d show the results when the logged quantity within the state is estimated as a function of the local weather variables.

The different crops exhibited different sensitivities to local and non-local weather events, although there were some commonalities across the tables. In comparisons of specifications for a crop, the coefficient estimates tended to be similar across the different model specifications. The inclusion of the OPW variables and the Palmer drought and wetness measures had little effect on the coefficient estimates for local average temperature and average precipitation.

6.1 The Dominant Shifts in Supply or Demand Associated with Weather Changes

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[11] The inclusion of the fixed effects cause the R^2 to be so close to one. Without the fixed effects the R-squared ranges from 0.15 to 0.35 across the specifications.

Our analysis of local supply and demand adjustments in Figures 1 and 2 focuses on supply shifts because in most cases they are the dominant shifts associated with local weather changes. For corn and hay, where narrative evidence suggests a great deal of local consumption, the weather coefficients in the Table 3 price regressions and the Table 4 quantity regressions are consistent with a supply shift dominating any demand effects associated with changes in the weather. The coefficient of local temperature in the crop price equations had the opposite sign of the coefficient of local temperature in the crop output equations for nearly every crop. This was also true for local precipitation.

For example, the local temperature coefficients for corn output in Table 4b showed that a rise in local temperature raised corn output at a diminishing rate. The coefficients of local temperature in Table 3b in the corn price regressions had the opposite sign, so that increases in local temperature lowered farm-gate corn prices at a diminishing rate. The coefficients of local precipitation have similar opposing signs in the Table 3b price regressions and the Table 4b quantity regressions in Table 4b. Comparisons of the coefficients in the hay regressions in Tables 4c and 4b show the same opposing signs for the local weather coefficients in the price and quantity regressions. Increases in local temperature decreased hay output at a diminishing rate, while raising the farm-gate hay price at a diminishing rate. Meanwhile, increases in local precipitation lowered hay output at a diminishing rate and raised hay prices at a diminishing rate.

In the cotton and wheat markets, where transport costs were low and there was limited local consumption, the relationships of local weather with prices and quantities had the opposing signs associated with dominant supply shifts for precipitation, but not for temperature. In both the cotton and wheat markets, increases in local precipitation raised output at a diminishing rate and lowered price at a diminishing rate (see Tables 3a and 4a for cotton and 3d and 4d for wheat). On the other hand, increases in local temperature increased both prices and quantities in both the cotton and wheat markets. As we will see below, the effects of local weather on prices in the corn and wheat markets were weak relative to the effects in the corn and hay markets, which is consistent with a setting where local conditions had little effect on prices.

Many of the same patterns arise when examining the impact of weather outside the state on the state's prices and quantities. The corn market results for the impact of weather elsewhere on local price in Table 3b and the general effect of weather on output in 4b display the exact same pattern as for the impact of local weather. Increases in temperature raised corn output at a diminishing rate in general, and the temperature rise elsewhere was associated with declines in farm-gate corn prices at a diminishing rate. Increases in precipitation show the same patterns. Similarly, the hay market results for the impact of weather elsewhere on farm-gate prices in Table 3c and the general effect of weather on output in 4c display the exact same pattern as for the impact of local weather. More precipitation raised hay output at a diminishing rate in general, and more precipitation elsewhere lowered hay prices at a diminishing rate; higher temperatures lowered hay output at a diminishing rate and higher temperatures elsewhere raised hay prices at a diminishing rate.

The markets for cotton, described in Tables 3a and 4a, and for wheat, described in Tables 3d and 4d, again have mixed effects of weather elsewhere on output and farm-gate prices. In both the cotton and wheat markets, a rise in temperature lowered output at a diminishing rate while raising prices at diminishing rate. On the other hand, demand shifts seemed to have been more dominant with respect to changes in precipitation elsewhere. In the cotton market increases in precipitation raised output at a diminishing rate in general but increases in precipitation elsewhere also raised the state farm-gate price at a diminishing rate. In the wheat market increases in precipitation lowered output at a diminishing rate while increases in precipitation elsewhere also raised the state price.

6.2 Cotton Prices and Weather -- Tables 3a and 4a and Figures 3a-3d

Cotton output was sensitive to fluctuations in temperature, extreme or severe wetness and changes in weather variability, as shown by the coefficients of the temperature and extreme or severe wetness variables in Table 4a. Despite this sensitivity of output, state cotton prices barely responded to local weather changes. Increases in local weather variability tended to slightly decrease the state farm-gate price of cotton, but state prices were most sensitive to changes in precipitation and drought conditions in other producing states.

Figures 3a and 3b plot price response functions that show the percentage change in the state price associated with an increase of one degree Fahrenheit in local state temperature (3a) and in temperature elsewhere (3b). Figure 3c shows the percentage change in the state farm-gate price in response to an increase of one inch of rainfall in that state's precipitation. Figure 3d shows the percentage change in the state farm-gate price in response to an additional inch of average precipitation experienced by producers in the rest of the U.S. These estimates are derived from the coefficients in column 5 of Table 3a. We plot the relationships because the inclusion of both linear and squared terms for temperature in the log price equations causes the relationship between temperature and the price to change as the temperature rises. The same linear and squared terms are used in the precipitation measures.

In general, the results suggest that state cotton prices were not very sensitive to fluctuations in local weather. None of the local temperature or precipitation coefficients in Table 3a are statistically significant, and the price response functions are much flatter and closer to zero percent change than for any other crop. As seen in Figure 3a, the percentage change in cotton prices associated with an increase in local state temperature decreases slightly as temperature increases. Until about 60° F, a 1 degree rise in annual average temperature is associated with very little change in price. As the temperature approaches the mid-70s, a one degree rise in local temperature is associated with roughly a one percent drop in state cotton prices. The other price response functions for cotton in figures 3b through 3d are flatter and even closer to zero than for local temperatures. The only statistically significant relationships between weather and prices is for precipitation in areas outside the state, but the plotted relationship in Figure 3d shows very weak responsiveness even at the upper ranges of precipitation. The cotton price responses to precipitation and temperature changes are much weaker than those for corn and hay described below.

6.3 Corn Prices and Weather – Tables 3b and 4b and Figures 4a-4d

Corn output at the state level responded to increases in temperature and precipitation in roughly the same way. The coefficients in Table 4b show that increases in average annual temperature led to increases in corn production at a diminishing rate, as did increases in precipitation. The local increases in corn output are associated with increases in temperature and precipitation, which themselves are also associated with reductions in local corn prices as shown in Table 3b. Similarly, increases in temperature and precipitation that likely would have increased output in other states, also contributed to lower corn prices in the state of interest. Our findings for the era before the powerful influences of the federal farm programs are similar in that regard to Mundlak and Larson’s (1992) findings that international markets played an important role in determining local prices.

Comparisons of Figures 4a and 3a show that state farm-gate corn prices were far more responsive to local temperatures than were cotton prices. Once the average annual temperature exceeded 40 degrees, corn prices started rising in response to increases in temperature and the responsiveness rose significantly from there. Similarly, the state corn price response function for temperature changes occurring in the rest of the country (Figure 4b) had a much stronger positive slope than state cotton price response in Figure 3b. However, comparisons of Figures 3c with 4c and 3d with 4d show that state precipitation and precipitation elsewhere had much stronger impacts at higher levels of precipitation on corn prices than on cotton prices.

6.4 Hay Prices and Weather – Tables 3c and 4c and Figures 5a-5d

Hay, like corn, was sensitive to many of the different weather variables, both local and non-local. Local weather variables that had statistically significant coefficients included the temperature and precipitation variables, as well as the variables that proxy for extreme or severe drought and wetness conditions. The price response function to local temperature was negatively sloped for hay in Figure 5a. After about 54 degrees Fahrenheit, as state-level temperatures rose, prices fell. At levels below that, a 1 percent rise in average yearly temperature was associated with up to a 1 percent rise in the farm-gate price. In contrast, the relationship between hay prices and local precipitation in Figure 5c had a mild U shape. Local monthly precipitation had little impact on state hay prices until it reached the upper end of the range. When precipitation approached seven inches per month, an additional inch rise in precipitation led to more than a one percent rise in that state’s hay price. This is nearly double the effect seen for corn in Figure 4c.

The price response function in Figure 5b for temperatures in the rest of the country shows that a one unit increase in temperature elsewhere contributed to about a one percent decrease in the state farm-gate price at every temperature level. However, none of the temperature coefficients were statistically significant, so there may have been no effect. The precipitation coefficients were statistically significant, and the path of the price response to precipitation outside the state in Figure 5d is nearly a direct contrast to the response path to local precipitation in Figure 5c. The response function for out-of-state precipitation is hump-shaped, and as the precipitation approaches an average of 7 inches per month elsewhere, a one unit increase leads to 2 percent reduction in hay prices in the state. This response is nearly twice as large in a negative direction in comparison to the positive response to increased local precipitation. In general, the state hay price responses to higher levels of precipitation either locally or elsewhere are much larger in magnitude than for any other crop.

6.5 Wheat Prices and Weather – Tables 3d and 4d and Figures 6a-6d

Wheat is sold in an international market, and as might be expected, the responses of a state's prices to local weather shocks were muted for both local temperature and precipitation. The response functions for both types of weather in figures 6a and 6c are much flatter and closer to the origin throughout the range than for hay in figures 5a and 5c and corn in figures 4a and 4c. They more closely resemble the responses seen for cotton, the other strongly international crop, in figures 3a and 3c. The slight sensitivity to local weather fluctuations is likely due to wheat being grown in many of the different states, even though it is primarily concentrated in the Dakotas and Kansas. If a local weather shock did not affect the local price too much, it would still make sense to purchase locally grown wheat at a slightly higher price. However, if local supply was hit hard, then it would not be too difficult to import from the outside market.

Wheat prices were very sensitive to temperatures in other parts of the country. The wheat price response function to temperatures elsewhere in Figure 6b looks very similar to the corn price response function in Figure 4b. A one degree rise in average temperature elsewhere as temperatures elsewhere were near 33 degrees, led to a reduction in state corn prices of nearly 2 percent. At higher temperatures, there was a much stronger response in the other direction. A rise in temperature elsewhere by one degree as temperatures elsewhere neared the high end around 70 degrees, led to an increase of state corn prices of nearly 5 percent.

The effects of precipitation elsewhere on wheat prices were also statistically significant, as seen in Table 6d. The response function to precipitation elsewhere looks similar to the one for hay, but the negative effect of more precipitation elsewhere at high levels of precipitation is about half the size of the one for hay.

7 Concluding Remarks

The study of the impact of weather on crop prices in unfettered markets has become increasingly important for two reasons. First, one of the major worries associated with climate change relates to increased fluctuations in weather, which, in turn, will influence food supplies and food prices. Weather shocks that lead to reductions in output and rising food prices can have major negative effects on health as people shift their consumption to lower-priced foods, often with less nutritional quality.[12] Second, in the World Trade Organization negotiations, lesser

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[12] See Komlos 1987; Haines, Craig, and Weiss 2003; and Steckel 1992. As another example, Galloway (1985) used annual data for London from 1670 to 1830 to show how bad weather and poor harvests conspired to raise both agricultural prices and mortality.

developed countries have been pressuring the developed nations to change their farm policies to stop interfering with markets and to stop propping up farms in the developed countries. In evaluating these changes, therefore, it is important to examine the way that unfettered crop markets work. Studies of the U.S. since the 1930s cannot illuminate much about the operation of unfettered markets because of the extensive farm programs in place; therefore, we need to look at the preceding period.

We estimated the responsiveness of crop prices to both localized weather shocks, as well as weighted measures of the weather shocks experienced by other producers of each crop. Four crops, cotton, corn, hay and wheat, were chosen for study not only because they were fundamental to the U.S. economy, but also because their inherent characteristics differed in an important way. Both cotton and wheat have relatively high value-to-weight ratios, and between 1895 and 1932, were sold in a true international market. For these crops, localized weather shocks might have affected the size of the harvest within a state, but the effects on state commodity prices should have been limited. Over the 37-year period studied, that is what we find.

Corn and hay represent the flip side of that coin. Corn and hay have lower value-to-weight ratios than wheat and cotton, and thus higher transport costs. While cotton and wheat were not generally consumed locally, most of the value from corn and hay came from local uses and local agronomic activity. For corn and hay, localized weather shocks would have been expected to influence the prices in a state. Indeed, the results of the analysis show that hay and corn prices were substantially more responsive to local weather shocks than were cotton and wheat prices.

We identified the differential weather effects using the year-to-year variation in weather and commodity prices after controlling for time-invariant features of each state and controlling for national shocks such as warfare that would have influenced the markets. As a result, the analysis avoids much of the unobserved variable bias that seems to plague cross-sectional models. Furthermore, we focused on the period between 1895 and 1932 because there were not only substantial fluctuations in weather that influenced the yields of different commodities, but also because there was much less government interference in markets to protect farmers from falling prices. Despite the absence of price supports, state level cotton and wheat prices were not affected much by the weather shocks within the state.

The nationwide weather shocks and decline in prices that followed World War I helped usher in support for the federal farm programs of the New Deal. Several of these programs, such as the 1938 Federal Crop Insurance Act, were intended to address the income and production variability that the weather shocks induced. Others such as the Soil Conservation Act sought to remedy the environmental damage associated with the Dust Bowl. These federal farm programs persisted and expanded over the next 80 years and strongly influenced the ways that farm prices at the farm-gate responded to weather shocks within states and across the nation. Our next move is to investigate how the relationships between weather and prices changed as a result of these farm policies. Many of the policies were designed to diminish the downward volatility in farm gate prices and control the sale of the crop within the state and in outside markets. Such controls potentially reduced income volatility for farmers, although given the fluctuations in prices in response to local shocks for some crops in the unfettered markets, perhaps not as much as might have been thought. On the other hand, the programs may well have led to higher crop prices in the long run, with the consequent impact on health, within the United States. Understanding these tradeoffs will contribute to improvements in the quality of the policies chosen in the future.

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Map 1 - Crop Shares

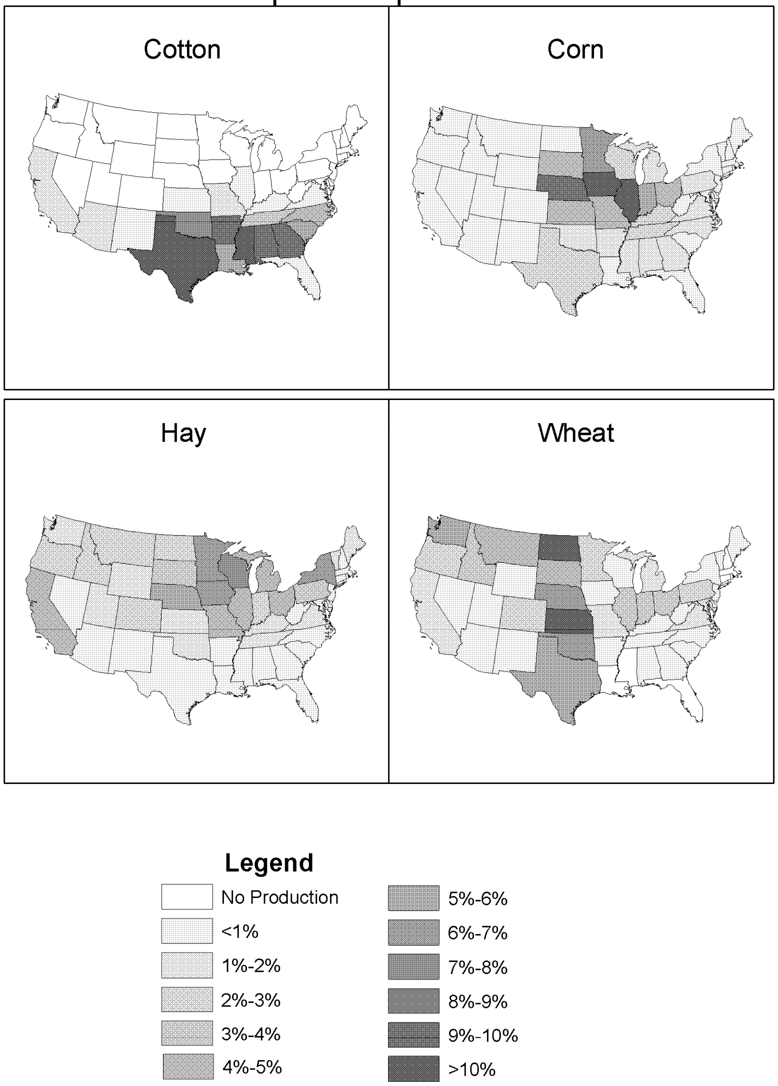


Figure 1: High transport costs and weak local market, adverse supply shock

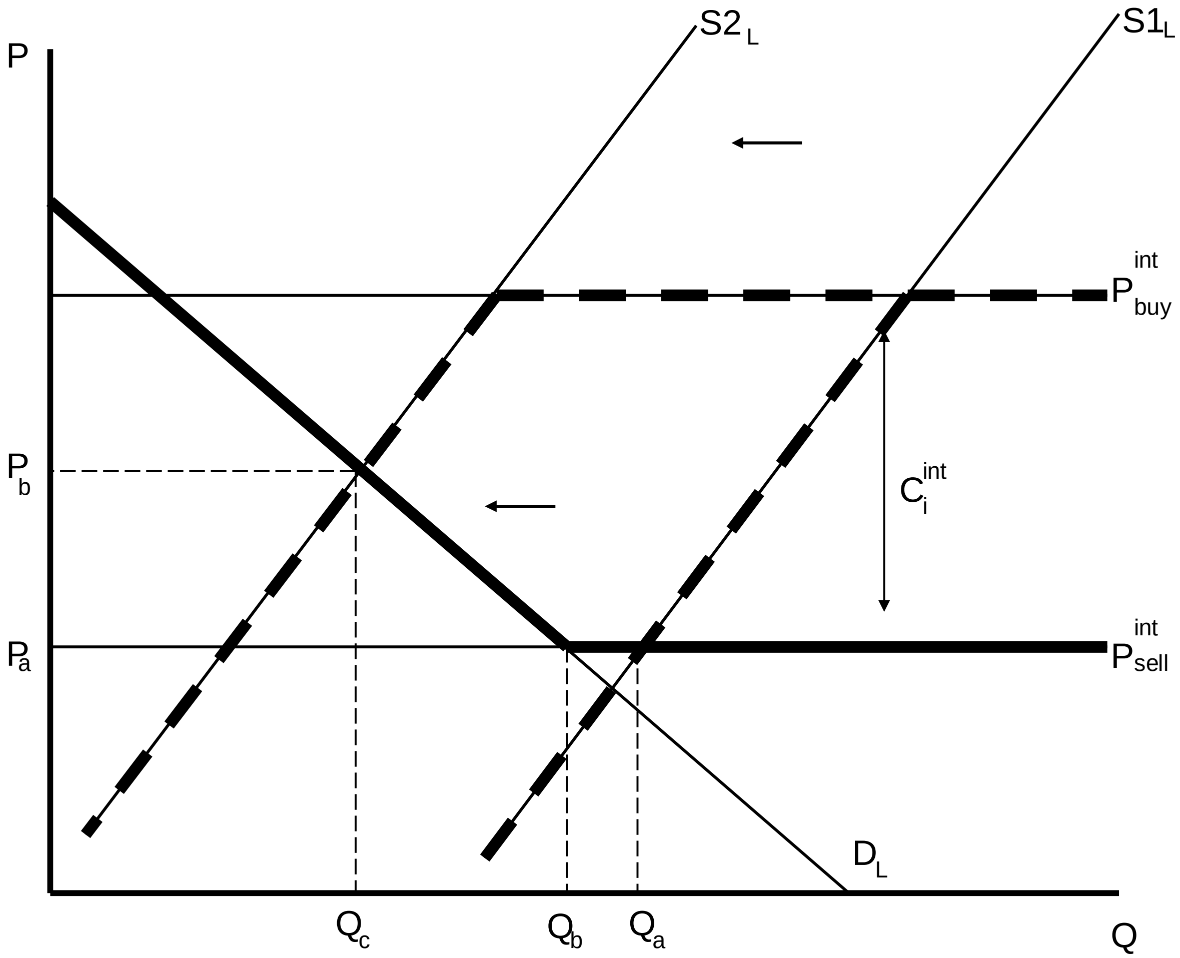
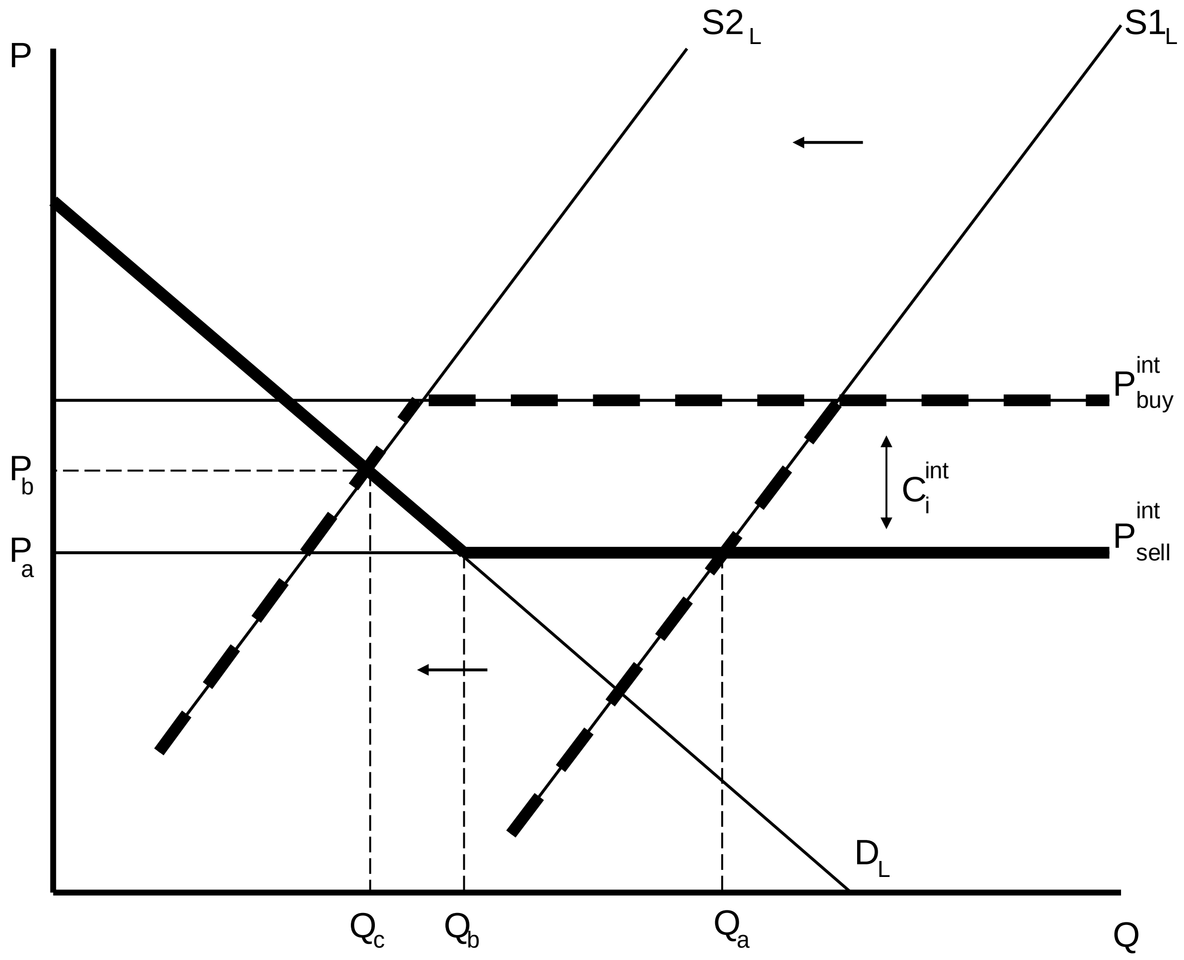


Figure 2: Low transport costs and strong local market, adverse supply shock



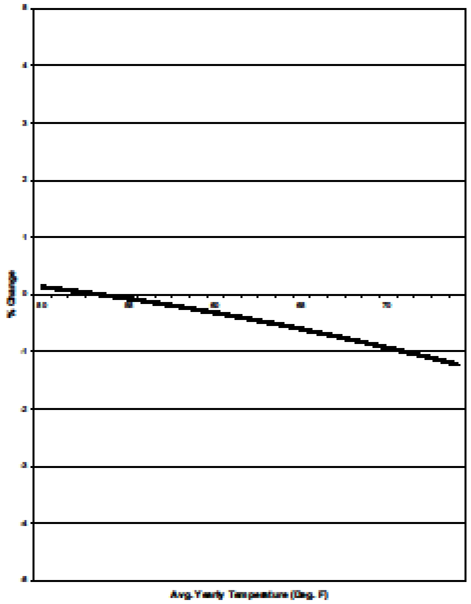


Figure 3a
Percent Change in Cotton Price
From Percent Change in Local Avg. Temperature

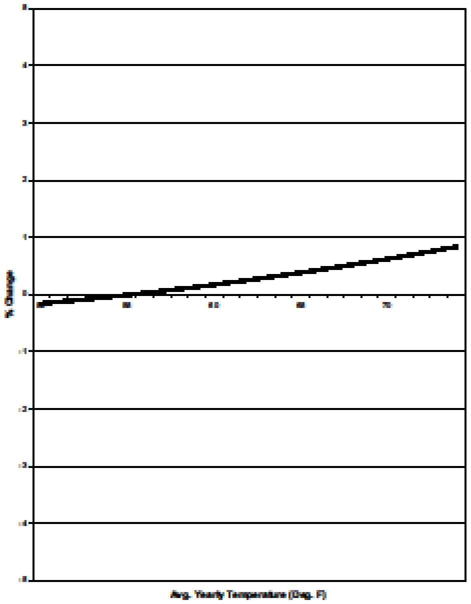


Figure 3b
Percent Change in Cotton Price
From Percent Change in OP Avg. Temperature

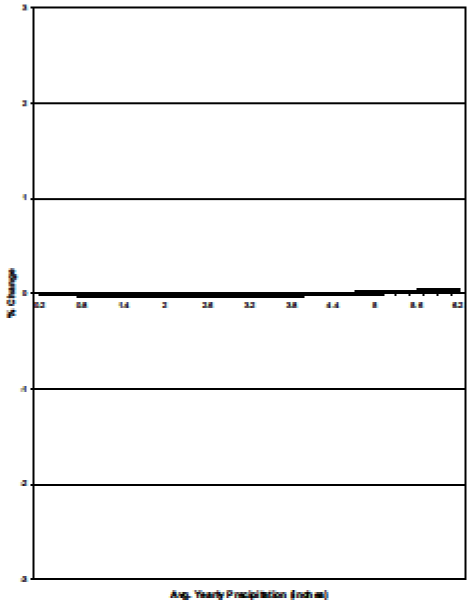


Figure 3c
Percent Change in Cotton Price
From Percent Change in Local Avg. Precipitation

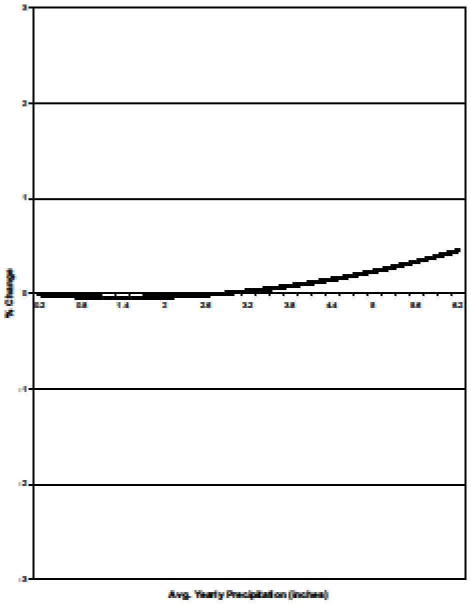


Figure 3d
Percent Change in Cotton Price
From Percent Change in OP Avg. Precipitation

Figure 4a
Percent Change in Corn Price
From Percent Change in Local Avg. Temperature

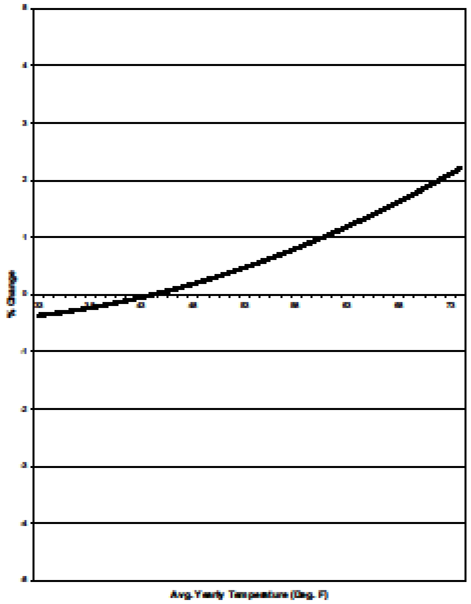


Figure 4b
Percent Change in Corn Price
From Percent Change in OP Avg. Temperature

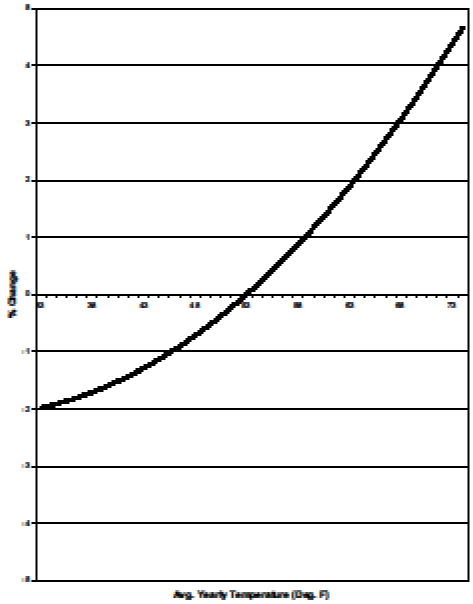


Figure 4c
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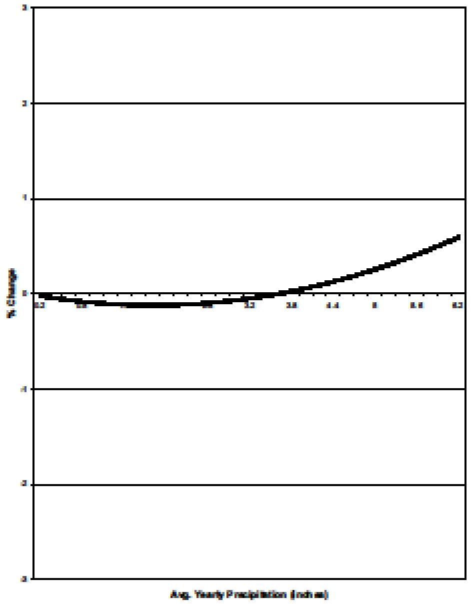
From Percent Change in Local Avg. Precipitation



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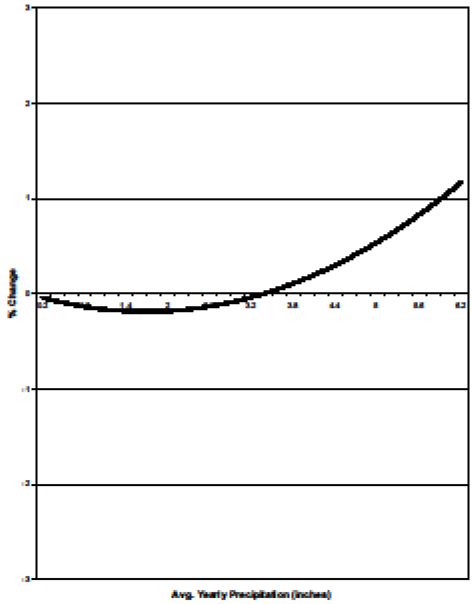


Figure 5a
Percent Change in Hay Price
From Percent Change in Local Avg. Temperature

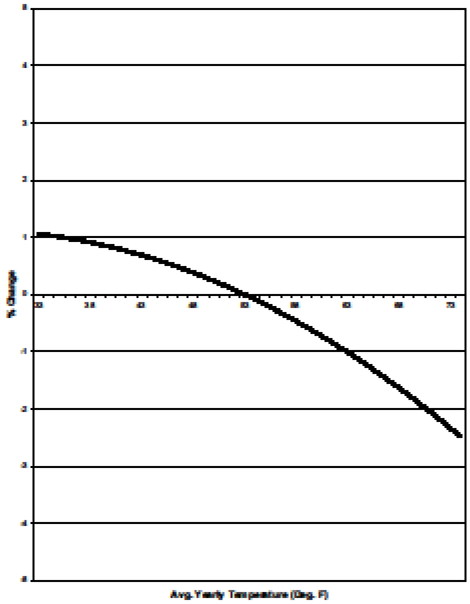
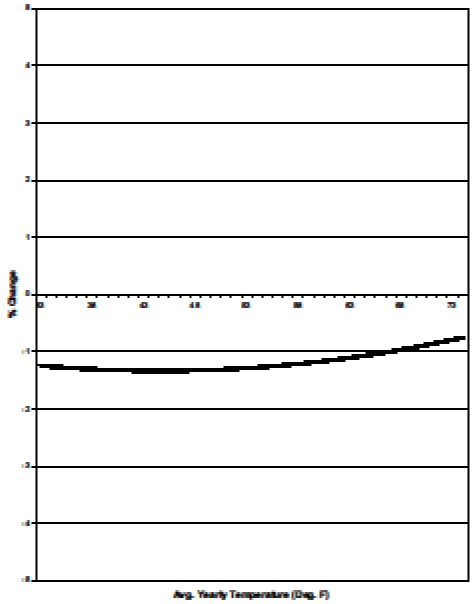


Figure 5b
Percent Change in Hay Price
From Percent Change in OP Avg. Temperature



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Percent Change in Hay Price
From Percent Change in Local Avg. Precipitation

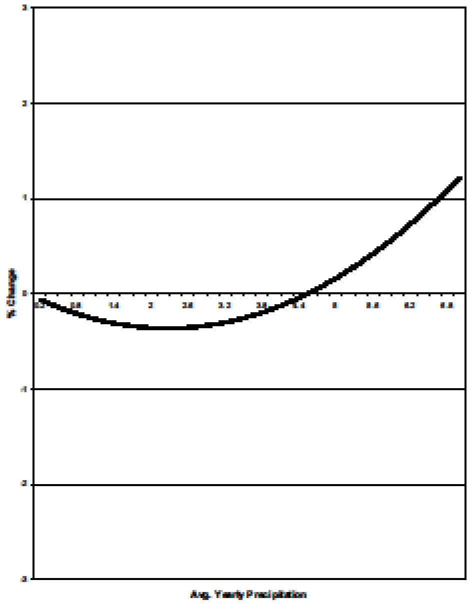


Figure 5d
Percent Change in Hay Price
From Percent Change in OP Avg. Precipitation

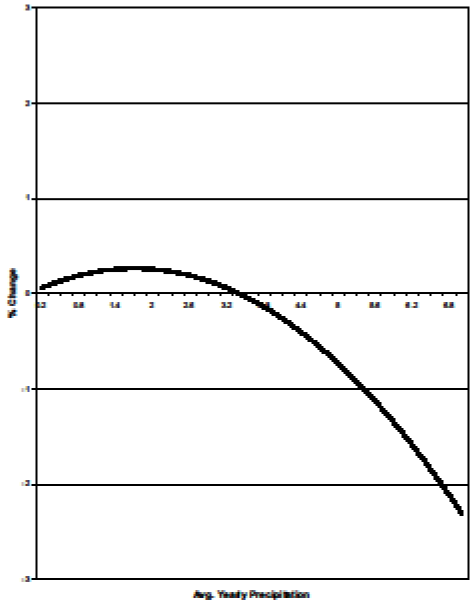


Figure 6a
Percent Change in Wheat Price
From Percent Change in Local Avg. Temperature

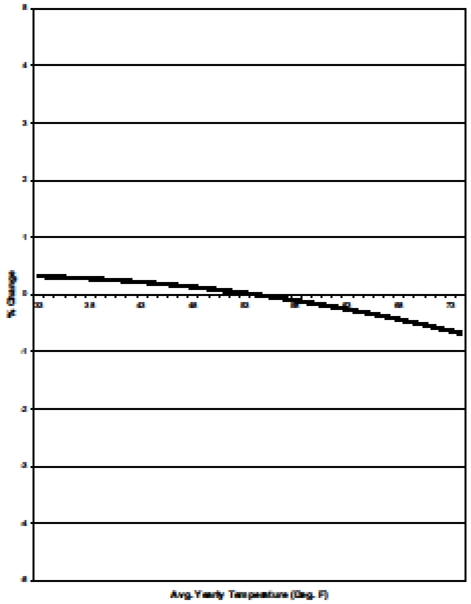


Figure 6b
Percent Change in Wheat Price
From Percent Change in OP Avg. Temperature

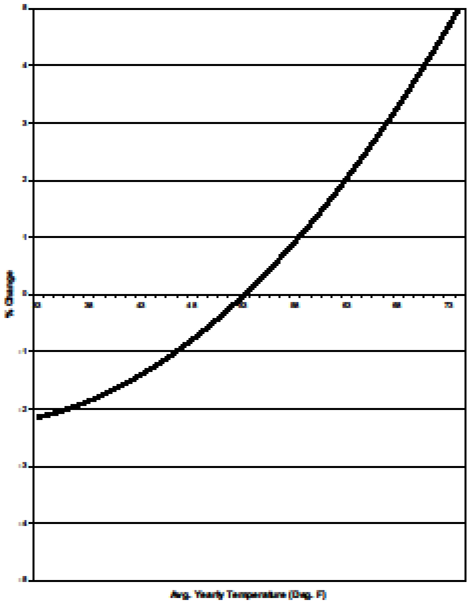


Figure 6c
Percent Change in Wheat Price
From Percent Change in Local Avg. Precipitation

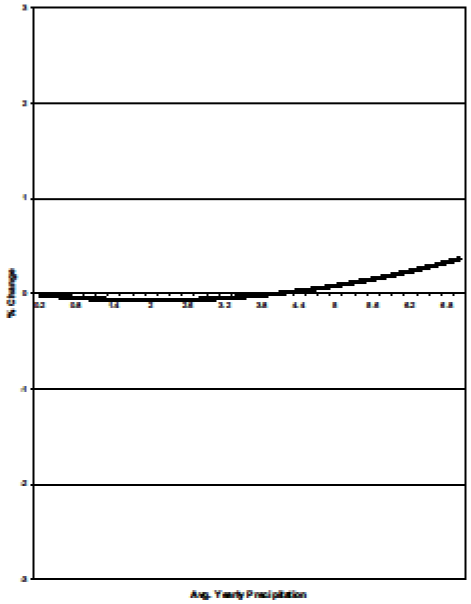
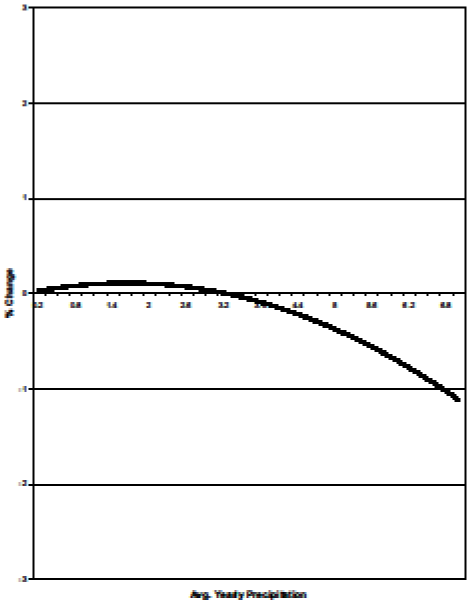


Figure 6d
Percent Change in Wheat Price
From Percent Change in OP Avg. Precipitation



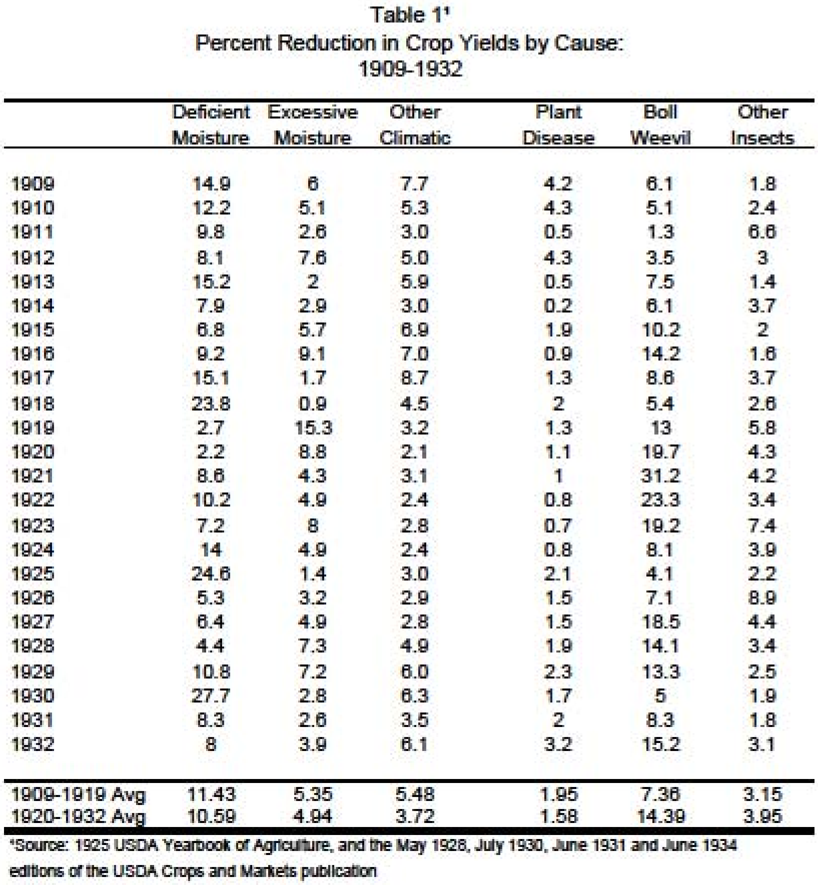


Table 1[1]
Percent Reduction in Crop Yields by Cause:
1909-1932

	Deficient Moisture	Excessive Moisture	Other Climatic	Plant Disease	Boll Weevil	Other Insects
1909	14.9	6	7.7	4.2	6.1	1.8
1910	12.2	5.1	5.3	4.3	5.1	2.4
1911	9.8	2.6	3.0	0.5	1.3	6.6
1912	8.1	7.6	5.0	4.3	3.5	3
1913	15.2	2	5.9	0.5	7.5	1.4
1914	7.9	2.9	3.0	0.2	6.1	3.7
1915	6.8	5.7	6.9	1.9	10.2	2
1916	9.2	9.1	7.0	0.9	14.2	1.6
1917	15.1	1.7	8.7	1.3	8.6	3.7
1918	23.8	0.9	4.5	2	5.4	2.6
1919	2.7	15.3	3.2	1.3	13	5.8
1920	2.2	8.8	2.1	1.1	19.7	4.3
1921	8.6	4.3	3.1	1	31.2	4.2
1922	10.2	4.9	2.4	0.8	23.3	3.4
1923	7.2	8	2.8	0.7	19.2	7.4
1924	14	4.9	2.4	0.8	8.1	3.9
1925	24.6	1.4	3.0	2.1	4.1	2.2
1926	5.3	3.2	2.9	1.5	7.1	8.9
1927	6.4	4.9	2.8	1.5	18.5	4.4
1928	4.4	7.3	4.9	1.9	14.1	3.4
1929	10.8	7.2	6.0	2.3	13.3	2.5
1930	27.7	2.8	6.3	1.7	5	1.9
1931	8.3	2.6	3.5	2	8.3	1.8
1932	8	3.9	6.1	3.2	15.2	3.1
1909-1919 Avg	11.43	5.35	5.48	1.95	7.36	3.15
1920-1932 Avg	10.59	4.94	3.72	1.58	14.39	3.95

[1] Source: 1925 USDA Yearbook of Agriculture, and the May 1928, July 1930, June 1931 and June 1934 editions of the USDA Crops and Markets publication

Table 2a

Statistics for Farm Commodities, 1895-1932

Crop prices per pound, 1982-84 dollars	Mean	Std. Dev.	Min	Max
Cotton	113.50	44.90	31.71	356.71
Corn	9.08	3.49	2.08	26.30
Hay	5.31	2.25	0.68	13.25
Wheat	15.16	5.15	3.61	39.00
Crop Output (for producing states)	**Mean**	**Std. Dev.**	**Min**	**Max**
Cotton (bushels)	396,235.10	453,382.70	144	2,697,848
Corn (bushels)	55,160.22	86,691.08	21	509,507
Hay (tons)	1,763.120	1,631.243	40	7,303.5
Wheat (bushels)	17,750.530	25,269.70	13	251,885

Table 2b
Summary Statistics for Climate Variables, 1895-1932

Climate Variables	Mean	Std. Dev.	Min	Max
Cotton states				
Average yearly temperature	61.198	5.004	50.564	73.324
Average yearly precipitation	3.644	1.054	0.648	6.193
Months of extreme or severe drought	0.750	1.640	0	9.857
Months of extreme or severe wet	0.926	1.914	0	11.750
Moisture index std. dev.	1.680	0.407	0.754	4.021
Corn states				
Average yearly temperature	51.813	8.029	35.495	73.324
Average yearly precipitation	2.927	1.131	0.366	6.193
Months of extreme or severe drought	1.196	2.335	0	12
Months of extreme or severe wet	0.996	2.022	0	12
Moisture index std. dev.	1.672	0.426	0.643	4.021
Hay States				
Average yearly temperature	51.907	8.073	35.495	73.324
Average yearly precipitation	2.886	1.149	0.366	5.930
Months of extreme or severe drought	1.154	2.300	0	12
Months of extreme or severe wet	1.059	2.109	0	12
Moisture index std. dev.	1.659	0.409	0.643	4.021
Wheat States				
Average yearly temperature	51.474	7.374	35.495	69.046
Average yearly precipitation	2.778	1.145	0.366	5.889
Months of extreme or severe drought	1.299	2.430	0	12
Months of extreme or severe wet	1.001	2.036	0	12
Moisture index std. dev.	1.671	0.422	0.643	4.021

Table 3a

Dependent variable: ln(price of cotton in $1982)

Local Weather	(1)	(2)	(3)	(4)	(5)
Avg.Temperature	0.0185	0.0183	0.0491	0.0493	0.0427
	(0.0510)	(0.0508)	(0.0640)	(0.0645)	(0.0633)
Avg. Temperature Sq.	-0.0002	-0.0002	-0.0004	-0.0004	-0.0004
	(0.0004)	(0.0004)	(0.0005)	(0.0005)	(0.0005)
Avg. Precipitation	-0.0142	-0.0246	-0.0319	-0.0399	-0.0197
	(0.0229)	(0.0240)	(0.0235)	(0.0253)	(0.0277)
Avg. Precipitation Sq	0.0016	0.0020	0.0037	0.0039	0.0021
	(0.0029)	(0.0028)	(0.0029)	(0.0030)	(0.0032)
Months of XS wetness		0.0035		0.0038	0.0047
		(0.0032)		(0.0033)	(0.0033)
Months of XS drought		-0.0015		-0.0006	-0.0001
		(0.0024)		(0.0023)	(0.0022)
Palmer Z Index Std. Dev.					-0.0182
					(0.0109)*
Other Producer's Weather					
Avg.Temperature			-0.0186	-0.0321	-0.0331
			(0.0214)	(0.0211)	(0.0213)
Avg. Temperature Sq.			0.0002	0.0003	0.0003
			(0.0002)	(0.0002)	(0.0002)
Avg. Precipitation			-0.0854	-0.0665	-0.0614
			(0.0277)***	(0.0270)**	(0.0296)**
Avg. Precipitation Sq			0.0130	0.0116	0.0108
			(0.0040)***	(0.0039)***	(0.0042)**
Months of XS wetness				-0.0011	-0.0007
				(0.0021)	(0.0022)
Months of XS drought				0.0040	0.0043
				(0.0019)**	(0.0019)**
Palmer Z Index Std. Dev.					-0.0038
					(0.0085)
Constant	4.1852	4.1704	5.3998	6.9183	7.1733
	(1.5478)***	(1.5423)***	(2.6576)**	(2.6464)***	(2.6305)***
Observations	559	559	559	559	559
Adjusted R-squared	0.97	0.97	0.97	0.97	0.97

Robust standard errors in parentheses

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

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

Local Weather	(1)	(2)	(3)	(4)	(5)
Avg.Temperature	-0.0411	-0.0421	-0.0435	-0.0437	-0.0441
	(0.0178)**	(0.0182)**	(0.0180)**	(0.0182)**	(0.0182)**
Avg. Temperature Sq.	0.0005	0.0005	0.0005	0.0005	0.0005
	(0.0002)***	(0.0002)***	(0.0002)***	(0.0002)***	(0.0002)***
Avg. Precipitation	-0.1306	-0.1166	-0.1277	-0.1166	-0.1349
	(0.0311)***	(0.0336)***	(0.0312)***	(0.0334)***	(0.0351)***
Avg. Precipitation Sq	0.0180	0.0168	0.0179	0.0170	0.0186
	(0.0041)***	(0.0043)***	(0.0041)***	(0.0042)***	(0.0043)***
Months of XS wetness		-0.0019		-0.0017	-0.0022
		(0.0021)		(0.0020)	(0.0020)
Months of XS drought		0.0015		0.0018	0.0012
		(0.0018)		(0.0018)	(0.0018)
Palmer Z Index Std. Dev.					0.0164
					(1.82)*
Other Producer's Weather					
Avg.Temperature			-0.1357	-0.1545	-0.1589
			(0.0376)***	(0.0346)***	(0.0341)***
Avg. Temperature Sq.			0.0013	0.0015	0.0015
			(0.0004)***	(0.0003)***	(0.0003)***
Avg. Precipitation			-0.1154	-0.2021	-0.2240
			(0.0609)*	(0.0697)***	(0.0662)***
Avg. Precipitation Sq			0.0186	0.0303	0.0332
			(0.0091)**	(0.0101)***	(0.0095)***
Months of XS wetness				0.0177	0.0159
				(0.0050)***	(0.0054)***
Months of XS drought				0.0101	0.0088
				(0.0036)***	(0.0037)**
Palmer Z Index Std. Dev.					0.0164
					(0.0090)*
Constant	7.0815	7.1046	9.6347	10.0489	10.1610
	(0.4743)***	(0.4804)***	(0.8512)***	(0.8175)***	(0.8062)***
Observations	1796	1796	1796	1796	1796
Adjusted R-squared	0.9	0.9	0.91	0.91	0.91

Robust standard errors in parentheses
* significant at 10%; ** significant at 5%; *** significant at 1%

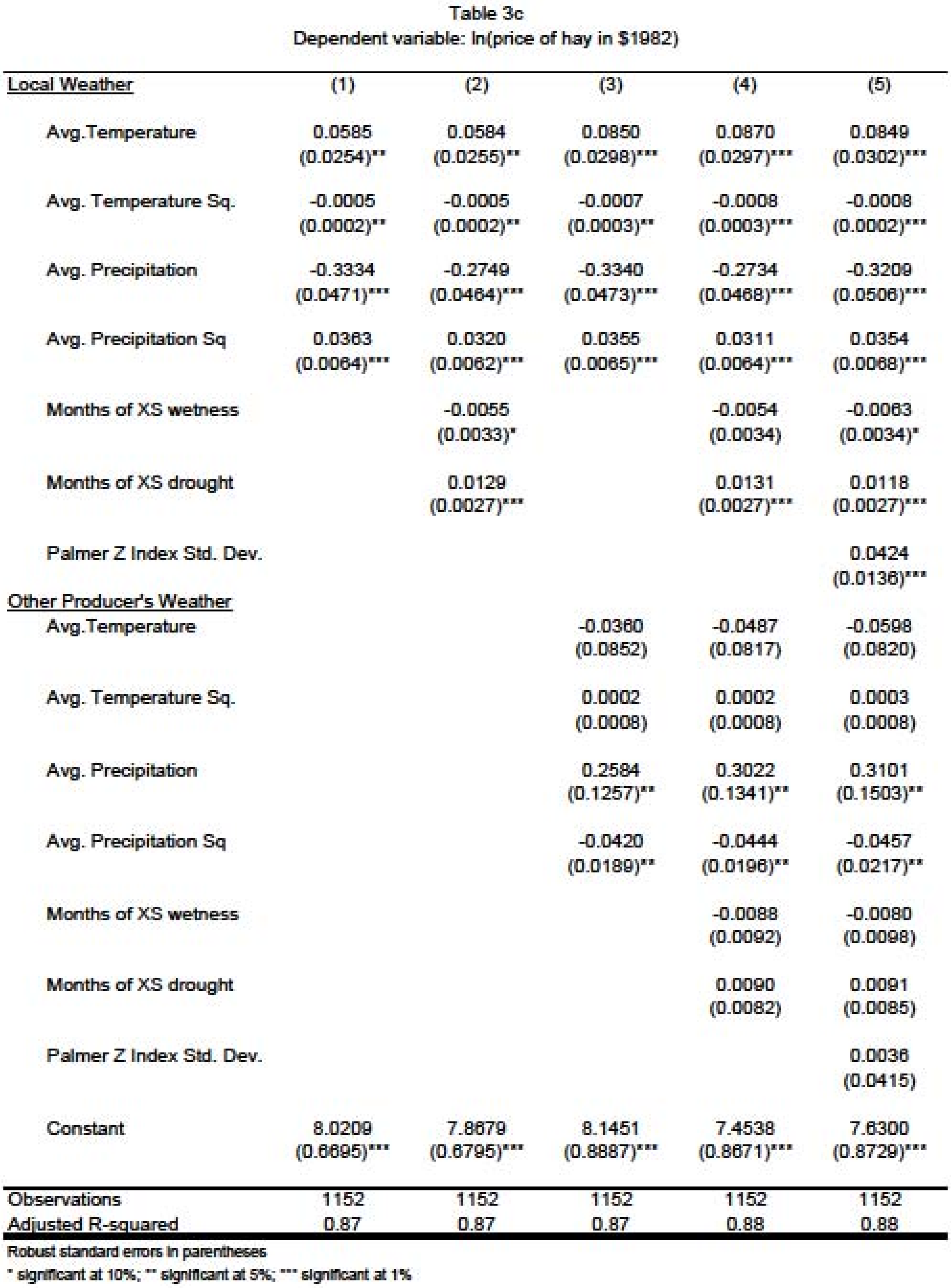


Table 3c
Dependent variable: ln(price of hay in $1982)

Local Weather	(1)	(2)	(3)	(4)	(5)
Avg.Temperature	0.0585	0.0584	0.0850	0.0870	0.0849
	(0.0254)**	(0.0255)**	(0.0298)***	(0.0297)***	(0.0302)***
Avg. Temperature Sq.	-0.0005	-0.0005	-0.0007	-0.0008	-0.0008
	(0.0002)**	(0.0002)**	(0.0003)**	(0.0003)***	(0.0002)***
Avg. Precipitation	-0.3334	-0.2749	-0.3340	-0.2734	-0.3209
	(0.0471)***	(0.0464)***	(0.0473)***	(0.0468)***	(0.0506)***
Avg. Precipitation Sq	0.0363	0.0320	0.0355	0.0311	0.0354
	(0.0064)***	(0.0062)***	(0.0065)***	(0.0064)***	(0.0068)***
Months of XS wetness		-0.0055		-0.0054	-0.0063
		(0.0033)*		(0.0034)	(0.0034)*
Months of XS drought		0.0129		0.0131	0.0118
		(0.0027)***		(0.0027)***	(0.0027)***
Palmer Z Index Std. Dev.					0.0424
					(0.0136)***
Other Producer's Weather					
Avg.Temperature			-0.0360	-0.0487	-0.0598
			(0.0852)	(0.0817)	(0.0820)
Avg. Temperature Sq.			0.0002	0.0002	0.0003
			(0.0008)	(0.0008)	(0.0008)
Avg. Precipitation			0.2584	0.3022	0.3101
			(0.1257)**	(0.1341)**	(0.1503)**
Avg. Precipitation Sq			-0.0420	-0.0444	-0.0457
			(0.0189)**	(0.0196)**	(0.0217)**
Months of XS wetness				-0.0088	-0.0080
				(0.0092)	(0.0098)
Months of XS drought				0.0090	0.0091
				(0.0082)	(0.0085)
Palmer Z Index Std. Dev.					0.0036
					(0.0415)
Constant	8.0209	7.8679	8.1451	7.4538	7.6300
	(0.6695)***	(0.6795)***	(0.8887)***	(0.8671)***	(0.8729)***
Observations	1152	1152	1152	1152	1152
Adjusted R-squared	0.87	0.87	0.87	0.88	0.88

Robust standard errors in parentheses
* significant at 10%; ** significant at 5%; *** significant at 1%

Table 3d
Dependent variable: ln(price of wheat in $1982)

Local Weather	(1)	(2)	(3)	(4)	(5)
Avg.Temperature	0.0158	0.0185	0.0216	0.0232	0.0248
	(0.0144)	(0.0147)	(0.0138)	(0.0143)	(0.0142)*
Avg. Temperature Sq.	-0.0001	-0.0002	-0.0002	-0.0002	-0.0002
	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
Avg. Precipitation	-0.1012	-0.0852	-0.0870	-0.0704	-0.0718
	(0.0249)***	(0.0253)***	(0.0248)***	(0.0249)***	(0.0253)***
Avg. Precipitation Sq	0.0124	0.0109	0.0103	0.0088	0.0088
	(0.0034)***	(0.0034)***	(0.0034)***	(0.0033)***	(0.0033)***
Months of XS wetness		0.0001		-0.0009	-0.0012
		(0.0015)		(0.0015)	(0.0015)
Months of XS drought		0.0041		0.0030	0.0028
		(0.0016)**		(0.0015)**	(0.0015)*
Palmer Z Index Std. Dev.					0.0028
					(0.0066)
Other Producer's Weather					
Avg.Temperature			-0.1745	-0.1646	-0.1721
			(0.0245)***	(0.0252)***	(0.0255)***
Avg. Temperature Sq.			0.0016	0.0016	0.0016
			(0.0002)***	(0.0002)***	(0.0002)***
Avg. Precipitation			0.1655	0.1761	0.1364
			(0.0403)***	(0.0470)***	(0.0497)***
Avg. Precipitation Sq			-0.0242	-0.0262	-0.0211
			(0.0058)***	(0.0063)***	(0.0068)***
Months of XS wetness				-0.0039	-0.0066
				(0.0034)	(0.0037)*
Months of XS drought				-0.0041	-0.0062
				(0.0025)	(0.0028)**
Palmer Z Index Std. Dev.					0.0448
					(4.12)***
Constant	6.6023	6.5575	6.3888	6.3510	6.2901
	(0.3803)***	(0.3848)***	(0.3637)***	(0.3729)***	(0.3733)***
Observations	1597	1597	1597	1597	1597
Adjusted R-squared	0.94	0.94	0.95	0.95	0.95

Robust standard errors in parentheses
* significant at 10%; ** significant at 5%; *** significant at 1%

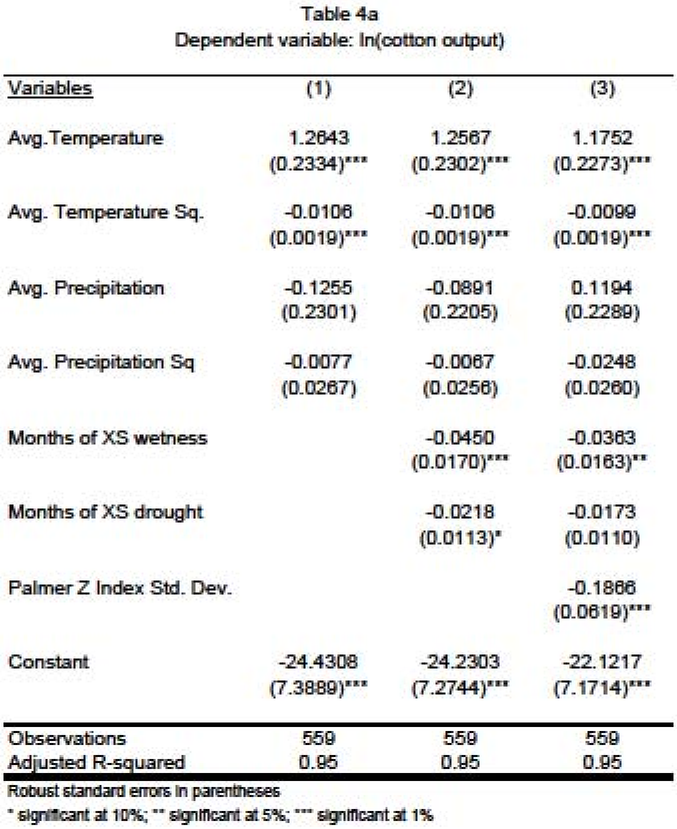


Table 4a
Dependent variable: ln(cotton output)

Variables	(1)	(2)	(3)
Avg.Temperature	1.2643 (0.2334)***	1.2567 (0.2302)***	1.1752 (0.2273)***
Avg. Temperature Sq.	-0.0106 (0.0019)***	-0.0106 (0.0019)***	-0.0099 (0.0019)***
Avg. Precipitation	-0.1255 (0.2301)	-0.0891 (0.2205)	0.1194 (0.2289)
Avg. Precipitation Sq	-0.0077 (0.0267)	-0.0067 (0.0256)	-0.0248 (0.0260)
Months of XS wetness		-0.0450 (0.0170)***	-0.0363 (0.0163)**
Months of XS drought		-0.0218 (0.0113)*	-0.0173 (0.0110)
Palmer Z Index Std. Dev.			-0.1866 (0.0619)***
Constant	-24.4308 (7.3889)***	-24.2303 (7.2744)***	-22.1217 (7.1714)***
Observations	559	559	559
Adjusted R-squared	0.95	0.95	0.95

Robust standard errors in parentheses
* significant at 10%; ** significant at 5%; *** significant at 1%

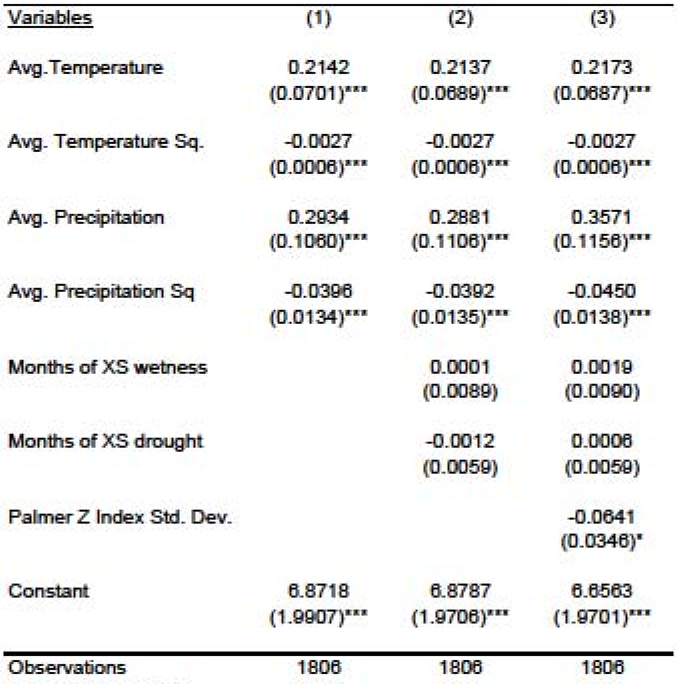


Table 4b

Dependent variable: ln(corn output)

Variables	(1)	(2)	(3)
Avg.Temperature	0.2142	0.2137	0.2173
	(0.0701)***	(0.0689)***	(0.0687)***
Avg. Temperature Sq.	-0.0027	-0.0027	-0.0027
	(0.0006)***	(0.0006)***	(0.0006)***
Avg. Precipitation	0.2934	0.2881	0.3571
	(0.1060)***	(0.1106)***	(0.1156)***
Avg. Precipitation Sq	-0.0396	-0.0392	-0.0450
	(0.0134)***	(0.0135)***	(0.0138)***
Months of XS wetness		0.0001	0.0019
		(0.0089)	(0.0090)
Months of XS drought		-0.0012	0.0006
		(0.0059)	(0.0059)
Palmer Z Index Std. Dev.			-0.0641
			(0.0346)*
Constant	6.8718	6.8787	6.6563
	(1.9907)***	(1.9706)***	(1.9701)***
Observations	1806	1806	1806
Adjusted R-squared	0.96	0.96	0.96

Robust standard errors in parentheses

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

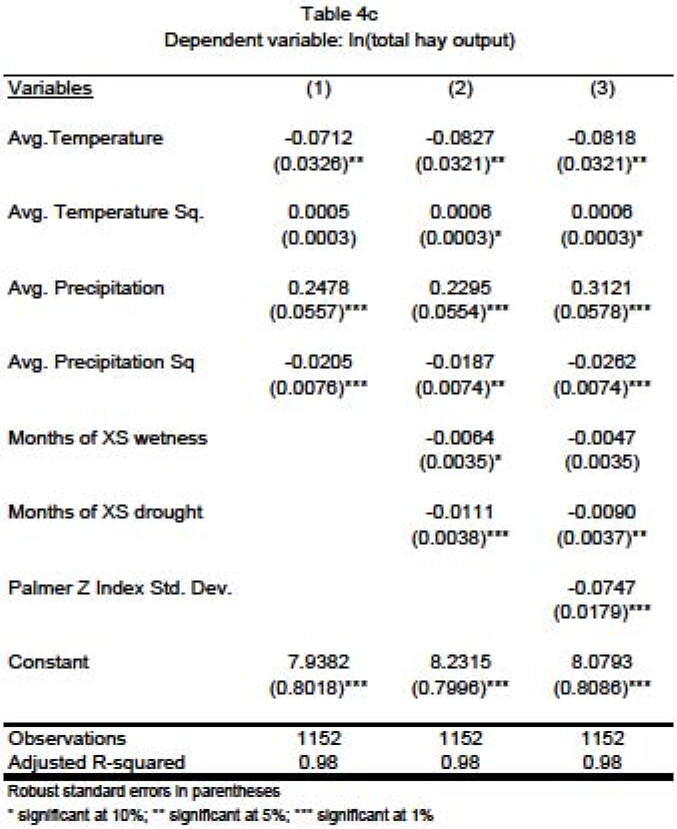


Table 4c

Dependent variable: ln(total hay output)

Variables	(1)	(2)	(3)
Avg.Temperature	-0.0712	-0.0827	-0.0818
	(0.0326)**	(0.0321)**	(0.0321)**
Avg. Temperature Sq.	0.0005	0.0006	0.0006
	(0.0003)	(0.0003)*	(0.0003)*
Avg. Precipitation	0.2478	0.2295	0.3121
	(0.0557)***	(0.0554)***	(0.0578)***
Avg. Precipitation Sq	-0.0205	-0.0187	-0.0262
	(0.0076)***	(0.0074)**	(0.0074)***
Months of XS wetness		-0.0064	-0.0047
		(0.0035)*	(0.0035)
Months of XS drought		-0.0111	-0.0090
		(0.0038)***	(0.0037)**
Palmer Z Index Std. Dev.			-0.0747
			(0.0179)***
Constant	7.9382	8.2315	8.0793
	(0.8018)***	(0.7996)***	(0.8086)***
Observations	1152	1152	1152
Adjusted R-squared	0.98	0.98	0.98

Robust standard errors in parentheses

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

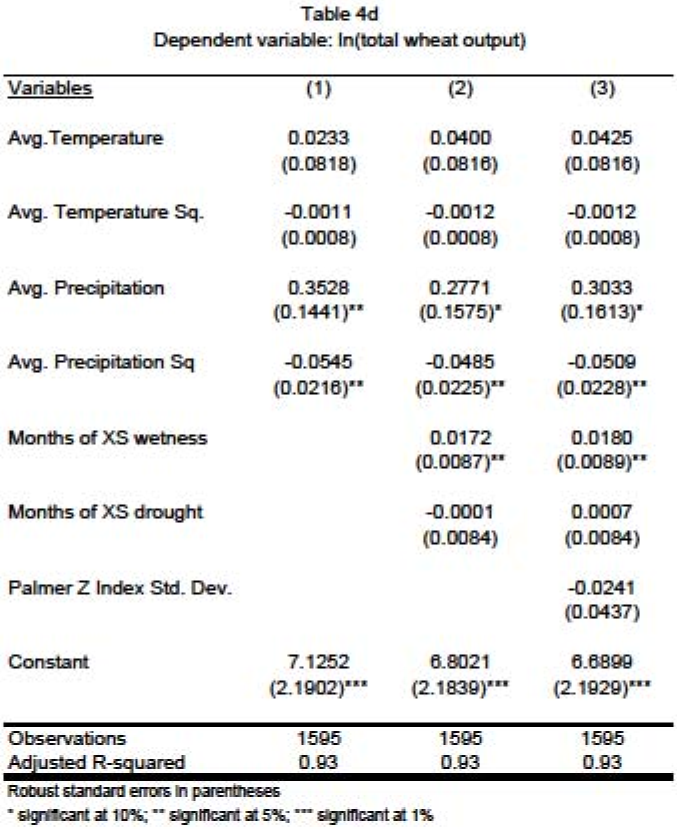


Table 4d
Dependent variable: ln(total wheat output)

Variables	(1)	(2)	(3)
Avg.Temperature	0.0233 (0.0818)	0.0400 (0.0816)	0.0425 (0.0816)
Avg. Temperature Sq.	-0.0011 (0.0008)	-0.0012 (0.0008)	-0.0012 (0.0008)
Avg. Precipitation	0.3528 (0.1441)**	0.2771 (0.1575)*	0.3033 (0.1613)*
Avg. Precipitation Sq	-0.0545 (0.0216)**	-0.0485 (0.0225)**	-0.0509 (0.0228)**
Months of XS wetness		0.0172 (0.0087)**	0.0180 (0.0089)**
Months of XS drought		-0.0001 (0.0084)	0.0007 (0.0084)
Palmer Z Index Std. Dev.			-0.0241 (0.0437)
Constant	7.1252 (2.1902)***	6.8021 (2.1839)***	6.6899 (2.1929)***
Observations	1595	1595	1595
Adjusted R-squared	0.93	0.93	0.93

Robust standard errors in parentheses
* significant at 10%; ** significant at 5%; *** significant at 1%