# Exploring the Causes Driving Hybrid Corn Adoption from 1933 to 1955

Keith Meyers, University of Southern Denmark, meyersk@sam.sdu.dk; meyersk@nber.org

Paul W. Rhode, University of Michigan and NBER, pwrhode@umich.edu

Abstract: Increasing global temperatures and frequent extreme weather events pose new challenges for modern agriculture. However, technology may provide some remedy to the symptom of climate change. Contemporary studies seeking to measure the agricultural sector's adaptive responses to a changing climate are often unable to observe the adoption of specific technologies. In this paper, we study the historic example of hybrid corn seeds and their adoption during a period of great drought and farm distress. This allows us to study how farmers adopt potentially weather mitigating technologies in response to drought. We reconstruct hybrid corn adoption data at a more disaggregated geographic level than previously available to researchers from the years 1931 to 1955. We match these data with information on drought conditions to test whether drought exposure hastened or hindered the adoption of hybrids. Our findings suggest that drought accelerated the adoption of hybrid seeds, but that this accelerative effect occurred several years after the initial shock. Our empirical results highlight the importance of the 1934 drought, rather than the 1936 event which has gained most of the attention in the literature.

As global temperatures increase, many of the agricultural centers of the world face new challenges and risks. Increasing average temperatures will plausibly increase the frequency and intensity of extreme weather events such as prolonged bouts of drought. Technology may provide a remedy to some of the symptoms of climate change. In this paper we study the historic diffusion of a drought mitigating technology, hybrid corn seed, and explore the role drought stresses played in the diffusion of this technology. A vigorous literature highlights the potential costs of higher temperatures on agriculture (Mendelsohn, Nordhaus, and Shaw, 1994; Schlenker, Hanemann, and Fisher, 2005, 2006; Deschênes and Greenstone 2007, 2012; Burke and Emerick 2016.). Recent research by Lobell et al. (2014) and Burke and Emerick (2016) suggest that the temperature sensitivity of corn is not decreasing over time. These findings

suggest that adaptation with respect to increasing global temperatures might not be occurring within the U.S. Cornbelt. Burke and Emerick (2016) posit that a lack of available technological remedies explains the absence of implied adaptation. To better understand the diffusion of drought-mitigating technologies and how farmers adapt in response to extreme weather stresses, we create a panel dataset matching historical weather conditions and archival data on hybrid corn adoption from 1933 to 1955. Hybrid seeds spread throughout the United States during the height of the Great Depression and Dust Bowl. This newly constructed dataset allows us to explore the relationship between hybrids and drought at a finer geographic level than previous work. With this new data, we can apply modern econometric techniques to test whether drought hastened or hindered the diffusion of hybrid seed technology.

Much of the research studying the patterns of hybrid corn adoption comes from the path-breaking work of Zvi Griliches (1957, 1958, 1960, 1980). Griliches's analysis posits that profitability of the new seed (as captured by expected yield improvements) drove adoption. Even though hybrid seeds diffused across the Cornbelt and Great Plains during a period of historically extreme drought, Griliches does not investigate the role that the adverse weather shocks. More recent research suggests that drought shocks in 1934 and 1936 accelerated hybrid adoption (Culver and Hyde 2000; Sutch 2008, 2011). Narrative evidence also suggests that corn producers adopted hybrids in response to droughts and that farmers learned about the potential benefits of hybrids by observing neighbors' crops (Dowell and Jesness, 1939; Crabb, 1947). Contemporaries agreed. As a *New York Times* headline read in 1940: "50% of Corn Crop in Hybrid Species.....Agricultural Marketing Service Lays its Popularity to Drought Resistance."[1]

Richard Hornbeck's (2012) seminal work regarding the Dust Bowl reveals that many of the adaptive responses to the Dust Bowl were relatively slow. In comparison, from 1931 onwards U.S. farmers rapidly adopted hybrid corn and these varieties eventually completely replaced the once dominant open pollinated varieties. This switch towards hybrids may have mitigated some the adverse effects of the Dust Bowl. Switching to hybrids was costly-- hybrid seed was far more expensive than open pollinated seeds (Olmstead and Rhode, 2008). Furthermore, hybrids required farmers to make a structural change in their practices and purchase seed from a seed company on an annual basis. Unlike the predominant open pollinated varieties, seeds derived from hybrid corns are biologically unsuitable for planting.

[1] *New York Times*, 10 Sept. 1940. The article's text noted the hybrid's advantages of both drought resistance and higher yields.

Nevertheless, hybrids promised beneficial qualities, included higher yields, shortened the time to maturity, stronger root systems, thicker stalks, disease resistance, and drought tolerance.

The effect of drought on the adoption of a new technology is potentially non-monotonic. The drought itself may induce financial stress and might make switching to a weather mitigating technology more difficult. Conversely, a historical experience with drought might make hybrid seeds more attractive to farmers. Similarly, if farmers have imperfect knowledge regarding the characteristics surrounding hybrid seeds, then observing hybrid corns' performance during droughts might induce learning about hybrid seed technology and thus induce adoption. In our analysis, we study whether singular transitory drought shocks influence hybrid adoption at an aggregate level. We then test if historical drought experiences influence hybrid adoption using a cumulative drought exposure measure.

We find that treating drought as a transitory shock that only affects hybrid adoption in the subsequent year slows hybrid adoption. We find the opposite effect when we use cumulative drought exposure measures from 1931 onwards. When drought exposure histories are accounted for, drought experience hastens the adoption of hybrid seed technology. Finally, we find some evidence that the 1936 drought accelerated the adoption of hybrid seeds in the 1940s. However, this effect is small relative to the 1934 drought wave's effect on hybrid adoption and disappears when both the 1934 and 1936 droughts are included in the same model. Most areas in the sample did not have substantial acreage of hybrid corns in 1934. It is plausible that the experience of extreme drought shifted farmers' preferences toward hybrids and that localized observational learning played less of a role in hastening adoption.

## Literature Review

The story of hybrid corn has been told many times (Crabb 1947, Fitzgerald 1990, Koppenrberg 1988, Olmstead and Rhode 2008). For economists, the starting point is Griliches (1957). In his seminal article, Griliches analyzed this "invention of a way to invent" and maps estimated parameters of diffusion process into economic variables of supply and demand. He views the diffusion process as primarily a shift between two equilibria over time, rather than as a shift of equilibria. He fit logistic curves to annual diffusion data for states and crop reporting districts, reducing the differences across regions to differences

in three parameters-- the origins, slopes, and ceilings.[2] The origin represented the year (relative to 1940) when diffusion in an area crossed 10 percent adoption threshold. Griliches related the origin date to "availability" of hybrid seed, and more specifically to supply-side forces included the profitability of seed producers, the cost of innovation, and potential market density. He related the slope (or speed of diffusion) and ceiling levels to demand-side forces, specifically to the profitability to farmers of using the new seed. Griliches found the estimated speed of adoption was rather uniform but declined as one moves away from the center of the Cornbelt. The origin date and ceiling level also declined with distance from the center.

Throughout, Griliches (1957) argued the diffusion process could be interpreted in a way consistent with rational, long-run profit-seeking behavior by seed producers and farmers. He made no reference to adverse weather shocks or to the drought-resistance qualities of hybrid varieties.[3] In his "preferred" specification, hybrids promised a time- and region-invariant percentage increase over existing yields. He further argued that including the changing advantages of the new seed, the prices of corn output, or the prices of hybrid seed, would add "nothing of significance" to the explanation of the diffusion process.

The path-breaking work of Griliches inspired a vigorous scholarly response. Dixon (1980) observed that the diffusion process continued through the late 1950s and 1960s beyond the ceiling levels that Griliches employed. Dixon reanalyzed the extended annual state-level data, considering that diffusion to reach nearly 100 percent almost everywhere by the end of the period. Griliches' modeling approach has also been criticized. Economist Paul David (2003) has cogently argued that it lacks micro-foundations; the logistic form is simply assumed, not derived from an underlying economic model. Rural sociologist Everett Rogers (1962) observed that Griliches abstracted from the contagion-like learning effects that are commonly used to justify the logistic form. Ryan and Gross (1950) had studied how Iowa farmers learned about hybrid technologies and how peer effects influenced their adoption decisions. They found that younger and more educated farmers adopted hybrids more readily than older or less

[2] The analysis covered 31 (out of 48) states, and 132 (out of 249) crop reporting districts in the period up to 1956. The USDA's Agricultural Marketing Service made available unpublished data for the crop reporting districts. Griliches restricted analysis to observations between 0.05 and 0.95 of his estimated ceiling level, K. The ceiling was estimated in an admittedly ad hoc way by picking the K that makes the resulting diffusion curves plotted on logistic graph paper look linear.

[3] Although weather conditions clearly affected the "availability" of seed on the supply side and the drought-resistance qualities of new seed impacted the farmer profitability and "acceptance" on the demand side, Griliches does not mention weather effects. (One can do a word search.)

educated farmers. Building on recent work in social economics, Suri (2011) investigates such forces driving hybrid corn adoption in a developing economy setting, namely in contemporary Kenya.

Sutch (2008, 2011) has revisited the early diffusion of hybrid corn, emphasizing the role of adverse weather shocks. Sutch (2008) argues that marketing campaigns and drought stresses (and the 1936 drought in particular) caused farmers to make the costly switch from open pollinated to hybrid corns. He argues that the early hybrid varieties were not inherently superior to available open-pollinated seeds and that farmers were rightly slow to adopt the expensive seeds in the late-1920s and early-1930s. It was the adverse weather shocks of the mid-1930s, in combination with propaganda from the USDA (headed by hybrid corn pioneer Henry A. Wallace), that convinced midwestern farmers to adopt the new seed.[4] Farmers readily noticed that hybrid corn with the dry conditions better than open-pollinated corn planted nearby. (As one farmer put it, in these very bad years, the hybrid corn was the last to die (Urban 1975).) Singling out the 1936 Dust Bowl drought, Sutch (2011) performed an analysis of hybrid diffusion on state-level data in the Cornbelt in the 1930s and argued that 1936 drought hastened the adoption of hybrids through learning effects. Sutch was hampered by the lack of geographically specific data. With our new data (or more accurately, newly recovered old data), we seek to address these issues afresh.

## Data Sources

Data on hybrid corn diffusion by state are available in USDA's *Agricultural Statistics*. These data, on the percentage of maize acreage planted with hybrid seed, have been available to scholars for many years. More novel is data on diffusion by crop reporting districts (CRDs), which come from the "Papers" of Zvi Griliches held at the Special Collections Library at Harvard University.[5] These more detailed records-- drawn from a grid of roughly nine entries per state-- are based unpublished data from the USDA's Agricultural Marketing Service. We have recovered these series for use for the first time in over six decades.

The crop reporting district data were compiled from a set of hand-written spreadsheets for the 1944-1955 period (Box 58), from typed sheets for all the CRDs in United States in 1959 (Box 60) and for

[4] Sutch (2008) notes the conflict of interest that USDA Secretary Henry A. Wallace faced as a producer of hybrid seed and as an owner of one of the leading commercial seed companies. Observers in the 1930s, including the *Chicago Tribune*, were even more critical, arguing the yield-enhancing seed increased output at the very time that federal farm programs, run by Wallace, sought to reduce output through acreage restriction.

[5] Papers of Zvi Griliches, ca. 1930-2000. Collection Identifier: HUGFP 153. Harvard Library. We thank Diane Griliches for allowing access to these materials.

Ohio CRDs for the 1935-1954 period (Box 58), and from very carefully marked diffusion graphs drawn by Griliches's own hand (Box 58). The graphs indicate the annual rate of diffusion by crop reporting district for each state on a 100 point (or finer) scale covering the period from first diffusion to 1954/55. The numbers derived from the graphs match exactly those from available non-graphical sources.[6] In addition, the records of Griliches include maps of CRD data from the Agricultural Adjustment Administration for the 1938-41 period (Box 57). The AAA data have more extensive geographic coverage than the AMS data that Griliches chiefly used. Where there is overlap, the differences are relatively minor. Figure 1 maps out the AMS diffusion data used in this paper from 1933 onwards and reports the year in which hybrid corns exceed 10 percent of planted acreage.[7]

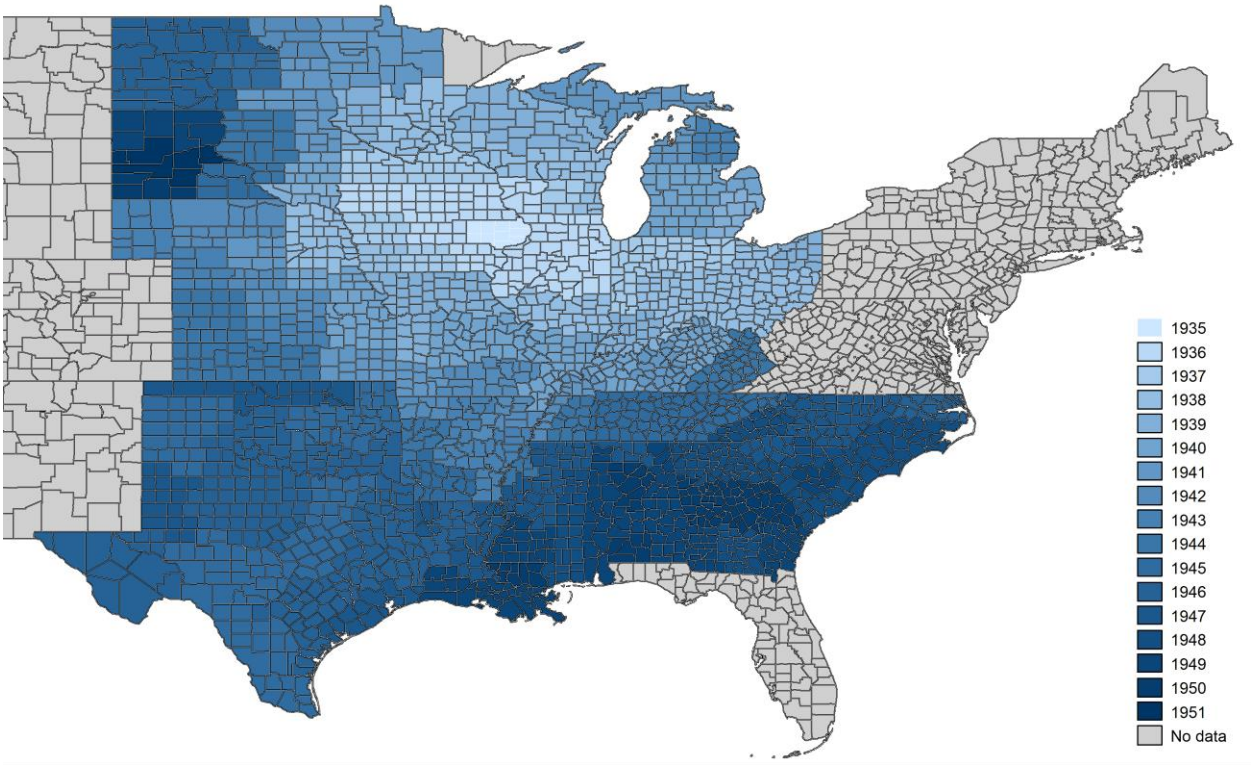



Figure 1: Year Hybrid Adoption First Exceeds 10%

[6] We have data for the northeastern states from 1945 on. We are seeking to supplement these data with more archival information.

[7] The map shapefile used consists of counties and each county is mapped to their CRD. This visualization was done because no shapefiles for historical crop reporting districts are available.

Griliches tabulated but did not use USDA data on the prices (per bushels) of hybrid and open-pollinated seed by state (Box 59).[8] He argued that the hybrid seed prices did not vary significantly across space and could be ignored in his analysis of the rate of diffusion (which was modeled as a transition between two equilibria). Griliches' treatment of hybrid seed prices is problematic for several reasons. The farmer's adoption decision did not the hybrid corn price alone, but the hybrid seed price relative to other prices, for example, relative to the price of open pollinated seed. Over the 1937-57 period, the coefficient of variation of the price of hybrid seed across states averaged approximately 10 percent. The coefficient of variations of the ratio of hybrid to open pollinated seed was substantially higher, averaging 16 percent. Griliches also ignores changes over time. In the late 1930s, hybrid seed cost about 3.5 times as much as open pollinated seed. By the mid-1950s, the ratio had fallen roughly in half, to about 1.8 times. (See Appendix Table A10.) Griliches tabulated but did not use state-level data on seeding rates (Box 59).[9] Again, he argues the cross-state variation is negligible. The coefficient of variation of seeding rates in bushels per acre was around 18.7 percent.

Griliches collected and did use data on the differential yields achieved by hybrid seed relative to open-pollinated seed. The data he collected included the results of state yield trials and of AAA surveys. These included yield data at the sub-state level but the regions did not always translate directly into crop report districts (Boxes 57, 60). The CRD data that he used was derived from AMS studies of "identicals," covering the period from 1939 on (Box 59). For early adopting states such as Iowa and Illinois, the series are brief because little or no open-pollinated seed was grown after the mid-1940s. And by using the AMS series, Griliches does not incorporate the effects of the weather shocks (e.g. droughts) of the 1930s which are of interest here.

Our historical weather records from 1895 to 1955 are derived from the data provided by the Global Historical Climatology Network (Lawrimore et. al. 2011).[10] This data includes measures of average monthly temperature, cumulative monthly precipitation, and monthly Palmer Drought Severity Indices (PDSI) for counties in the continental United States. Because we are interested in the effects of drought

[8] Griliches relied on a USDA publication entitled "Seed Crops." These are essentially the same as in USDA (1963).
[9] These data were based on USDA, *Agricultural Statistics*, 1945, 1949, 1950.
[10] We thank Price Fishback and Alex Hollingsworth for proving these data at the county level. Lawrimore, J. H., Menne, M. J., Gleason, B. E., Williams, C. N., Wuertz, D. B., Vose, R. S., & Rennie, J. (2011). An overview of the Global Historical Climatology Network monthly mean temperature data set, version 3. Journal of Geophysical Research: Atmospheres, 116(D19).

stress on hybrid diffusion, we use the PDSI in our empirical analysis. We aggregate these measures up to the CRD level and use the average value of all the counties within a CRD as our aggregated measure. The PDSI measures drought stress and the availability of water moisture in soil. With the PDSI, we measure average annual levels of drought stress over the growing season for corn (April to September) within CRDs.

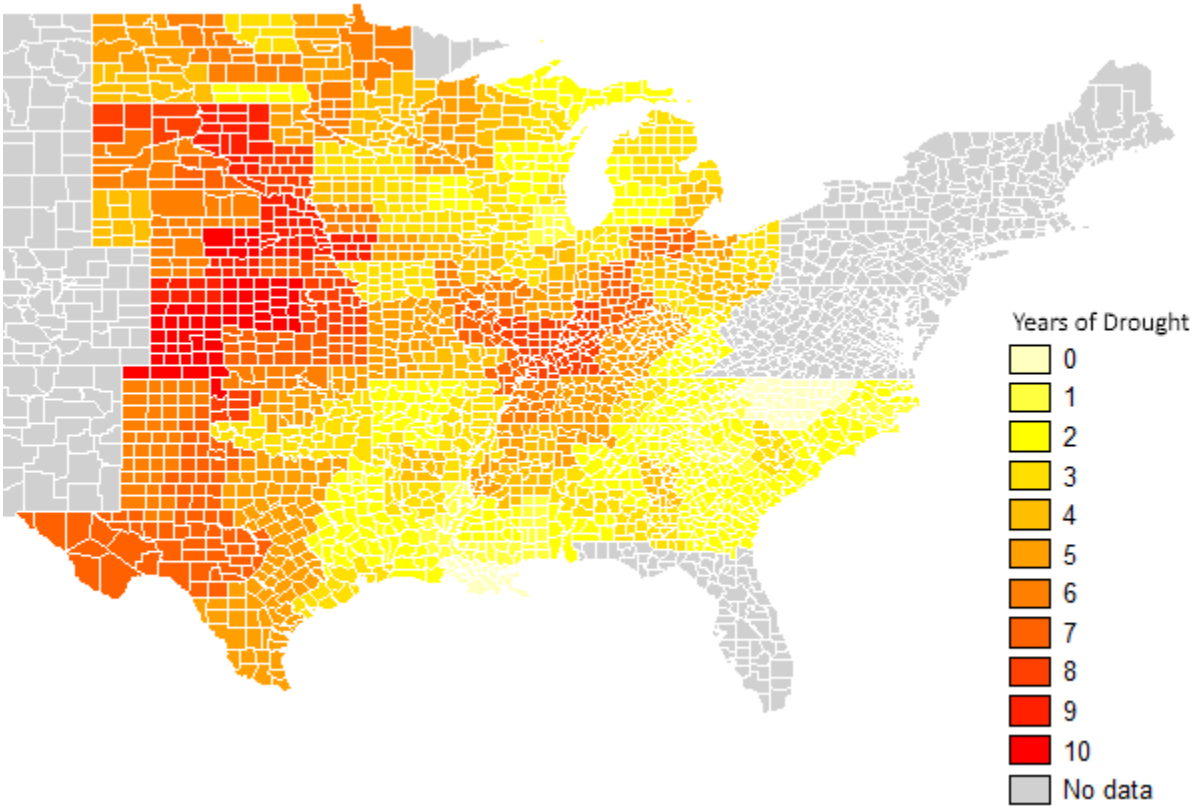



Figure 2: Year of Moderate or Worse Drought, 1931-1955

Figure 2 maps the number of years crop reporting districts experienced moderate or worse drought (PDSI <= -2). There is much heterogeneity in drought experience across regions in the Cornbelt and within Griliches' CRD sample. Some CRD's experience few to no droughts from 1931 to 1955, while other areas endured prolonged bouts of abnormal aridity. We match Griliches' hybrid adoption data with these records from the Global Historical Climatology Network to create an annual panel of CRDs from 1933 to 1955. We recode missing observations prior to the initial adoption of hybrid technologies as approximately zero.[11] With this panel, we can study the dynamics through which drought influences the adoption of hybrid corns.

[11] We treat the values of zero percent adoption as .001 and one hundred percent adoption as .999. We replaced missing observations with .001 in years before we observe reported hybrid adoption. e.g. If we observed small non

## Empirical Strategy and Results

To understand the temporal dynamics between drought and the hybrid adoption decision, we examine the effect of drought from multiple angles. First, we treat drought as a transitory shock that transpired in the previous year. Then we use cumulative measures of drought experience from 1931 onwards to analyze the effect of historical drought experience on adoption. Finally, we explore how the 1934 and 1936 episodes of drought shaped hybrid adoption from 1934 to 1955.

$$Y_{it} = \beta D_{it} + \gamma_t + \alpha_i + \varepsilon_{it} \quad (1)$$

Equation (1) reports the panel regression specification used in the econometric analysis. In this specification, we regress the log odds ratio for hybrid adoption, $Y_{it}$, for CRD *i* in year *t* on a drought stress measure, $D_{it}$. In the full specification we include both year and CRD fixed effects, $\gamma_t$ and $\alpha_i$. These account for common annual shocks shared across CRDs that might affect hybrid adoption and time invariant CRD specific factors that influence adoption. The error term, $\varepsilon_{it}$, denotes a heteroskedastic error term. We report robust heteroskedastic standard errors, clustered standard errors at the state level, and clustered standard errors at the CRD level where possible.

Table 1: Summary Statistics

| Variable | Obs | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|
| Percent Hybrid Corn | 4516 | 0.376 | 0.390 | 0.000 | 1.000 |
| ln Odds Ratio | 4516 | -1.581 | 4.158 | -6.907 | 6.907 |
| PDSI | 4516 | -0.291 | 1.709 | -4.000 | 4.000 |
| Cumulative PDSI | 4516 | -7.281 | 5.822 | -29.583 | 10.470 |
| Drought | 4516 | 0.165 | 0.371 | 0.000 | 1.000 |
| Cumulative Years of Drought | 4516 | 2.658 | 2.117 | 0.000 | 10.000 |

We construct several measures of drought stress using PSDI. The values of reported PDSI in the data range from -4 to 4, with negative values denoting drier conditions and positive values denoting wetter conditions. (The values are top and bottom codes at values of -4 and 4). Mild drought consists of values between -1 and -2; values between -2 and -3 denote moderate drought; values between -3 to -4

zero hybrid adoption in a CRD in 1935 but have no data for 1933 and 1934, we replace the missing values with .001. We do not top fill in missing data for Ohio and Minnesota. Minnesota is missing data from 1952 to 1955. Ohio is missing data for 1954 and 1955.

denote severe drought, and extreme drought is denoted by values -4 (and greater in non-top-coded data). The first measure we use is an indicator variable for moderate drought or worse during the past year's corn growing season. Regressions using this measure report the effect of a transitory drought shock during the previous year on hybrid adoption in the subsequent year. The second measure reports the number of years of drought stress experienced in a CRD from 1931 (the year when Pioneer Hi-Bred introduced its first commercially successful hybrid seed product). This measure of drought experience accounts for the potential cumulative effects of drought experience on hybrid adoption decisions. Similarly, we use an average measure of the PDSI index for the past year as a continuous measure of drought stress and use a cumulative measure that aggregates the PDSI as a sum from 1931 onwards. Summary statistics for the empirical sample are available in Table 1.

In Tables 2 and 3, we report the effect of drought stress on the ln odds ratio of hybrid adoption using a binary drought indicator and the running sum of these indicator variable from 1931 to 1955. The first measure provides insight regarding the effects of a transitory drought shock and the subsequent measure accounts for historical incidence of drought while hybrids were presumably available to farmers. Five empirical specification are reported. Specification (1) includes only state FE, (2) includes year FE, and (3) includes both. Specification (4) includes only CRD specific FE and (5) includes both CRD FE and year FE. Three sets of standard errors are reported, heteroskedastic robust standard errors in parentheses, standard errors clustered at the state level in square brackets, and standard errors clustered at the CRD level in curly brackets.[12]

In Table 2, the transitory drought measure has a negative and statistically significant relationship on hybrid adoption in the subsequent year in all specification except (2). We find the exact opposite result in Table 3 when we use years of drought experienced since 1931 as our measure. Apart from specification (3) when standard errors are clustered at the state level, we find a statistically significant and positive relationship between drought experience and hybrid adoption in the subsequent year. In Tables 4 and 5, we use the Palmer Drought Severity Index as a continuous measure of drought exposure. With values ranging from -4, (extreme drought), to +4, (extreme wetness), we find similar results. Treating drought as a transitory shock appears to slow hybrid adoption in the subsequent year, but the using a running sum

[12] Deschênes and Greenstone (2007) cluster standard errors at the state level, because they argue this is econometrically equivalent to spatially correlated standard errors. It is likely that drought shocks, hybrid adoption, and other variables have a common heteroskedastic structure and that clustering by CRD might be too narrow of a geographic region.

of PDSI measures from 1931 onwards suggests that a history of drought exposure hastened hybrid adoption.

The results presented in Tables 2 through 4 suggest that a singular drought shock is associated with slower hybrid adoption and that a history of drought exposure hastens adoption. These results suggest that there is a temporal dynamic between drought and hybrid adoption. The initial drought event might hinder farmers financially and make transitioning toward hybrids less feasible. This same experience might also make hybrid seeds more attractive to farmers, and thus farmers adopt hybrids more readily when they can afford to make the costly technological switch. To explore this temporal relationship between drought and adoption, we examine two major waves of drought that occurred during the initial transition towards hybrid seed. The first major shock occurred in 1934 and the second drought wave occurred in 1936. These stresses plausibly shaped farmers preferences towards hybrids and accelerated the hybrid seed transition.

Table 2: Effect of Drought Indicator on Hybrid Log Odds Ratio

| | ln(%h/(1-%h)) | | | | |
|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) |
| Drought, t-1 | -1.740 | 0.140 | -0.373 | -1.742 | -0.324 |
| | (0.167)*** | (0.114) | (0.069)*** | (0.204)*** | (0.074)*** |
| | [0.506]*** | [0.250] | [0.130]*** | [0.512]*** | [0.127]** |
| | {0.201}*** | {0.148} | {0.079}*** | {0.204}*** | {0.074}*** |
| State FE | Y | N | Y | N | N |
| Year FE | N | Y | Y | N | Y |
| CRD FE | N | N | N | Y | Y |
| N | 4516 | 4516 | 4516 | 4516 | 4516 |
| adj. R-sq | 0.331 | 0.570 | 0.890 | 0.032 | 0.887 |

Drought denotes a year when an observation was in moderate or worse drought, <-2 on the PDSI. White robust standard errors are in parentheses. Clustered standard errors at the state level are in brackets. Clustered standard errors at the crop reporting district are in curly brackets.

* p<0.10, ** p<0.05, *** p<0.01

Table 3: Effect of Cumulative Drought on Hybrid Log Odds Ratio

| | ln(%h/(1-%h)) | | | | |
|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) |
| Years of Drought, t-1 | 1.189 | 0.524 | 0.113 | 2.003 | 0.327 |
| | (0.026)*** | (0.020)*** | (0.016)*** | (0.092)*** | (0.060)*** |
| | [0.084]*** | [0.173]*** | [0.095] | [0.210]*** | [0.119]** |
| | {0.066}*** | {0.081}*** | {0.051}** | {0.092}*** | {0.060}*** |
| State FE | Y | N | Y | N | N |
| Year FE | N | Y | Y | N | Y |
| CRD FE | N | N | N | Y | Y |
| N | 4516 | 4516 | 4516 | 4516 | 4516 |
| adj. R-sq | 0.496 | 0.627 | 0.890 | 0.487 | 0.892 |

Drought denotes a year when an observation was in moderate or worse drought, <-2 on the PDSI. These are added from 1931 to form a cumulative measure. White robust standard errors are in parentheses. Clustered standard errors at the state level are in brackets. Clustered standard errors at the crop reporting district are in curly brackets.
* p<0.10, ** p<0.05, *** p<0.01

Table 4: Effect of PDSI on Hybrid Log Odds Ratio

| | ln(%h/(1-%h)) | | | | |
|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) |
| PDSI, t-1 | 0.538 | 0.091 | 0.061 | 0.544 | 0.063 |
| | (0.029)*** | (0.027)*** | (0.014)*** | (0.037)*** | (0.014)*** |
| | [0.099]*** | [0.043]** | [0.027]** | [0.099]*** | [0.027]** |
| | {0.037}*** | {0.024}*** | {0.015}*** | {0.037}*** | {0.014}*** |
| State FE | Y | N | Y | N | N |
| Year FE | N | Y | Y | N | Y |
| CRD FE | N | N | N | Y | Y |
| N | 4516 | 4516 | 4516 | 4516 | 4516 |
| adj. R-sq | 0.356 | 0.571 | 0.889 | 0.073 | 0.886 |

PDSI denotes the average Palmer Drought Severity Index between April and September in a given year. These months coincide with the growing season window for corn. White robust standard errors are in parentheses. Clustered standard errors at the state level are in brackets. Clustered standard errors at the crop reporting district are in curly brackets.
* p<0.10, ** p<0.05, *** p<0.01

Table 5: Effect of Cumulative PDSI on Hybrid Log Odds Ratio

| | ln(%h/(1-%h)) | | | | |
|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) |
| Cumulative PDSI, t-1 | -0.090 | -0.145 | -0.049 | -0.119 | -0.063 |
| | (0.012)*** | (0.006)*** | (0.005)*** | (0.031)*** | (0.011)*** |
| | [0.044]* | [0.042]*** | [0.021]** | [0.060]* | [0.024]** |
| | {0.023}*** | {0.023}*** | {0.012}*** | {0.031}*** | {0.011}*** |
| State FE | Y | N | Y | N | N |
| Year FE | N | Y | Y | N | Y |
| CRD FE | N | N | N | Y | Y |
| N | 4516 | 4516 | 4516 | 4516 | 4516 |
| adj. R-sq | 0.319 | 0.605 | 0.891 | 0.017 | 0.889 |

PDSI denotes the average Palmer Drought Severity Index between April and September in a given year. These are added from 1931 onwards to form a cumulative measure. These months coincide with the growing season window for corn. White robust standard errors are in parentheses. Clustered standard errors at the state level are in brackets. Clustered standard errors at the crop reporting district are in curly brackets.
* p<0.10, ** p<0.05, *** p<0.01

$$Y_{it} = \beta_1 D1934_i + \beta_2 D1936_i + \sum_{t=1934}^{1955} \delta_t * D1934_i + \sum_{t=1934}^{1955} \theta_t * D1936_i + \gamma_t + \alpha_s + \varepsilon_{it} \quad (2)$$

To explore this temporal relationship between drought shocks and hybrid diffusion, we run a flexible form regression described by Equation 2. In these regressions, we include time-invariant variables denoting a CRD's drought status in 1934 or 1936. We then interact these 1934 and 1936 drought measures with year indicator variables. We run three specifications, one for each drought year and one where both droughts are accounted for. We then plot these coefficients in Figures 3 to 8 to visualize the temporal effects these shocks had on hybrid adoption. In the above equation, $Y_{it}$ represents the log odds ratio of hybrid adoption. $D1934_i$ and $D1936_i$ denote drought shocks specific to 1934 and 1936. The

interactions of the drought measures with year indicator variables are denoted by $\delta_t$ and $\theta_t$. We include both year and state fixed effects, $\gamma_t$ and $\alpha_s$.[13] Finally, $\varepsilon_{it}$ denote heteroskedastic robust standard errors.[14]

We plot the regression coefficients for drought and the 99% confidence interval in Figures 3, 4 and 5. Each figure reports the effects of drought treated separately and included together. In Figures 3 and 4, the 1934 and 1936 drought indicator variables both suggest that these drought events have negative effects on hybrid adoption. Over time, the coefficients on the interaction terms become a net positive. This result suggests that exposure to either the 1934 or 1936 droughts accelerated hybrid adoption, but that this effect is delayed. The magnitude of the drought's effect on hybrid adoption is larger for the 1934 drought than the 1936 drought wave. In Figure 5, when both droughts are accounted for, the effect of the 1936 drought on hybrid adoption attenuates while the 1934 drought coefficients remain large and statistically significant.

We find similar results when we use a continuous measure of drought intensity, the PDSI for the 1934 and 1936 growing seasons. In Figures 6, 7, and 8, since drought in the PDSI takes negative values, negative coefficients are associated with hastening hybrid adoption while positive coefficients suggest that drought slows hybrid adoption. When PDSI values for 1934 and 1936 are both included in the same model we find that the effects of the 1934 drought on hybrid adoption remain statistically significant and large in magnitude. The effects of the 1936 drought attenuate and many of the interaction terms switch signs.

[13] Plots with CRD fixed effects are reported in the appendix and do not fundamentally alter the results.
[14] Using CRD FE or Clustering at the CRD level increases statistical significance of the coefficient. Clustering at the state level is not possible as the number of estimators exceed the number of clusters due to the number of interactions.

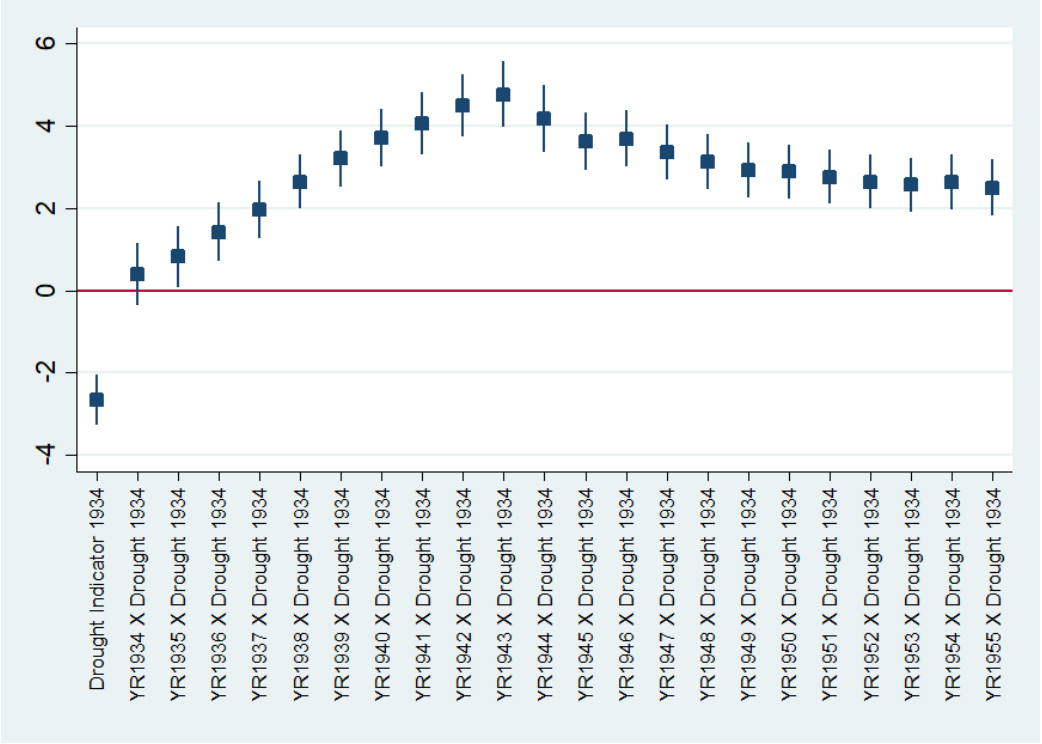



Figure 3: Regression Coefficients and Year Interactions with 1934 Drought

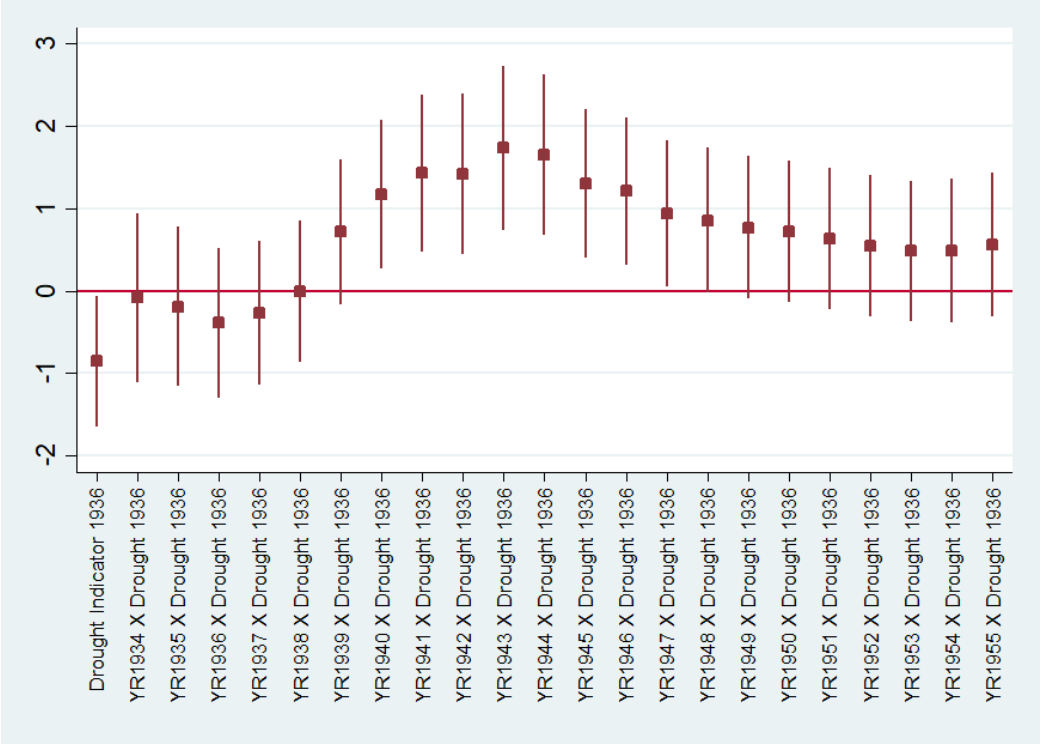



Figure 4: Regression Coefficients and Year Interactions with 1934 Drought

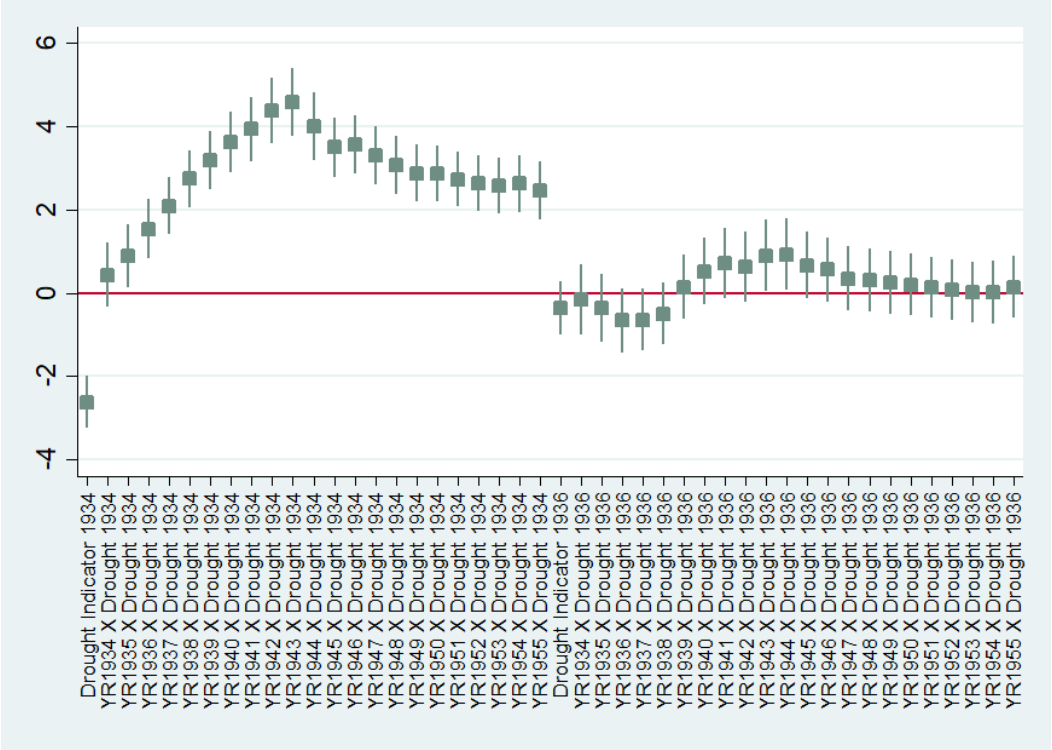



Figure 5: Regression Coefficients and Year Interactions with 1934 and 1936 Droughts

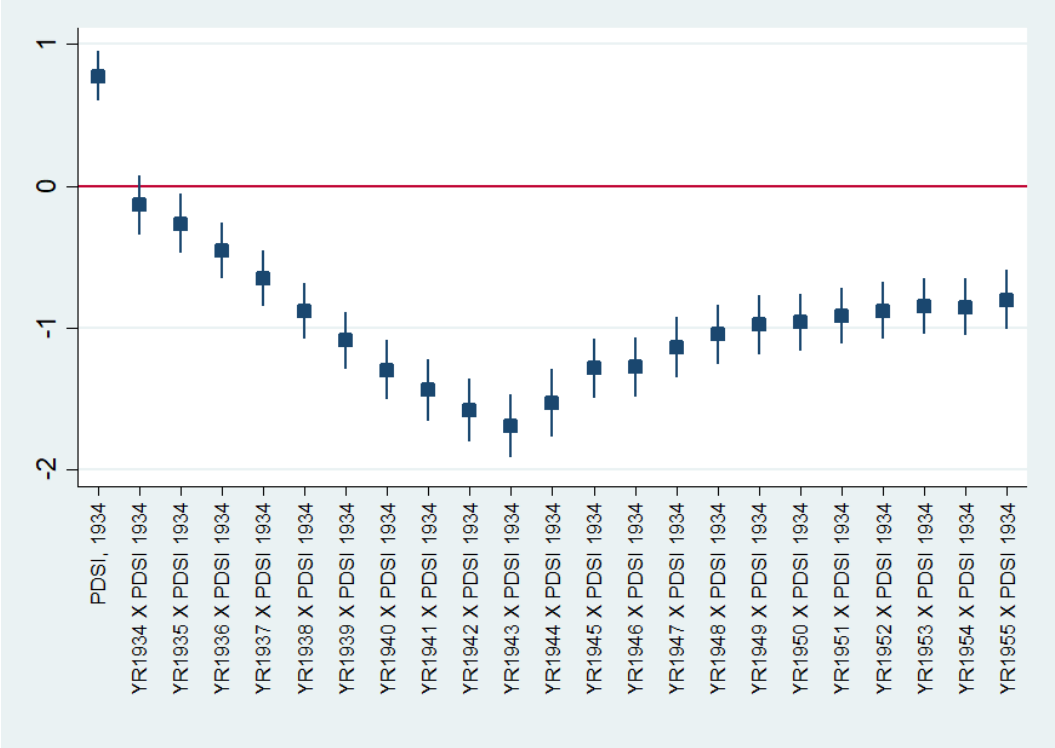



Figure 6: Regression Coefficients and Year Interactions with 1934 PDSI

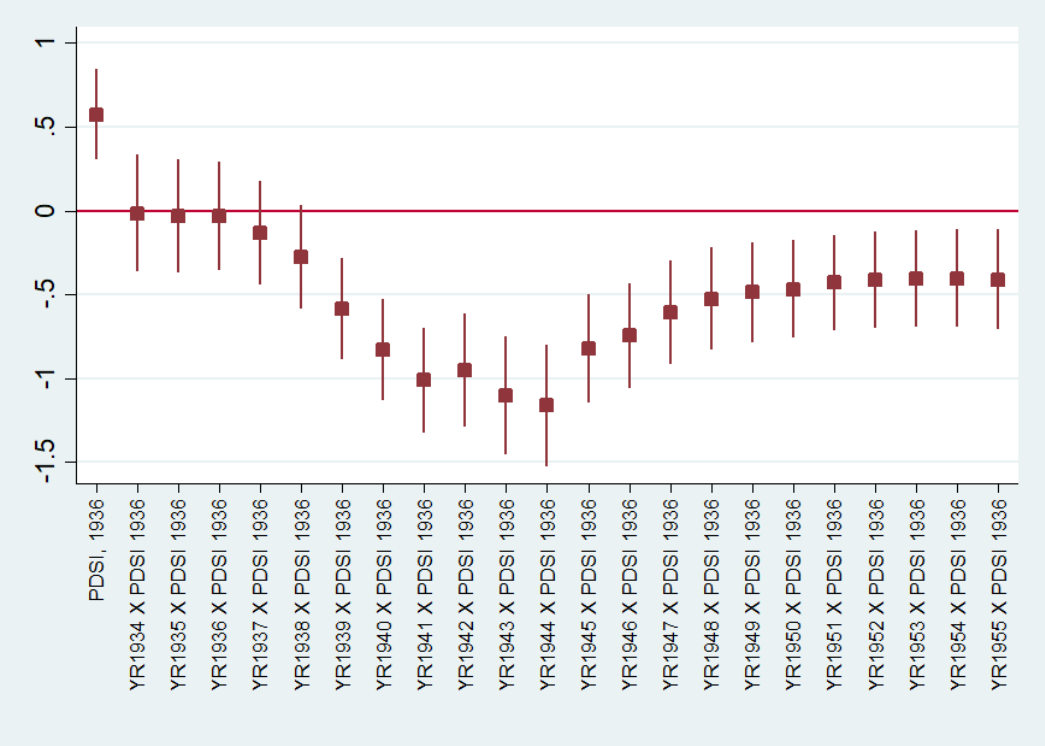



Figure 7: Regression Coefficients and Year Interactions with 1936 PDSI

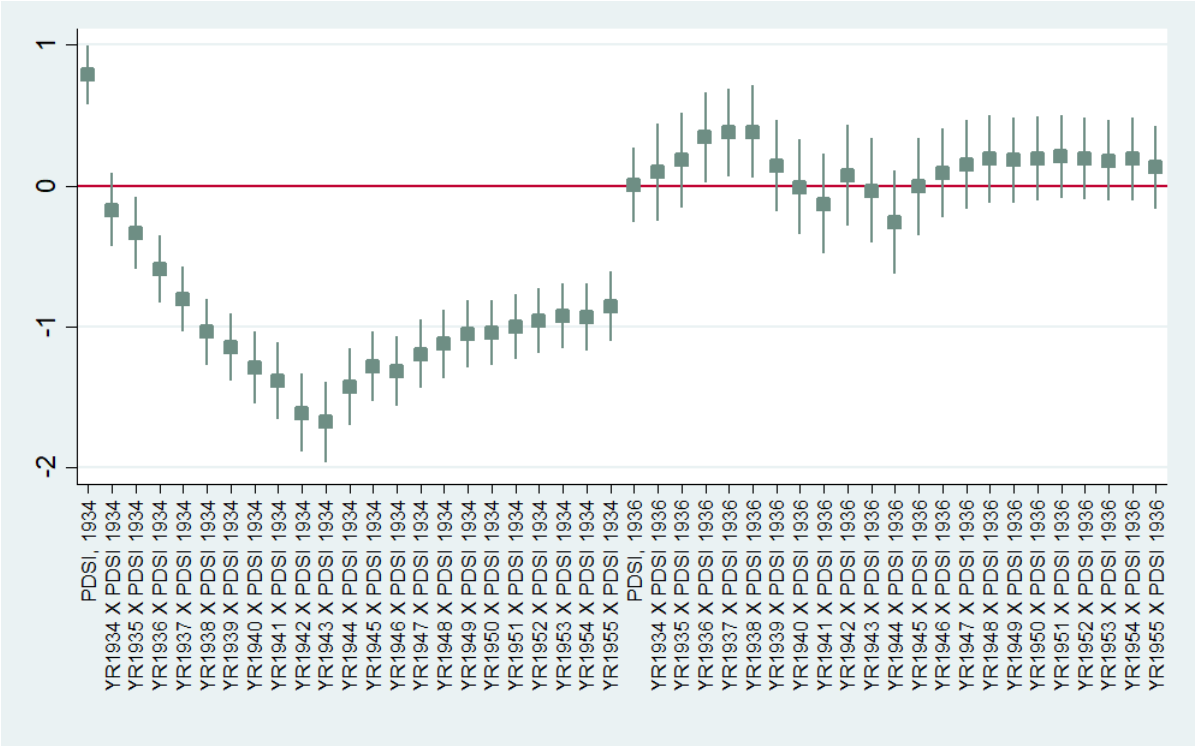



Figure 8: Regression Coefficients and Year Interactions with 1934 and 1936 PDSI

As an alternative to the panel regressions with interaction terms, we conduct a series of cross sectional regressions using CRDs and drought measures. Taking inspiration from Gilchrist and Sands (2016) work analyzing social spillovers in movie consumption, we use a series of repeated cross-sectional regressions to study how drought shocks permeate across time and affect hybrid adoption within CRDs.

$$Y_{ij} = \beta D1934_{ij} + \gamma_j + \varepsilon_i \quad (2)$$

$Y_{i,j}$ measures the log ratio of hybrid adoption in CRD *i*, between periods j and j − 1. The j = 0 period denotes the first year when hybrid corn seed was reported in a CRD in Griliches' records. $D1934_{ij}$ represents a drought measure for the 1934 drought wave. $\gamma_j$ denotes a time fixed effect that addresses common evolution patters of hybrids over time. $\varepsilon_i$ represents the White's robust heteroskedastic standard error term. The empirical results in Table 6 reveal that the 1934 drought exposure is associated with slower initial adoption and more rapid adoption in later years after hybrid seeds were observed in a CRD.

Table 6: Cross Sectional Regressions. Effects of 1934 Drought on Hybrid Adoption Relative to Year Zero

| | (1) T= 0 | (2) T = 1 | (3) T = 2 | (4) T = 3 | (5) T = 4 | (6) T = 5 | (7) T = 6 | (8) T = 7 | (9) T = 8 |
|---|---|---|---|---|---|---|---|---|---|
| Drought Status, 1934 | -0.759*** | -0.623*** | -0.262* | -0.043 | 0.341* | 0.679*** | 1.014*** | 1.218*** | 1.433*** |
| | (0.159) | (0.108) | (0.108) | (0.130) | (0.132) | (0.142) | (0.149) | (0.166) | (0.180) |
| N | 198 | 198 | 198 | 198 | 198 | 198 | 198 | 198 | 198 |
| adj. R-sq | 0.098 | 0.140 | 0.026 | -0.005 | 0.025 | 0.084 | 0.157 | 0.172 | 0.189 |
| | (1) T= 0 | (2) T = 1 | (3) T = 2 | (4) T = 3 | (5) T = 4 | (6) T = 5 | (7) T = 6 | (8) T = 7 | (9) T = 8 |
| PDSI, 1934 | 0.249*** | 0.219*** | 0.133*** | 0.061 | -0.054 | -0.153** | -0.275*** | -0.364*** | -0.452*** |
| | (0.048) | (0.034) | (0.039) | (0.046) | (0.049) | (0.052) | (0.054) | (0.059) | (0.063) |
| N | 198 | 198 | 198 | 198 | 198 | 198 | 198 | 198 | 198 |
| adj. R-sq | 0.105 | 0.167 | 0.068 | 0.005 | 0.002 | 0.036 | 0.104 | 0.140 | 0.173 |

All regressions include Time fixed effects. Time is defined as number of years from initial non zero hybrid adoption is observed. PDSI denotes the average Palmer Drought Severity Index between April and September in a given year. These months coincide with the growing season window for corn. Drought denotes a year when an observation was in moderate or worse drought, <-2 on the PDSI. White robust standard errors are in parentheses.

* p<0.10, ** p<0.05, *** p<0.01

## Robustness and Additional Information

In the Appendix, we present several robustness checks and additional information. This includes Tables A1 and A2 which report the correlation of annual drought and PDSI measures from 1933 to 1940. Tables A3 and A4 report the regression results without the recoding of missing (omitted) observations from 1933 to the first year of Griliches' data as zero. Table A5 presents a placebo falsification test where drought measures from twenty-five years prior are used. Tables A6 and A7 report replace the outcome of interest with change in percent hybrid. Tables A8 and A9 includes annual drought shock splines which are zero in the year before the shock and take constant values for the year of the shock and each subsequent year. Figures A1 to A8 map PDSI measures for each year between 1933 and 1940. Figures A9 to A17 present alterative specifications for Figures 3 to 8 using CRD fixed effects instead of state fixed effects. We also include specifications that cluster standard errors at the CRD level instead of using heteroskedastic robust standard errors.

The robustness checks in Tables A3 and A4 suggest that omitting the recoded observations makes some specifications sensitive to the inclusion (or exclusion) of year fixed effects. For the transitory drought shock indicator, the inclusion of year and geographic fixed effects attenuates all statistical significance. With the cumulative drought measure this attenuation appears only in specification (3) where both year and state fixed effects are used. With the PDSI, there is similar attenuation. However, when PDSI is treated as a transitory variable, the sign flips when both geographic and year fixed effects are included together. The cumulative PDSI measure also exhibits a sign switch when year fixed effects are excluded. The statistical significance of these coefficients depends on how the models account for heteroscedasticity.

The placebo test in Table A5 find that drought twenty-five years prior to the current date generally suggest that transitory drought shocks accelerate hybrid adoption. This result is opposite of what we find in the main models and the statistical significance of these effects are not consistent across specifications. Tables A6 and A7 present a series of annual dummy variables for the years of 1931 to 1940. These variables take the value zero in the year before a drought shock and either one if PDSI<-2 or the PDSI value depending on the specification. Generally, we find consistent, strong, and statistically significant positive effects of drought on hybrid adoption when the drought shocks coincide with major Dust Bowl drought episodes in 1934, 1936, and 1940. The effects of drought in other years does not follow the same pattern

and the coefficients sometimes suggest that drought in other years are associated with slowed adoption. Examining the PDSI maps, it appears that drought hits the core of the Cornbelt more in 1934, 1936, and 1940. In the other years, more peripheral corn producing regions experienced heavy drought. Finally, with Figures A9 to A17, the inclusion of CRD fixed effects does not substantially affect the coefficients presented in Figures 3 to 8. However, clustering at the CRD level decreases the 99 percent confidence interval surround a few coefficients around the year of the drought shock.

## Discussion

By reconstructing the hybrid corn dataset Zvi Griliches used in his groundbreaking work on technological diffusion, we have been able to examine the role drought played in the adoption of hybrid seed technology. Griliches did not explore this mechanism in his original work. Sutch (2008, 2011) and Culver and Hyde (2000) pointed to the narrative history surrounding hybrid diffusion and highlighted the importance drought played in farmers' adoption decisions. Sutch (2011) argues that the drought of 1936 revealed the beneficial drought-resistant quality of hybrids and induced switching.

In our analysis, we uncover a more complicated relationship between drought and hybrid adoption. We find that transitory drought shocks slowed hybrid adoption in the subsequent year. Our estimates suggest that a single year of moderate or worse drought would decrease the likelihood an acre of corn would be hybrid seed by 27.7 percent (similarly, going from mild drought to moderate drought on the PDSI implies a 27.9 percent reduction.) Interestingly, when we allow drought experience to accumulate year to year we find that an additional year of drought hastens hybrid adoption. We find that an additional year of moderate or worse drought increases the likelihood that an acre of corn is hybrid seed by 6.5 percent (similarly going from 0 to -2 on PDSI increase this likelihood by 13 percent). We also do not find strong evidence that indicates observational learning during the 1936 drought accelerated hybrid adoption in the years following the shock. Instead, we find exposure to the droughts of 1934, i.e. those associated with the first wave of the Dust Bowl, hastened hybrid adoption.

The historical scenario of hybrid corn diffusion during the 1930s reveals that farmers more readily adopt potential drought and weather mitigating technologies in response to weather stresses. In a world where increasing temperatures threaten agricultural productivity, technological solutions may mitigate

some of the symptoms of climate change. Recent research suggests that the temperature sensitivity of major commercial crops is not decreasing over time in the U.S. Our findings are consistent with Burke and Emerick's (2016) hypothesis that adaption is slow due to a lack of technological solutions. However, this might not be the only explanation as to why there is little evidence of temperature adaptation in aggregate agricultural data. USDA policy, technological lock-in, and preferences towards upside risk are other potential factors influencing the agricultural sector's adaptive responses to climate change.

The narrative evidence indicates that the droughts of the 1930s increased the willingness to farmers to adopt hybrid seed. Simon Casady of Pioneer Hi-bred opined "One of the things that may have started the company off with a good boast was the drought of 1934 and again in 36 because both those adverse years proved to farmers that hybrid corn could endure such conditions better that normal corn and this really was the beginning of bid demand for hybrid seed." Culver and Hyde (2000, p. 149) concurred: "Almost overnight, demand for hybrid seed exploded" after the 1936 drought. Hybrid 307, a variety developed to survive in the dry and cold conditions, was especially popular. R. J. Liable (1936) wrote: "out of the worst drouth in the history of America's Corn Belt comes one welcome discovery which may, in the years to come, repay farmers many times over the losses they suffered in 1936."

But the narrative evidence and the archival records of Pioneer Hi-bred Company also indicate that negative weather shocks adversely affected the supply of hybrid seed. Commercial seed was produced like other agricultural products; a long dry spell or late freeze during the growing season when the seed was produced reduced supplies available to be sold to farmers to plant in the next year. The severe drought of 1934 cut production not only of the corn crop of 1934 but also the parent seed crop for 1935. Seed yields at Pioneer Hi-bred fell from 31.4 bushels per planted acre in 1933-34 to 15.9 bushels in 1934-35. The higher unit costs led Pioneer Hi-bred, for example, to sharply raise seed prices from an average of $6.58 per bushel in the 1934 crop year to $9.54 in 1935. The drought of 1936 had similar effects in seed yields, reducing locally-produced seed and threatening to slowing diffusion in the 1937 crop year. Other weather shocks mattered too; a freeze in Iowa in 1935 adversely affected the quality and quantity of the seed available for planting in the spring of 1936. (See Appendix Table A11.)

In response to weather-related challenges, Pioneer made innovations to its seed testing and cultivation processes and to its marketing program. In 1933, the firm created cold testing laboratory. The

firm was then better able to adapt to the 1935 freeze, which severely impacted germination rates of Pioneer's main local competitor, the Sioux City Seed Company. In 1935-36, Pioneer also shifted a part of its seed breeding operations to Argentina to take advantage of the southern hemisphere growing season. This made it possible to create two generations per year instead on just one. In 1936-37, the firm shifted a part of its multiplication operations there too. This move alleviated, though did not completely eliminate, the shortages of parent seed in 1937 arising from low yields during the 1936 drought. And in 1938, taking advantage of its greater supply capacities and superior germination rates, the firm announced a marketing program guaranteeing farmers free replacement seed if replanting proved necessary for any reason. The "replant agreement" gained wide acceptance. Pioneer's competitive success depended on its superior ability to adapt to weather-related challenges. Focusing exclusively on the demand side for hybrid seed misses important channels on the supply side.

Fitzgerald (1990, p. 196) observes that the droughts of 1934 and 1936 reduced the availability of seed for planting. Many farmers had to buy outside seed, of either open pollinated or hybrid types. The Funk Brothers Seed Company, a leading firm in Illinois produced both types of seed. It responded to the shortage by increasing prices across the board. In 1933, Funk sold hybrid seed for $4.11 per bushel and open-pollinated seed for $1.48. In 1937, it sold the former for $9.46 and the later for $3.55 (Fitzgerald 1990, p. 164). Funk's seed was not especially noted for its drought resistance. Breeding at the federal field station at the Funk Brothers focused primarily on disease resistance, cold-tolerance, and insect resistance (Fitzgerald 1990, pp. 154-61). The price co-movements are consistent with an increase in total demand and reduction in supply, rather the increase in demand solely for drought-resistant hybrid seed (as suggested in Sutch 2008).

## Summary and Conclusion

As the effects of climate change become more pronounced and the challenges of increasing temperatures accumulate, technology may provide agriculture some solutions. The contemporary studies measuring how the agricultural sector adapts to a changing climate often unable to observe the adoption of specific technologies. In this paper, we study the historic example of hybrid corn seeds and their adoption during a period of great drought and farm distress. This historic example provides an opportunity to study how farmers adopt potentially weather mitigating technologies in response to adverse weather stress. In our research, we reconstruct hybrid corn adoption data at a more disaggregated geographic

level than previously available to researchers from the years 1931 to 1955. By matching this data with information on drought conditions, we test whether drought exposure hastened or hindered the adoption hybrids. Our findings suggest that drought accelerated the adoption of hybrid seeds, but that this accelerative effect occurs several years after the initial weather shock. Our empirical results also highlight the importance of the 1934 drought, rather than the 1936 event which has gained most of the attention in the literature.

## References


Cavanagh, H. (1959). *Seed, Soil, and Science: The Story of Eugene D. Funk*. Chicago: Lakeside Press.

Crabb, A. R. (1947). *The Hybrid-Corn Makers: Prophets Of Plenty*. Rutgers University Press: New Brunswick.

Culver, John C.; and John Hyde. (2000). *American Dreamer: The Life and Times of Henry A. Wallace*. Norton.

David, Paul (2003). "Zvi Griliches on Diffusion, Lags and Productivity Growth ... Connecting the Dots."

Dixon, R. (1980). Hybrid corn revisited. *Econometrica* 48, no. 6, 1451-62.

Dowell, A. A. and O. B. Jesness (1939). Economic aspects of hybrid corn. *Journal of Farm Economics 21*(2), 479–488.

Fitzgerald, Deborah (1990). *The Business of Breeding: Hybrid Corn in Illinois, 1890-1940*. (Ithaca, NY: Cornell Univ. Press.)

Gilchrist, D. S. and E. G. Sands (2016). Something to talk about: Social spillovers in movie consumption. *Journal of Political Economy 124*(5), 1339–1382.

Griliches, Z. (1957). Hybrid corn: An exploration in the economics of technological change. *Econometrica*, 501–522.

Griliches, Z. (1958). Research costs and social returns: Hybrid corn and related innovations. *Journal of political economy 66*(5), 419–431.

Griliches, Z. (1960). Hybrid corn and the economics of innovation. *Science 132*(3422), 275–280.

Griliches, Z. (1980). Hybrid corn revisited: a reply. *Econometrica* 1463–1465.

Griliches, Z. papers. Special Collection Library. Harvard University.

Liable. R. J. (1936). *The Furrow*. (Nov.-Dec).

Kloppenburg, J. (1988). *First the Seed: The Political Economy of Biotechnology, 1492-2000*. Cambridge Univ. Press.

Mendelsohn, R., Nordhaus, W. D., & Shaw, D. (1994). The impact of global warming on agriculture: a Ricardian analysis. *The American economic review*, 753-771.

National Oceanic and Atmospheric Administration (2015). Monthly Historic U.S. Weather Data. Dataset.

Olmstead, Alan L. and Paul W. Rhode (2008). *Creating Abundance: Biological Innovation and American Agricultural Development*. Cambridge Univ. Press.

Pioneer Hi-Bred Company records. Iowa State Univ. Library.

Rogers, Everett (1962). *Diffusion of Innovation*. New York: Free Press.

Ryan, B. and N. Gross (1950). Acceptance and diffusion of hybrid corn seed in two Iowa communities. *Research Bulletin (Iowa Agriculture and Home Economics Experiment Station) 29*(372), 1.

Schlenker, W., Hanemann, W. M., & Fisher, A. C. (2005). Will US agriculture really benefit from global warming? Accounting for irrigation in the hedonic approach. *American Economic Review*, *95*(1), 395-406.

Schlenker, W., Hanemann, W. M., & Fisher, A. C. (2006). The impact of global warming on US agriculture: an econometric analysis of optimal growing conditions. *Review of Economics and statistics*, *88*(1), 113-125.

Schlenker, W. and M. J. Roberts (2009). Nonlinear temperature effects indicate severe damages to US crop yields under climate change. *Proceedings of the National Academy of sciences 106*(37), 15594–15598.

Suri, Tavneet (2011). Selection and Comparative Advantage in Technology Adoption. *Econometrica* 79, no. 1 (Jan.), 159-209.

Sutch, R. (2008). "Henry Agard Wallace, the Iowa Corn Yield Tests, and the Adoption of Hybrid Corn." NBER Working Paper No. 14141.

Sutch, R. (2011). The Impact of the 1936 Corn Belt Drought on American Farmers' Adoption of Hybrid Corn. In *The economics of climate change: Adaptations past and present*, pp. 195–223. Univ. of Chicago Press.

USDA. *Agricultural Statistics*. GPO: Washington, DC.

USDA (1963). *Prices paid by farmers for seed: spring season averages, 1926-1961: September 15 prices, 1949-1961, by states and United States.* Statistical Bulletin No. 328. GPO: Washington, DC.

**Appendix: Robustness Checks and Additional Figures**

Table A1: Correlation of Drought Indicator Measures, 1931 to 1940

| | D1931 | D1932 | D1933 | D1934 | D1935 | D1936 | D1937 | D1938 | D1939 | D1940 |
|---|---|---|---|---|---|---|---|---|---|---|
| D1931 | 1 | | | | | | | | | |
| D1932 | 0.1409 | 1 | | | | | | | | |
| D1933 | 0.0292 | 0.1213 | 1 | | | | | | | |
| D1934 | 0.1895 | 0.1278 | 0.2599 | 1 | | | | | | |
| D1935 | -0.0319 | 0.0456 | 0.3144 | 0.3568 | 1 | | | | | |
| D1936 | -0.0568 | -0.0505 | 0.1676 | 0.1855 | 0.2758 | 1 | | | | |
| D1937 | -0.1278 | -0.0225 | 0.3277 | 0.3293 | 0.4114 | 0.3176 | 1 | | | |
| D1938 | -0.1448 | -0.0786 | 0.1551 | 0.2365 | 0.5635 | 0.2716 | 0.571 | 1 | | |
| D1939 | -0.1972 | -0.0192 | 0.291 | 0.3223 | 0.3865 | 0.2812 | 0.5802 | 0.5329 | 1 | |
| D1940 | -0.0173 | -0.0682 | 0.3065 | 0.3887 | 0.3112 | 0.287 | 0.4418 | 0.4067 | 0.5431 | 1 |

Table A2: Correlation of PDSI Measures, 1931 to 1940

| | D1931 | D1932 | D1933 | D1934 | D1935 | D1936 | D1937 | D1938 | D1939 | D1940 |
|---|---|---|---|---|---|---|---|---|---|---|
| D1931 | 1 | | | | | | | | | |
| D1932 | 0.2982 | 1 | | | | | | | | |
| D1933 | -0.1261 | 0.0603 | 1 | | | | | | | |
| D1934 | 0.1408 | 0.0581 | 0.3812 | 1 | | | | | | |
| D1935 | -0.0956 | -0.0677 | 0.4136 | 0.2813 | 1 | | | | | |
| D1936 | 0.1842 | 0.0492 | 0.0161 | 0.5065 | 0.2429 | 1 | | | | |
| D1937 | -0.2647 | -0.1462 | 0.3456 | 0.3254 | 0.2022 | 0.4084 | 1 | | | |
| D1938 | -0.306 | -0.1891 | 0.23 | 0.1826 | 0.399 | 0.3414 | 0.5764 | 1 | | |
| D1939 | -0.2741 | -0.112 | 0.4155 | 0.5035 | 0.2932 | 0.3051 | 0.6275 | 0.6177 | 1 | |
| D1940 | 0.0221 | -0.0581 | 0.4512 | 0.5312 | 0.2224 | 0.3364 | 0.3577 | 0.2862 | 0.4584 | 1 |

Table A3: Robustness, Omitting Missing Observation Recode. Effect of Drought Indicator on Hybrid Log Odds Ratio

| | ln(%h/(1-%h)) | | | | |
|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) |
| Drought, t-1 | -1.588 | -0.448 | -0.014 | -1.682 | 0.017 |
| | (0.172)*** | (0.135)*** | (0.074) | (0.217)*** | (0.063) |
| | [0.494]*** | [0.265] | [0.099] | [0.521]*** | [0.100] |
| | {0.209}*** | {0.167}*** | {0.080} | {0.217}*** | {0.063} |
| N | 3393 | 3393 | 3393 | 3393 | 3393 |
| adj. R-sq | 0.285 | 0.325 | 0.869 | 0.045 | 0.937 |
| | ln(%h/(1-%h)) | | | | |
| | (1) | (2) | (3) | (4) | (5) |
| Years of Drought, t-1 | 0.742 | 0.345 | -0.012 | 2.315 | 0.166 |
| | (0.033)*** | (0.021)*** | (0.017) | (0.120)*** | (0.051)*** |
| | [0.117]*** | [0.159]** | [0.095] | [0.231]*** | [0.077]** |
| | {0.077}*** | {0.080}*** | {0.058} | {0.120}*** | {0.051}*** |
| N | 3393 | 3393 | 3393 | 3393 | 3393 |
| adj. R-sq | 0.357 | 0.369 | 0.869 | 0.474 | 0.939 |
| State FE | Y | N | Y | N | N |
| Year FE | N | Y | Y | N | Y |
| CRD FE | N | N | N | Y | Y |

Drought denotes a year when an observation was in moderate or worse drought, <-2 on the PDSI. White robust standard errors are in parentheses. Clustered standard errors at the state level are in brackets. Clustered standard errors at the crop reporting district are in curly brackets.

* p<0.10, ** p<0.05, *** p<0.01

Table A4: Robustness, Omitting Missing Obs Recode. Effect of PDSI on Hybrid Log Odds Ratio

| | ln(%h/(1-%h)) | | | | |
|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) |
| PDSI, t-1 | 0.317 | 0.107 | -0.033 | 0.342 | -0.017 |
| | (0.030)*** | (0.031)*** | (0.014)** | (0.043)*** | (0.012) |
| | [0.110]*** | [0.066] | [0.023] | [0.112]*** | [0.025] |
| | {0.042}*** | {0.032}*** | {0.013}** | {0.043}*** | {0.012} |
| N | 3393 | 3393 | 3393 | 3393 | 3393 |
| adj. R-sq | 0.286 | 0.325 | 0.869 | 0.048 | 0.938 |
| | ln(%h/(1-%h)) | | | | |
| | (1) | (2) | (3) | (4) | (5) |
| Cumulative PDSI, t-1 | 0.039 | -0.082 | -0.030 | 0.092 | -0.031 |
| | (0.010)*** | (0.007)*** | (0.005)*** | (0.034)*** | (0.008)*** |
| | [0.043] | [0.042]* | [0.018] | [0.066] | [0.011]** |
| | {0.023}* | {0.024}*** | {0.014}** | {0.034}*** | {0.008}*** |
| N | 3393 | 3393 | 3393 | 3393 | 3393 |
| adj. R-sq | 0.260 | 0.344 | 0.870 | 0.014 | 0.938 |
| State FE | Y | N | Y | N | N |
| Year FE | N | Y | Y | N | Y |
| CRD FE | N | N | N | Y | Y |

PDSI denotes the average Palmer Drought Severity Index between April and September in a given year. These months coincide with the growing season window for corn. White robust standard errors are in parentheses. Clustered standard errors at the state level are in brackets. Clustered standard errors at the crop reporting district are in curly brackets.
* p<0.10, ** p<0.05, *** p<0.01

Table A5: Placebo - Drought 25 Years Prior

| | ln(%h/(1-%h) | | | | |
|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) |
| Placebo, Drought, t-25 | 0.103 | 0.035 | -0.003 | 0.115 | 0.010 |
| | (0.033)*** | (0.029) | (0.016) | (0.026)*** | (0.013) |
| | [0.047]** | [0.081] | [0.035] | [0.048]** | [0.028] |
| | {0.026}*** | {0.041} | {0.021} | {0.026}*** | {0.013} |
| N | 4516 | 4516 | 4516 | 4516 | 4516 |
| adj. R-sq | 0.310 | 0.570 | 0.889 | 0.003 | 0.886 |
| | ln(%h/(1-%h) | | | | |
| | (1) | (2) | (3) | (4) | (5) |
| Placebo, PDSI, t-25 | -0.378 | -0.695 | -0.055 | -0.372 | -0.040 |
| | (0.180)** | (0.145)*** | (0.071) | (0.193)* | (0.066) |
| | [0.429] | [0.293]** | [0.152] | [0.435] | [0.143] |
| | {0.190}** | {0.142}*** | {0.074} | {0.193}* | {0.066} |
| N | 4516 | 4516 | 4516 | 4516 | 4516 |
| adj. R-sq | 0.310 | 0.572 | 0.889 | 0.001 | 0.886 |
| State FE | Y | N | Y | N | N |
| Year FE | N | Y | Y | N | Y |
| CRD FE | N | N | N | Y | Y |

Drought denotes a year when an observation was in moderate or worse drought, <-2 on the PDSI. PDSI denotes the Palmer Drought Severity Index. White robust standard errors are in parentheses. Clustered standard errors at the state level are in brackets. Clustered standard errors at the crop reporting district are in curly brackets.
* p<0.10, ** p<0.05, *** p<0.01

Table A6: Robustness. Effect of Drought Indicator on Change in % Hybrid

| | %Hybrid, t - %Hybrid, t-1 | | | | |
|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) |
| Drought, t-1 | -0.841 | 0.044 | -0.198 | -0.855 | -0.191 |
| | (0.260)*** | (0.281) | (0.288) | (0.314)*** | (0.366) |
| | [0.535] | [0.518] | [0.509] | [0.538] | [0.523] |
| | {0.308}*** | {0.358} | {0.353} | {0.314}*** | {0.366} |
| N | 4318 | 4318 | 4318 | 4318 | 4318 |
| adj. R-sq | 0.018 | 0.077 | 0.094 | 0.002 | 0.079 |
| | %Hybrid, t - %Hybrid, t-1 | | | | |
| | (1) | (2) | (3) | (4) | (5) |
| Years of Drought, t-1 | 0.299 | 0.185 | 0.035 | 0.579 | 0.137 |
| | (0.062)*** | (0.048)*** | (0.075) | (0.090)*** | (0.142) |
| | [0.122]** | [0.074]** | [0.103] | [0.197]*** | [0.240] |
| | {0.058}*** | {0.038}*** | {0.059} | {0.090}*** | {0.142} |
| N | 4318 | 4318 | 4318 | 4318 | 4318 |
| adj. R-sq | 0.021 | 0.081 | 0.094 | 0.010 | 0.080 |
| State FE | Y | N | Y | N | N |
| Year FE | N | Y | Y | N | Y |
| CRD FE | N | N | N | Y | Y |

Drought denotes a year when an observation was in moderate or worse drought, <-2 on the PDSI. White robust standard errors are in parentheses. Clustered standard errors at the state level are in brackets. Clustered standard errors at the crop reporting district are in curly brackets.

* p<0.10, ** p<0.05, *** p<0.01

Table A7: Robustness. Effect of PDSI on Change in % Hybrid

| | %Hybrid, t - %Hybrid, t-1 | | | | |
|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) |
| PDSI, t-1 | 0.132 | -0.075 | -0.081 | 0.132 | -0.084 |
| | (0.054)** | (0.066) | (0.065) | (0.073)* | (0.089) |
| | [0.151] | [0.166] | [0.168] | [0.151] | [0.170] |
| | [0.151] | [0.166] | [0.168] | [0.151] | [0.170] |
| N | 4318 | 4318 | 4318 | 4318 | 4318 |
| adj. R-sq | 0.017 | 0.078 | 0.094 | 0.001 | 0.080 |
| | %Hybrid, t - %Hybrid, t-1 | | | | |
| | (1) | (2) | (3) | (4) | (5) |
| Cumulative PDSI, t-1 | -0.181 | -0.073 | -0.063 | -0.278 | -0.102 |
| | (0.022)*** | (0.018)*** | (0.024)*** | (0.045)*** | (0.053)* |
| | [0.062]*** | [0.042]* | [0.062] | [0.096]*** | [0.111] |
| | {0.030}*** | {0.020}*** | {0.030}** | {0.045}*** | {0.053}* |
| N | 4318 | 4318 | 4318 | 4318 | 4318 |
| adj. R-sq | 0.034 | 0.082 | 0.095 | 0.027 | 0.082 |
| State FE | Y | N | Y | N | N |
| Year FE | N | Y | Y | N | Y |
| CRD FE | N | N | N | Y | Y |

PDSI denotes the average Palmer Drought Severity Index between April and September in a given year. These months coincide with the growing season window for corn. White robust standard errors are in parentheses. Clustered standard errors at the state level are in brackets. Clustered standard errors at the crop reporting district are in curly brackets.
* p<0.10, ** p<0.05, *** p<0.01

Table A8: Robustness. Pre/Post Drought Dummies from 1931 to 1940, ln odds ratio

| | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| drought_31 | 0.388 | 1.619 | 0.239 | . | . |
| | (0.151)** | (0.068)*** | (0.072)*** | (.) | (.) |
| | [0.373] | [0.464]*** | [0.258] | [.] | [.] |
| | {0.313} | {0.274}*** | {0.215} | {.} | {.} |
| drought_32 | -0.009 | -0.417 | -0.193 | . | . |
| | (0.227) | (0.136)*** | (0.101)* | (.) | (.) |
| | [0.568] | [0.705] | [0.381] | [.] | [.] |
| | {0.506} | {0.562} | {0.278} | {.} | {.} |
| drought_33 | -0.481 | -0.626 | -0.340 | -1.930 | -0.630 |
| | (0.194)** | (0.106)*** | (0.107)*** | (0.796)** | (0.456) |
| | [0.821] | [0.391] | [0.630] | [0.897]** | [0.494] |
| | {0.545} | {0.423} | {0.363} | {0.796}** | {0.456} |
| drought_34 | 2.402 | 3.076 | 0.862 | 3.724 | 2.746 |
| | (0.172)*** | (0.077)*** | (0.083)*** | (0.310)*** | (0.231)*** |
| | [0.647]*** | [0.614]*** | [0.325]** | [0.632]*** | [0.500]*** |
| | [0.500]*** | {0.355}*** | {0.303}*** | {0.210}*** | {0.310}*** |
| drought_35 | 0.429 | 0.165 | 0.590 | -0.289 | 0.214 |
| | (0.174)** | (0.117) | (0.080)*** | (0.715) | (0.404) |
| | [0.350] | [0.499] | [0.282]** | [0.952] | [0.495] |
| | [0.495] | {0.395} | {0.459} | {0.247}** | {0.715} |
| drought_36 | 1.805 | 0.437 | 0.108 | 3.844 | 0.835 |
| | (0.132)*** | (0.069)*** | (0.060)* | (0.277)*** | (0.237)*** |
| | [0.531]*** | [0.421] | [0.306] | [0.598]*** | [0.478]* |
| | {0.297}*** | {0.269} | {0.188} | {0.277}*** | {0.237}*** |
| drought_37 | 0.025 | -1.536 | -0.907 | -0.554 | -1.078 |
| | (0.161) | (0.128)*** | (0.088)*** | (0.631) | (0.304)*** |
| | [0.772] | [0.567]** | [0.593] | [0.792] | [0.444]** |
| | {0.445} | {0.494}*** | {0.303}*** | {0.631} | {0.304}*** |
| drought_38 | -0.252 | 1.307 | 0.298 | -0.093 | 0.823 |
| | (0.228) | (0.206)*** | (0.122)** | (0.868) | (0.460)* |
| | [0.647] | [0.767] | [0.483] | [1.051] | [0.423]* |
| | {0.608} | {0.789}* | {0.391} | {0.868} | {0.460}* |
| drought_39 | 1.266 | -1.715 | -0.152 | 0.827 | -0.498 |
| | (0.184)*** | (0.142)*** | (0.094) | (0.577) | (0.244)** |
| | [0.658]* | [0.759]** | [0.416] | [0.853] | [0.394] |
| | {0.502}** | {0.523}*** | {0.287} | {0.577} | {0.244}** |
| drought_40 | 2.998 | 1.635 | 0.573 | 4.185 | 0.805 |
| | (0.138)*** | (0.116)*** | (0.074)*** | (0.322)*** | (0.205)*** |
| | [0.424]*** | [0.392]*** | [0.207]** | [0.456]*** | [0.293]** |
| | {0.323}*** | {0.411}*** | {0.178}*** | {0.322}*** | {0.205}*** |
| State FE | Y | N | Y | N | N |
| Year FE | N | Y | Y | N | Y |
| CRD FE | N | N | N | Y | Y |
| N | 4516 | 4516 | 4516 | 4516 | 4516 |
| adj. R-sq | 0.488 | 0.783 | 0.898 | 0.405 | 0.905 |

Drought denotes a year when an observation was in moderate or worse drought, <-2 on the PDSI. White robust standard errors are in parentheses. Clustered standard errors at the state level are in brackets. Clustered standard errors at the crop reporting district are in curly brackets.

* p<0.10, ** p<0.05, *** p<0.01

Table A9: Robustness. Pre/Post Drought PDSI from 1931 to 1940, ln odds ratio

| | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| pdsi_y31 | 0.012 | -0.396 | -0.102 | . | . |
| | (0.055) | (0.023)*** | (0.025)*** | (.) | (.) |
| | [0.217] | [0.142]** | [0.117] | [.] | [.] |
| | {0.126} | {0.088}*** | {0.077} | {.} | {.} |
| pdsi_y32 | -0.238 | 0.150 | 0.050 | . | . |
| | (0.060)*** | (0.033)*** | (0.030)* | (.) | (.) |
| | [0.221] | [0.260] | [0.164] | [.] | [.] |
| | {0.145} | {0.136} | {0.093} | {.} | {.} |
| pdsi_y33 | -0.124 | 0.292 | 0.029 | 0.041 | 0.221 |
| | (0.069)* | (0.037)*** | (0.037) | (0.135) | (0.112)** |
| | [0.253] | [0.170] | [0.204] | [0.248] | [0.170] |
| | {0.157} | {0.140}** | {0.115} | {0.135} | {0.112}** |
| pdsi_y34 | -0.522 | -1.175 | -0.416 | -0.529 | -0.862 |
| | (0.051)*** | (0.028)*** | (0.033)*** | (0.061)*** | (0.067)*** |
| | [0.172]*** | [0.202]*** | [0.124]*** | [0.124]*** | [0.161]*** |
| | {0.109}*** | {0.097}*** | {0.082}*** | {0.061}*** | {0.067}*** |
| pdsi_y35 | 0.272 | 0.245 | 0.053 | 0.336 | 0.242 |
| | (0.040)*** | (0.027)*** | (0.021)** | (0.130)** | (0.085)*** |
| | [0.123]** | [0.130]* | [0.096] | [0.179]* | [0.122]* |
| | {0.088}*** | {0.107}** | {0.062} | {0.130}** | {0.085}*** |
| pdsi_y36 | -1.166 | 0.033 | -0.123 | -1.631 | -0.488 |
| | (0.054)*** | (0.036) | (0.034)*** | (0.108)*** | (0.086)*** |
| | [0.244]*** | [0.175] | [0.147] | [0.227]*** | [0.157]*** |
| | {0.125}*** | {0.131} | {0.089} | {0.108}*** | {0.086}*** |
| pdsi_y37 | 0.045 | 0.395 | 0.227 | 0.136 | 0.425 |
| | (0.051) | (0.032)*** | (0.027)*** | (0.150) | (0.074)*** |
| | [0.245] | [0.155]** | [0.153] | [0.257] | [0.138]*** |
| | {0.130} | {0.119}*** | {0.081}*** | {0.150} | {0.074}*** |
| pdsi_y38 | 0.657 | 0.291 | 0.121 | 1.132 | 0.120 |
| | (0.061)*** | (0.046)*** | (0.031)*** | (0.227)*** | (0.101) |
| | [0.286]** | [0.211] | [0.149] | [0.354]*** | [0.144] |
| | {0.171}*** | {0.173}* | {0.091} | {0.227}*** | {0.101} |
| pdsi_y39 | -0.605 | 0.029 | -0.108 | -0.715 | -0.148 |
| | (0.064)*** | (0.040) | (0.030)*** | (0.228)*** | (0.072)** |
| | [0.401] | [0.211] | [0.145] | [0.500] | [0.140] |
| | {0.188}*** | {0.135} | {0.078} | {0.228}*** | {0.072}** |
| pdsi_y40 | -1.139 | -0.551 | -0.301 | -1.292 | -0.293 |
| | (0.047)*** | (0.027)*** | (0.024)*** | (0.147)*** | (0.044)*** |
| | [0.300]*** | [0.130]*** | [0.086]*** | [0.345]*** | [0.087]*** |
| | {0.128}*** | {0.087}*** | {0.048}*** | {0.147}*** | {0.044}*** |
| State FE | Y | N | Y | N | N |
| Year FE | N | Y | Y | N | Y |
| CRD FE | N | N | N | Y | Y |
| N | 4516 | 4516 | 4516 | 4516 | 4516 |
| adj. R-sq | 0.590 | 0.806 | 0.902 | 0.514 | 0.912 |

PDSI denotes the average Palmer Drought Severity Index between April and September in a given year. These months coincide with the growing season window for corn. White robust standard errors are in parentheses. Clustered standard errors at the state level are in brackets. Clustered standard errors at the crop reporting district are in curly brackets.
* p<0.10, ** p<0.05, *** p<0.01

## Table A10: Seed Prices in Dollars per Bushel, 1926-57

| | Open Pollinated | | | | Hybrid | | | | Hybrid-OP Ratio | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | National | State | | Coeff. Of | National | State | | Coeff. Of | National | State | | Coeff. Of |
| | Average | Average | St Dev | Variation | Average | Average | St Dev | Variation | Average | Average | St Dev | Variation |
| 1926 | 3.39 | 330 | 1.06 | 0.32 | | | | | | | | |
| 1927 | 3.29 | 3.43 | 1.29 | 0.38 | | | | | | | | |
| 1928 | 3.05 | 3.18 | 0.75 | 0.24 | | | | | | | | |
| 1929 | 2.87 | 3.02 | 0.53 | 0.18 | | | | | | | | |
| 1930 | 3.08 | 3.13 | 0.55 | 0.18 | | | | | | | | |
| 1931 | 2.56 | 2.78 | 0.49 | 0.17 | | | | | | | | |
| 1932 | 1.59 | 1.88 | 0.62 | 0.33 | | | | | | | | |
| 1933 | 1.19 | 1.51 | 0.57 | 0.37 | | | | | | | | |
| 1934 | 1.70 | 1.88 | 0.44 | 0.24 | | | | | | | | |
| 1935 | 2.47 | 2.63 | 0.65 | 0.25 | | | | | | | | |
| 1936 | 2.60 | 2.86 | 0.88 | 0.31 | | | | | | | | |
| 1937 | 2.85 | 2.93 | 0.40 | 0.14 | 10.00 | 10.23 | 1.38 | 0.13 | 350.9 | 314.0 | 28.76 | 0.09 |
| 1938 | 2.00 | 2.19 | 0.41 | 0.19 | 7.30 | 7.25 | 0.62 | 0.09 | 365.0 | 342.1 | 80.16 | 0.23 |
| 1939 | 1.85 | 2.03 | 0.44 | 0.22 | 6.55 | 6.57 | 0.37 | 0.06 | 354.1 | 365.9 | 80.22 | 0.22 |
| 1940 | 2.00 | 2.13 | 0.31 | 0.15 | 6.10 | 6.08 | 0.92 | 0.15 | 305.0 | 290.0 | 65.37 | 0.23 |
| 1941 | 2.02 | 2.23 | 0.40 | 0.18 | 6.20 | 6.14 | 0.72 | 0.12 | 306.9 | 280.1 | 59.43 | 0.21 |
| 1942 | 2.50 | 2.70 | 0.39 | 0.14 | 6.90 | 6.73 | 0.62 | 0.09 | 276.0 | 256.0 | 46.22 | 0.18 |
| 1943 | 3.28 | 3.60 | 0.83 | 0.23 | 7.67 | 7.56 | 0.74. | 0.10 | 233.8 | 217.9 | 37.44 | 0.17 |
| 1944 | 3.82 | 4.14 | 0.69 | 0.17 | 8.49 | 8.26 | 0.54 | 0.07 | 222.3 | 203.9 | 34.71 | 0.17 |
| 1945 | 3.95 | 4.16 | 0.70 | 0.17 | 8.63 | 8.54 | 0.42 | 0.05 | 218.5 | 210.9 | 35.94 | 0.17 |
| 1946 | 4.32 | 4.64 | 1.15 | 0.25 | 8.80 | 8.84 | 0.57 | 0.06 | 203.7 | 198.4 | 39.64 | 0.20 |
| 1947 | 4.70 | 5.01 | 0.86 | 0.17 | 9.35 | 9.30 | 0.83 | 0.09 | 198.9 | 191.0 | 25.38 | 0.13 |
| 1948 | 5.57 | 5.73 | 0.78 | 0.14 | 11.10 | 10.76 | 1.06 | 0.10 | 199.3 | 188.9 | 21.98 | 0.12 |
| 1949 | 4.79 | 5.05 | 0.54 | 0.11 | 10.50 | 10.09 | 0.82 | 0.08 | 219.2 | 202.0 | 24.64 | 0.12 |
| 1950 | 4.56 | 4.81 | 0.53 | 0.11 | 9.81 | 9.62 | 0.77 | 0.08 | 215.1 | 202.8 | 23.91 | 0.12 |
| 1951 | 5.17 | 5.40 | 0.66 | 0.12 | 10.30 | 9.96 | 1.02 | 0.10 | 199.2 | 186.1 | 22.72 | 0.12 |
| 1952 | 5.73 | 6.13 | 1.12 | 0.18 | 11.00 | 10.50 | 1.20 | 0.11 | 192.0 | 177.5 | 26.31 | 0.15 |
| 1953 | 5.97 | 6.08 | 0.54 | 0.09 | 11.20 | 11.08 | 1.06 | 0.10 | 187.6 | 183.4 | 19.53 | 0.11 |
| 1954 | 5.58 | 5.82 | 0.43 | 0.07 | 11.00 | 10.87 | 1.10 | 0.10 | 197.1 | 186.6 | 22.53 | 0.12 |
| 1955 | 5.54 | 5.88 | 0.54 | 0.09 | 11.00 | 10.82 | 1.07 | 0.10 | 198.6 | 187.5 | 24.60 | 0.13 |
| 1956 | 5.06 | 5.64 | 0.70 | 0.12 | 10.90 | 10.68 | 1.14 | 0.11 | 215.4 | 191.9 | 32.42 | 0.17 |
| 1957 | 5.15 | 5.92 | 0.85 | 0.14 | 10.70 | 10.58 | 1.31 | 0.12 | 207.8 | 182.0 | 29.41 | 0.16 |

Source: USDA (1963). *Prices paid by farmers for seed: spring season averages, 1926-1961: September 15 prices, 1949-1961, by states and United States.* Statistical Bulletin No. 328. GPO: Washington, DC.

Table A11: Pioneer Prices, Yields, Costs, and Sales

| Year | Seed Price | Seed Yield | Unit | Sales | Source and Notes |
|---|---|---|---|---|---|
| | $/bu | Bu/acre | Production | Bushels | |
| | | | Cost,$/bu | Customers | |
| 1926-27 | | 20.0 | | 605 | History of Pioneer's First Ten Years |
| 1927-28 | 7.20 | 24.0 | | 928 | " |
| 1928-29 | | 25.2 | | 2,055 | " |
| 1929-30 | 10.43 | 31.0 | | 2,281 | " |
| 1930-31 | 10.60 | 18.0 | | 1,870 | " Realized price=$7.83 |
| 1931-32 | 6.50 | 19.5 | | 2,656 | " Net sales of 470 bu to other cos |
| 1932-33 | 5.41 | 27.1 | | 3,643 | " Net sales of 663 bu to other cos |
| 1933-34 | 6.58 | 31.4 | | 16,252 | " Net sales of 1,570 bu to other cos |
| 1934-35 | 9.54 | 15.9 | | 23,771 | " Net sales of 813 bu to other cos |
| 1935-36 | 8.86 | 20.0 | | 31,700 | " Net sales of 1,968 bu to other cos |
| 1936-37 | 9.96 | 16.6 | | 40,586 | " Net sales of 6,057 bu to other cos |
| | | | | Total | |
| 1933-34 | 6.85 | 31.4 | 4.33 | 18,617 | 1937 Annual Report |
| 1934-35 | 9.79 | 16.1 | 7.56 | 25,313 | 1937 Annual Report |
| 1935-36 | 8.79 | 19.3 | 7.13 | 33,744 | 1937 Annual Report |
| 1936-37 | 11.11 | 17.5 | 8.29 | 54,910 | 1937 Annual Report |
| 1937-38 | 7.88 | 35.9 | 6.49 | 109,000 | 1938 Annual Report |
| 1938-39 | 7.30 | 41.9 | 5.66 | 152,157 | 1940 Annual Report |
| 1939-40 | 7.20 | 34.9 | 7.00 | 160,127 | 1940 Annual Report |
| 1940-41 | 7.01 | 36.0 | 6.29 | 166,503 | 1942 Annual Report |
| 1941-42 | 7.73 | 35.4 | 6.85 | 192,700 | 1942 Annual Report |
| 1942-43 | 8.40 | 56.1 | 6.62 | 269,378 | 1944 Annual Report |
| 1943-44 | 8.84 | 47.7 | 7.22 | 292,113 | 1944 Annual Report |

Compiled from Pioneer Hi-Bred Company Records, Iowa State Univ. Library

**PDSI Figures: 1933 to 1940, -4 (extreme drought) to + 4 (extreme wetness)**

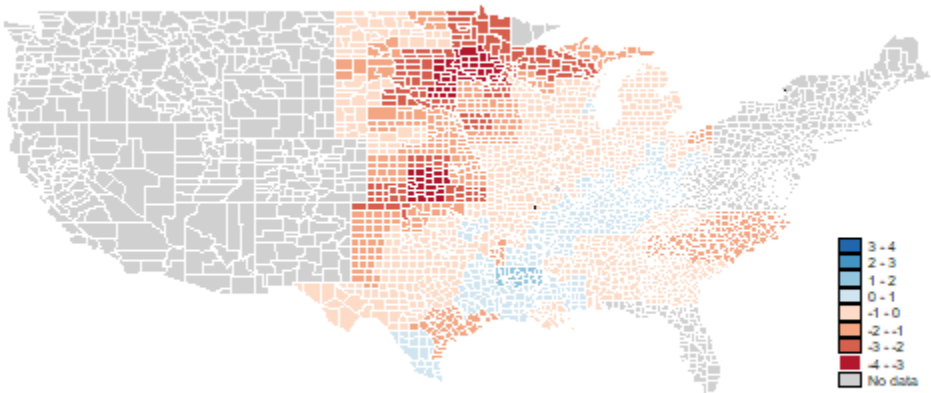



Figure A1: 1933

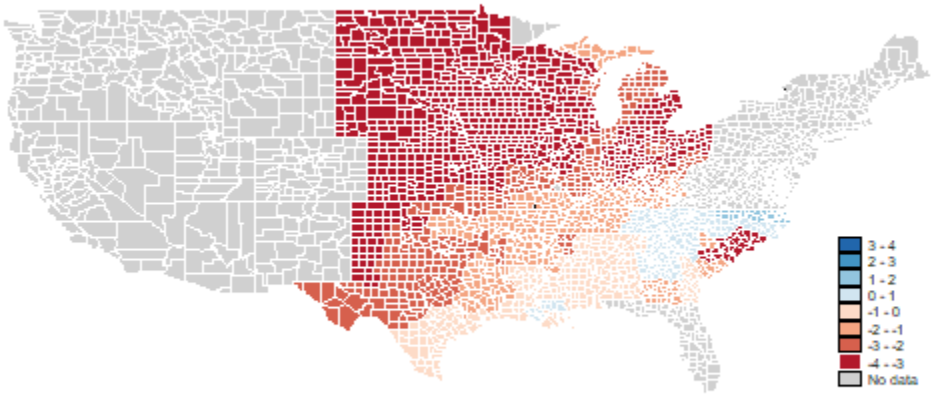



Figure A2: 1934

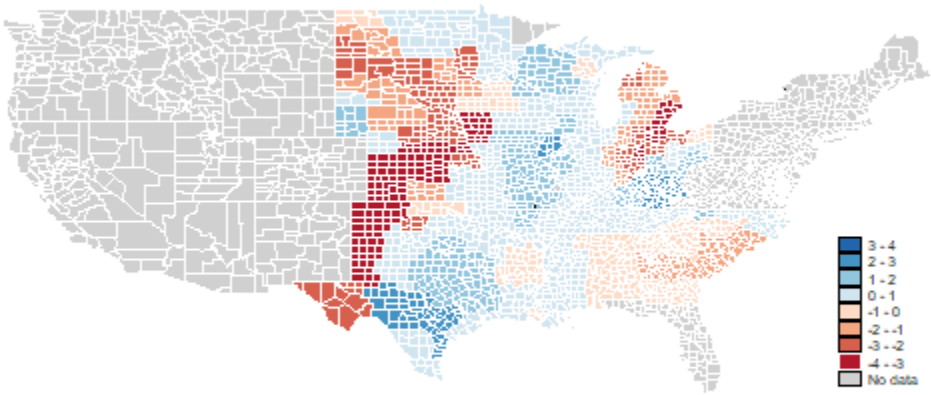



Figure A3: 1935

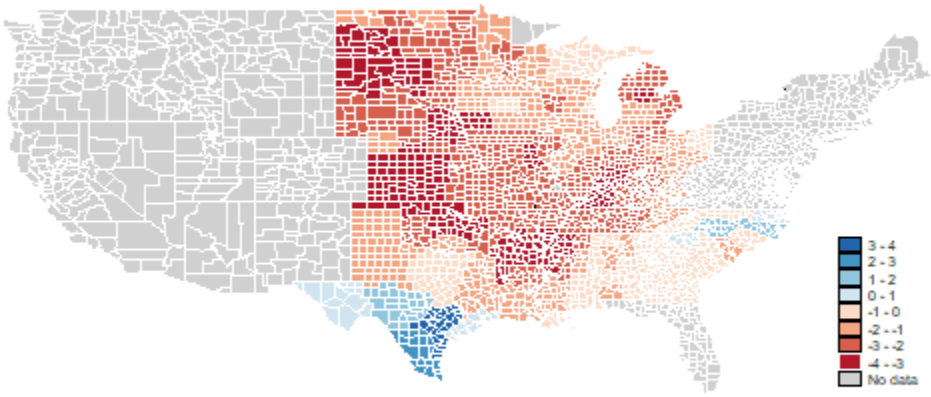



Figure A4: 1936

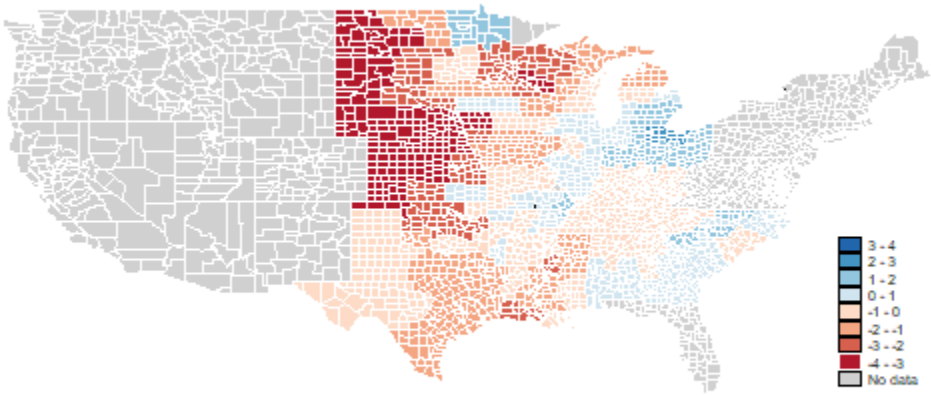



Figure A5: 1937

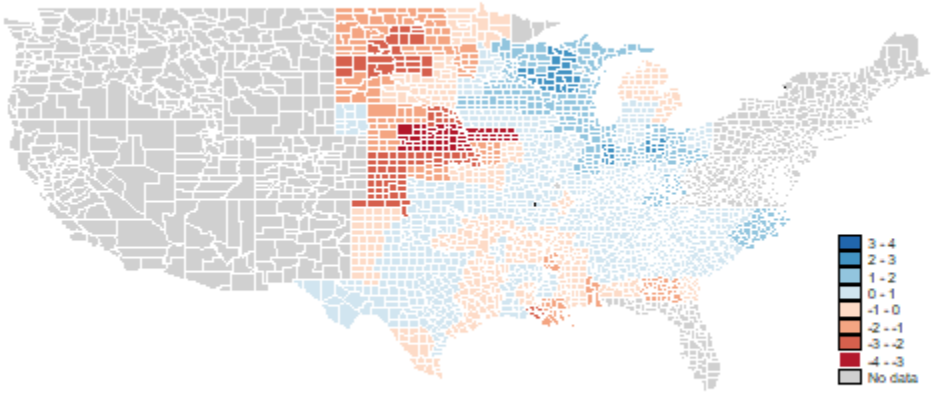



Figure A6: 1938

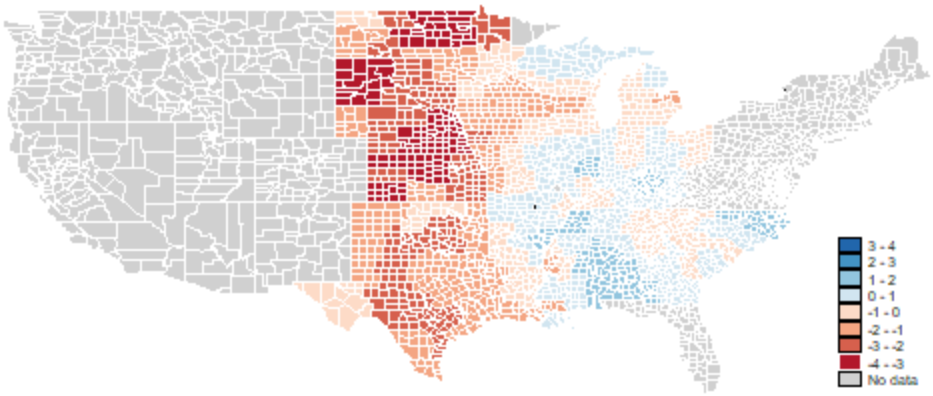



Figure A7: 1939

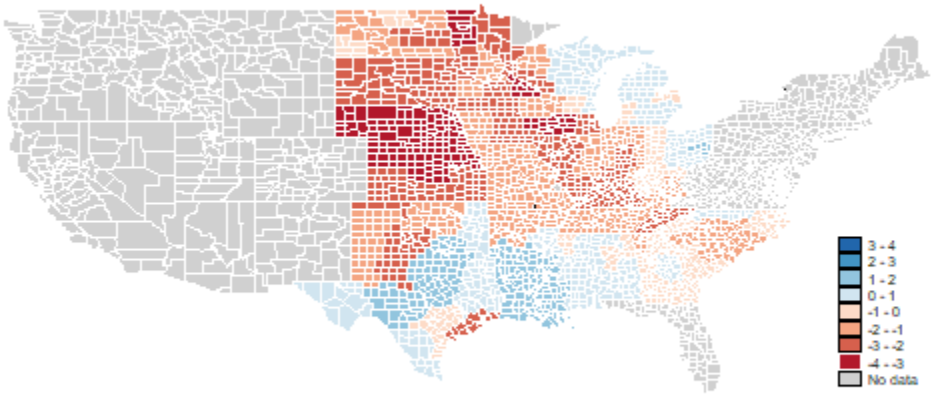



Figure A8: 1940

**Alternative Coefficient Plots, CRD FE and Clustered SE by CRD**

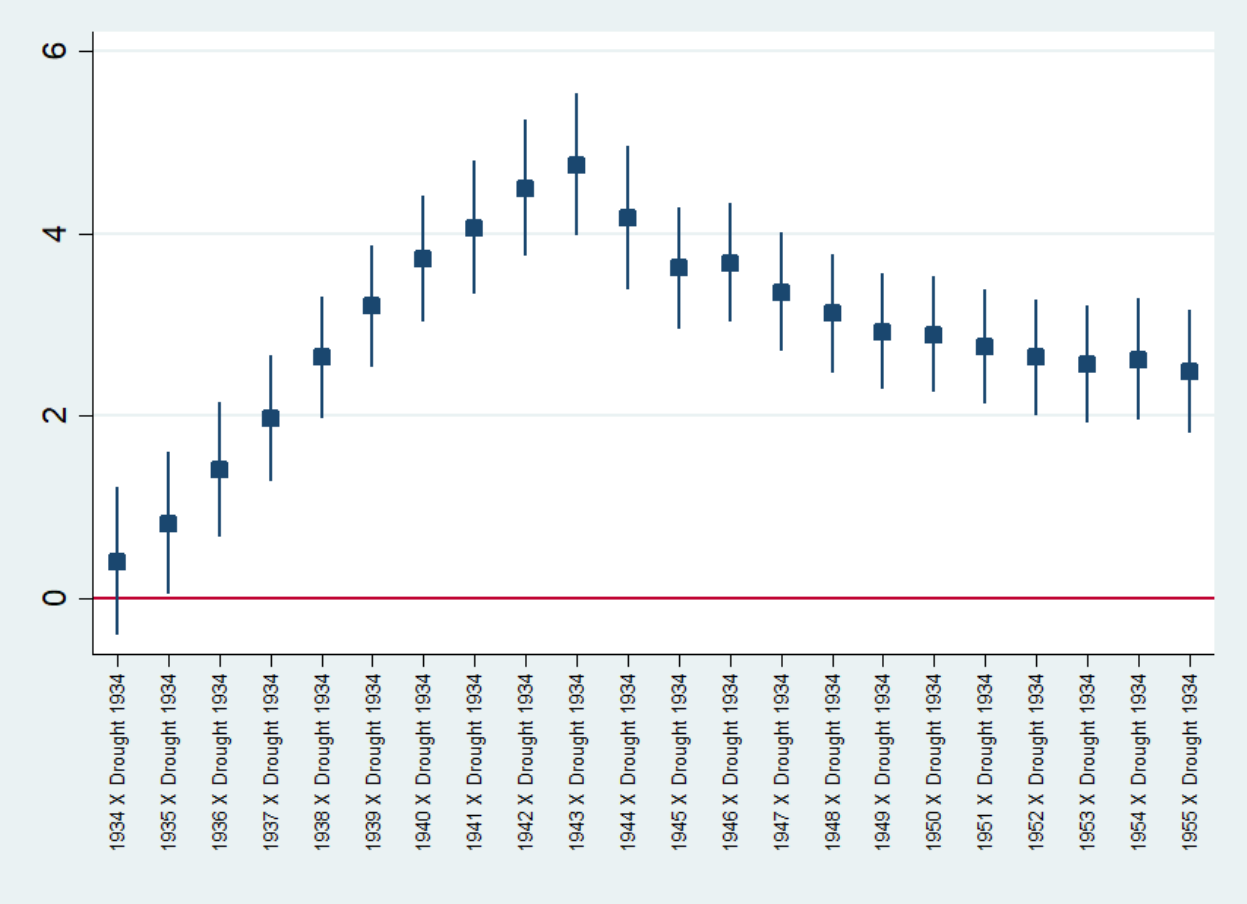



Figure A9: Robustness, CRD FE. Effect of 1934 Drought Indicator X Year Indicator on ln hybrid odds radio.

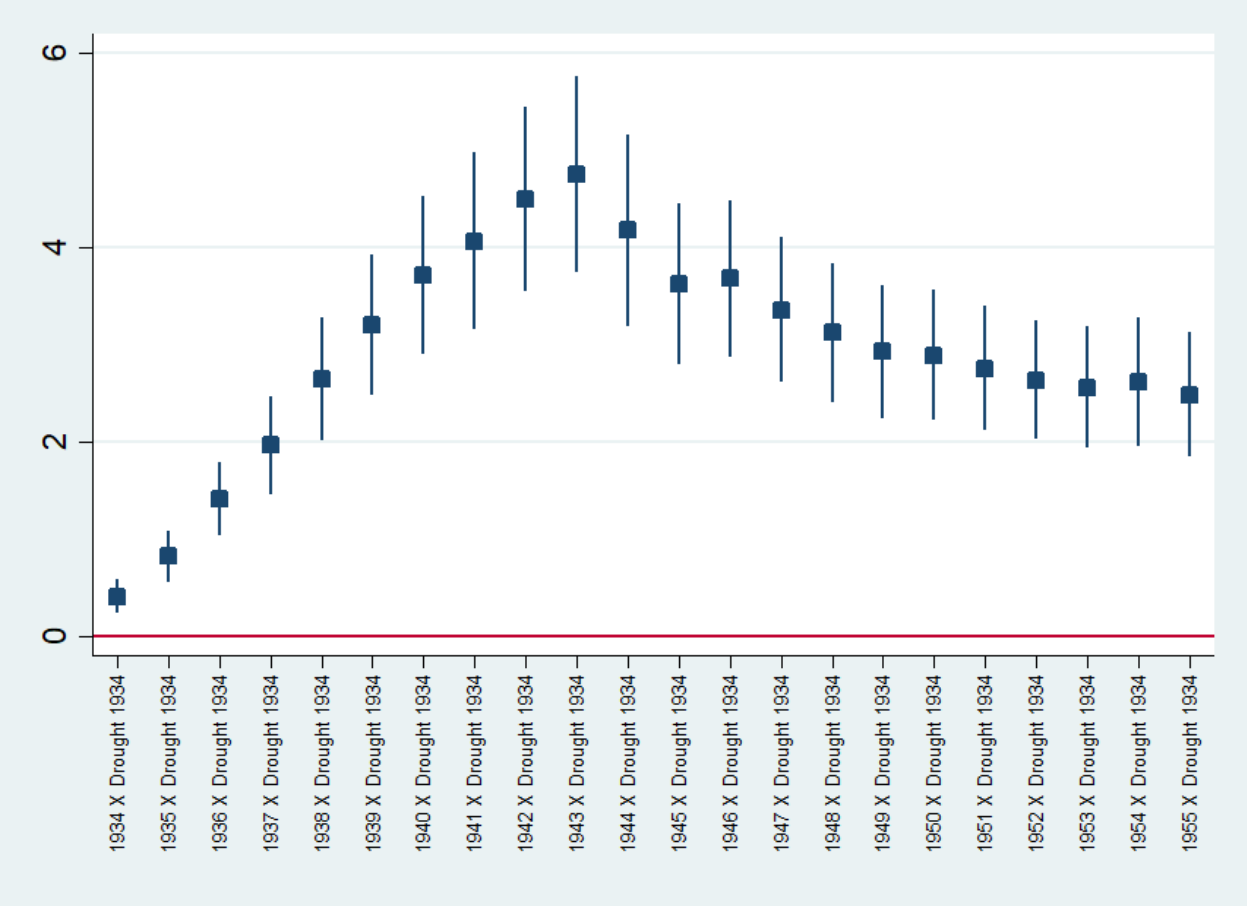



Figure A10: Robustness, CRD FE. SE Clustered by CRD. Effect of 1934 Drought Indicator X Year Indicator on ln hybrid odds radio.

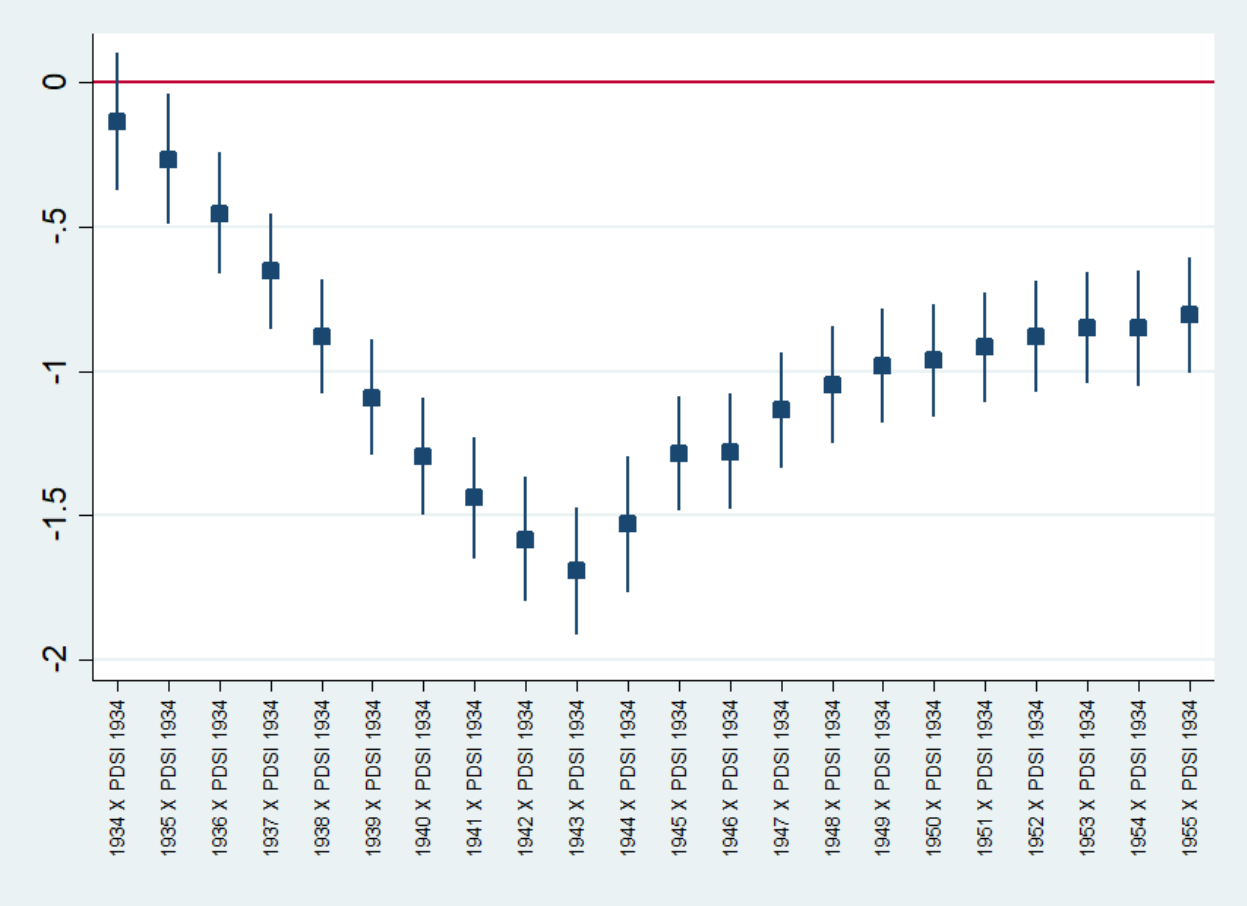



Figure A11: Robustness, CRD FE. Effect of 1934 PDSI X Year Indicator on ln hybrid odds radio.

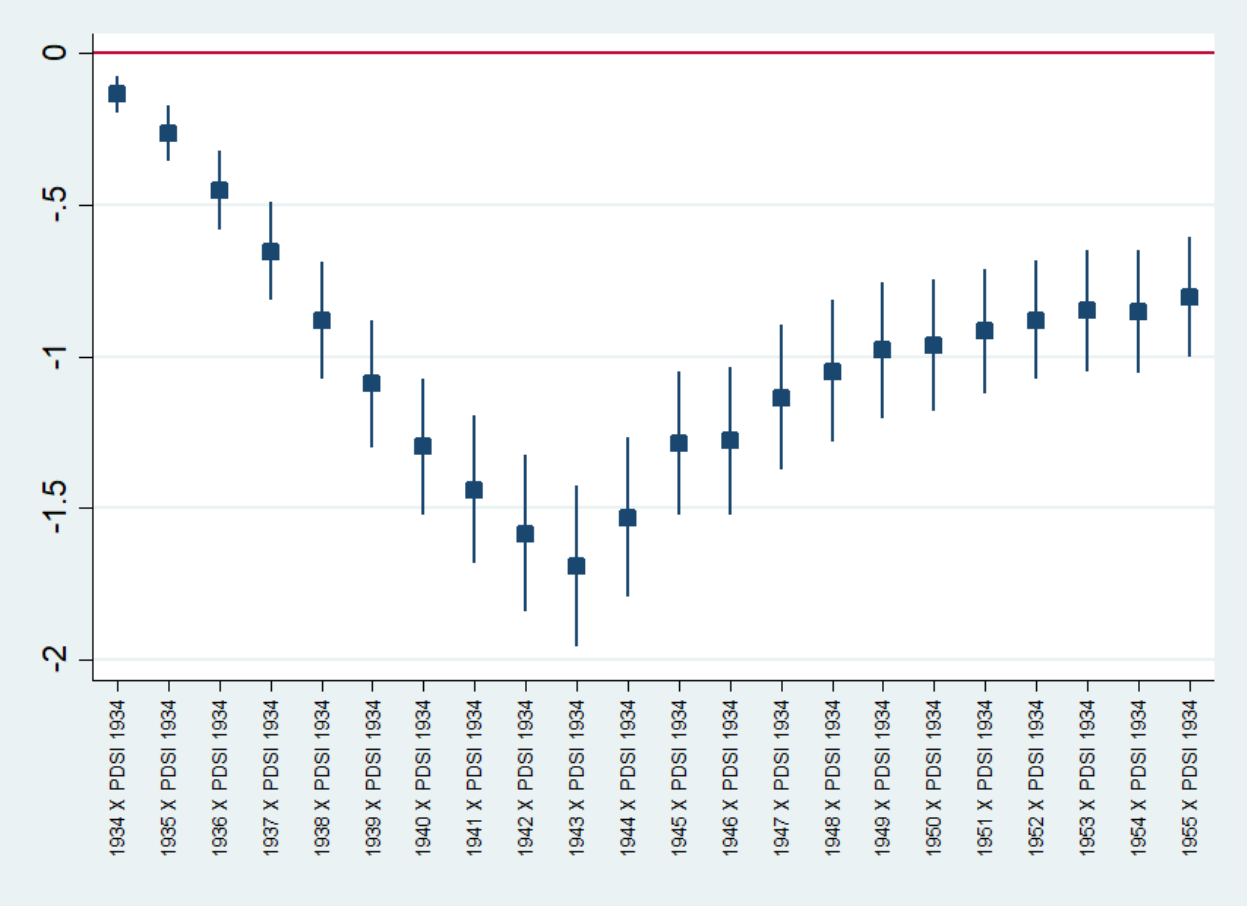



Figure A12: Robustness, CRD FE. SE Clustered by CRD. Effect of 1934 PDSI X Year Indicator on ln hybrid odds radio.

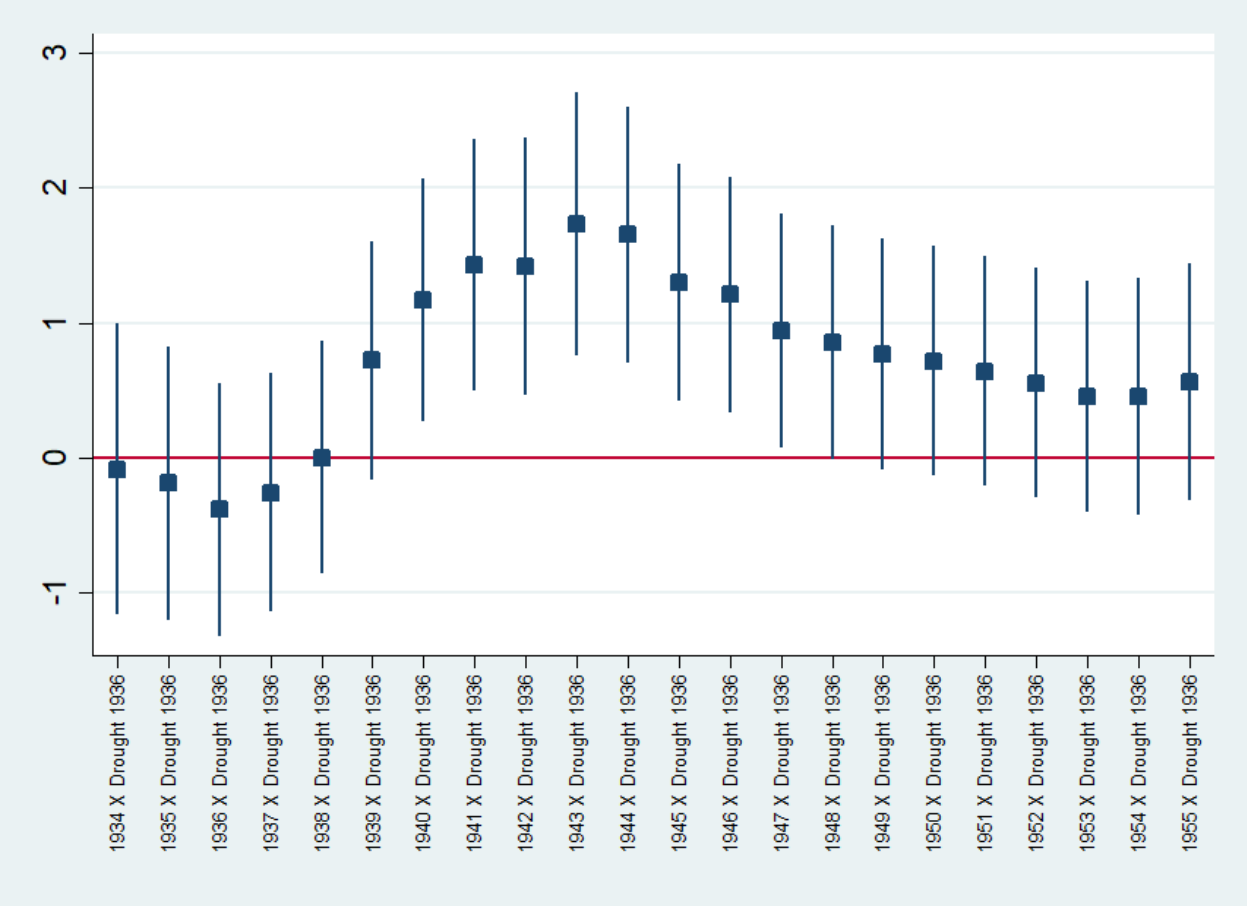



Figure A13: Robustness, CRD FE. Effect of 1936 Drought Indicator X Year Indicator on ln hybrid odds radio.

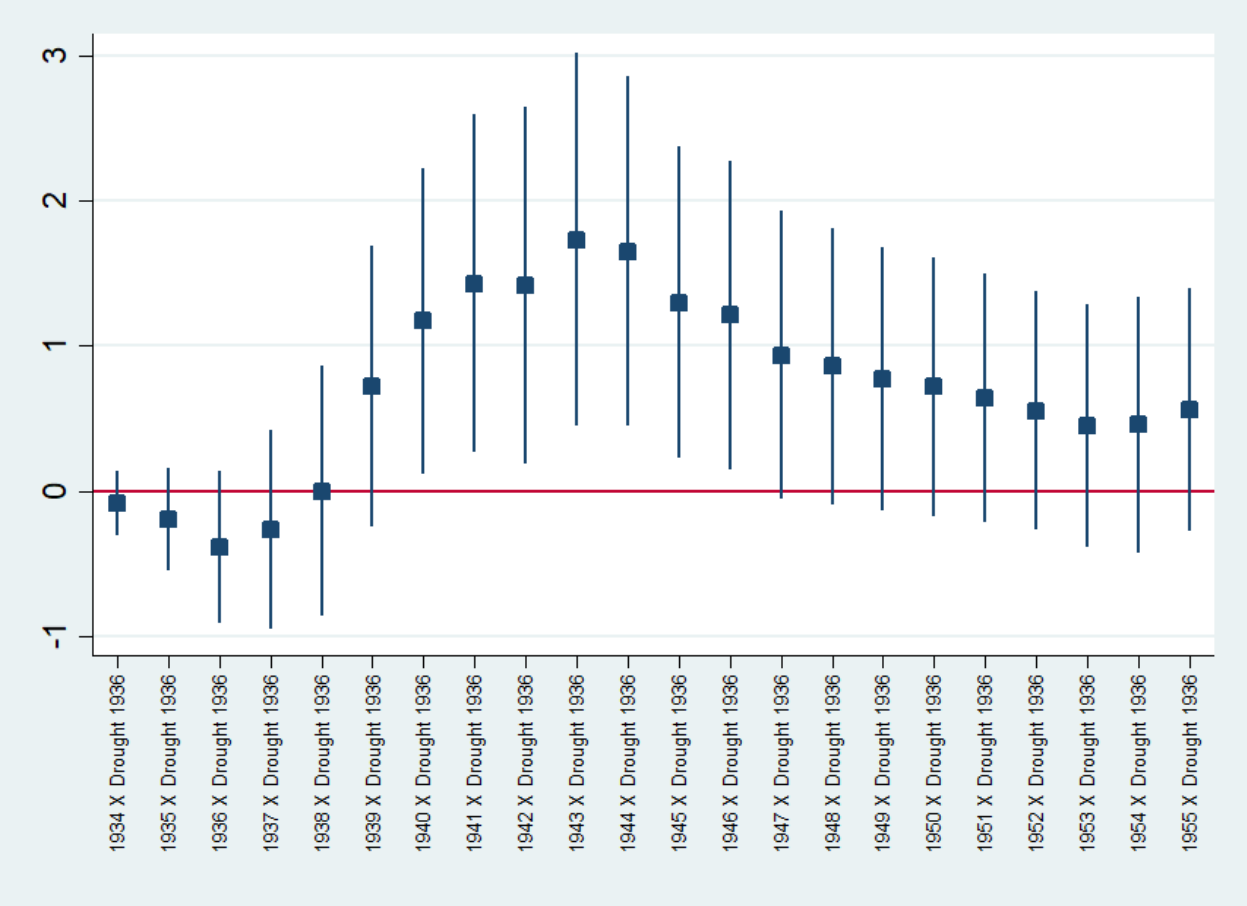



Figure A14: Robustness, CRD FE. SE Clustered by CRD. Effect of 1936 Drought Indicator X Year Indicator on ln hybrid odds radio.

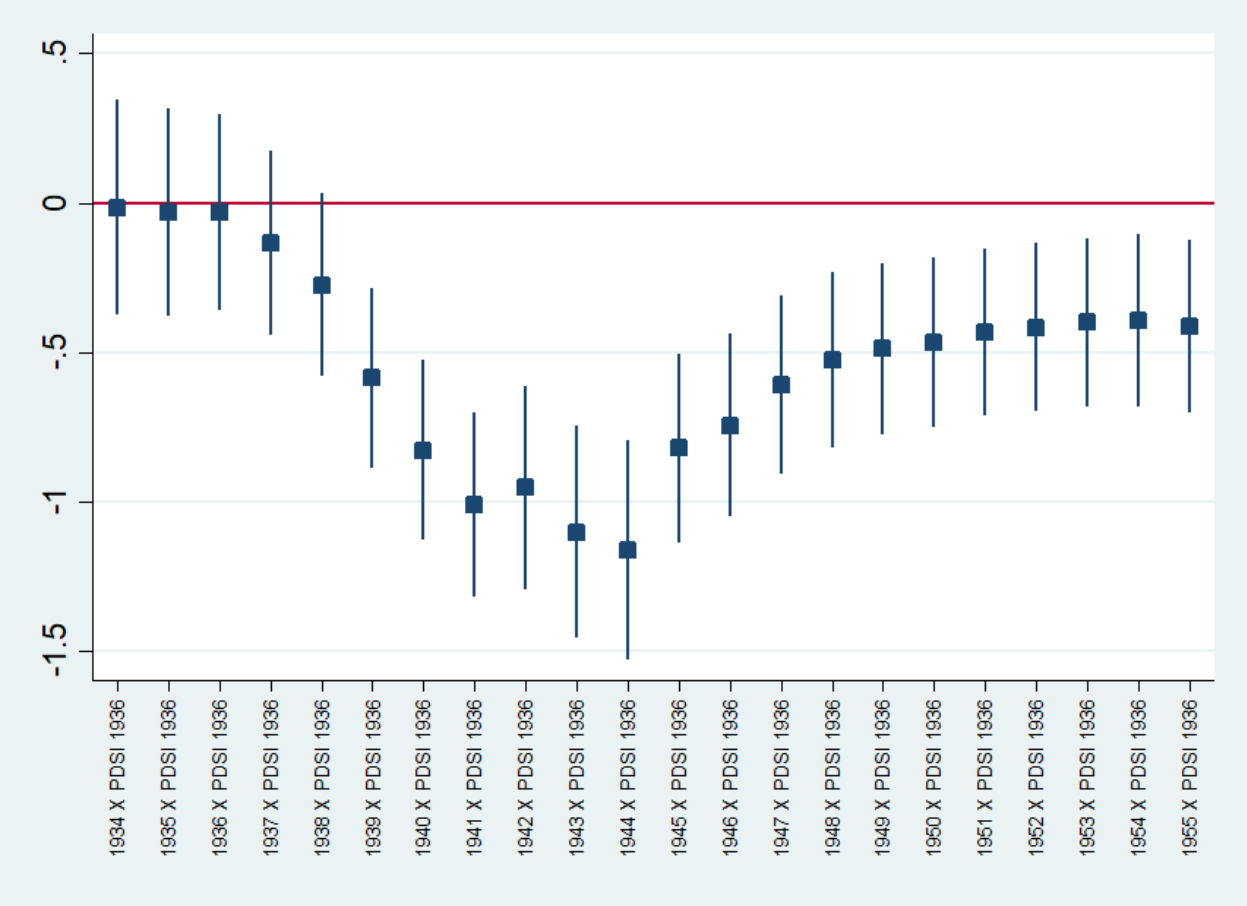



Figure A15: Robustness, CRD FE. Effect of 1936 PDSI X Year Indicator on ln hybrid odds radio.

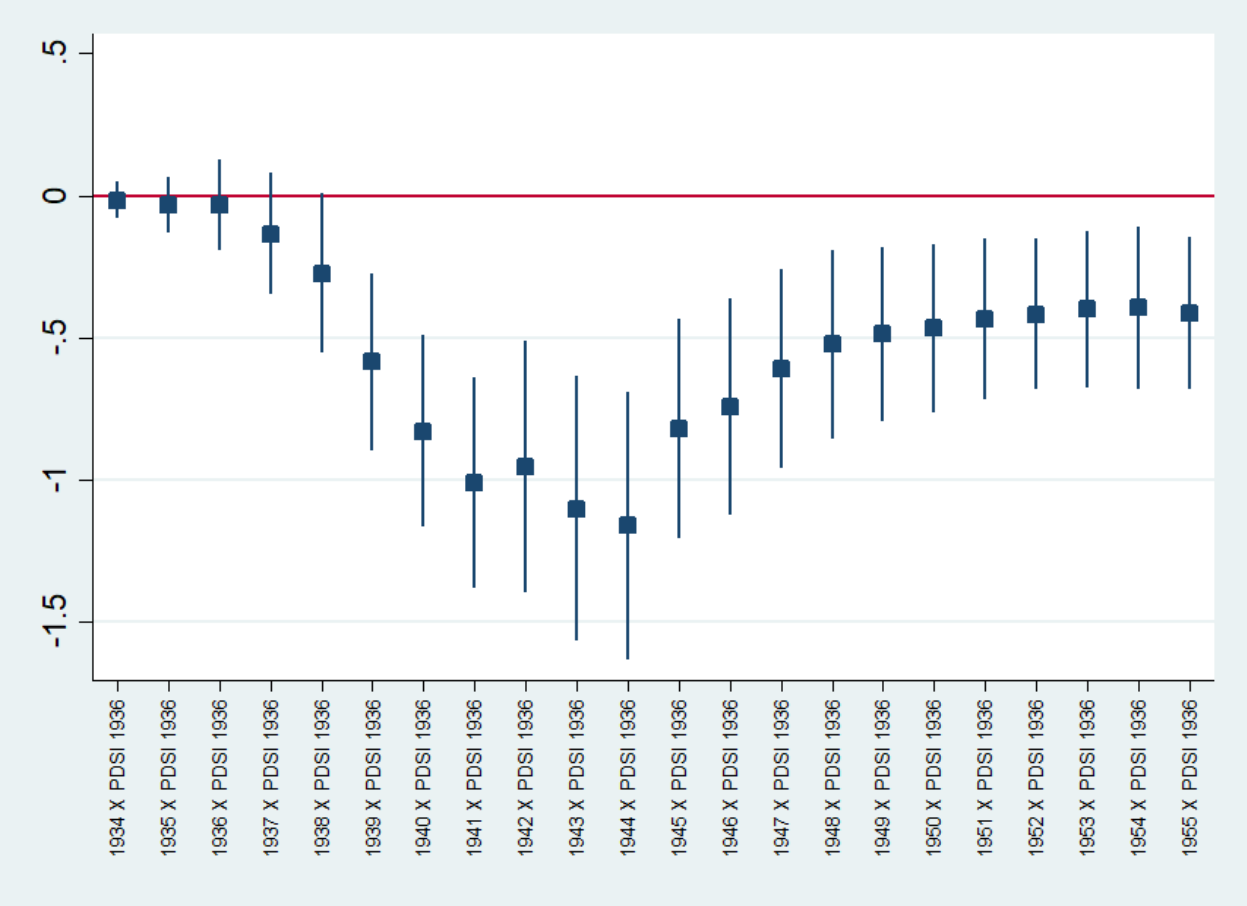



Figure A16: Robustness, CRD FE. SE clustered by CRD. Effect of 1936 PDSI X Year Indicator on ln hybrid odds radio.

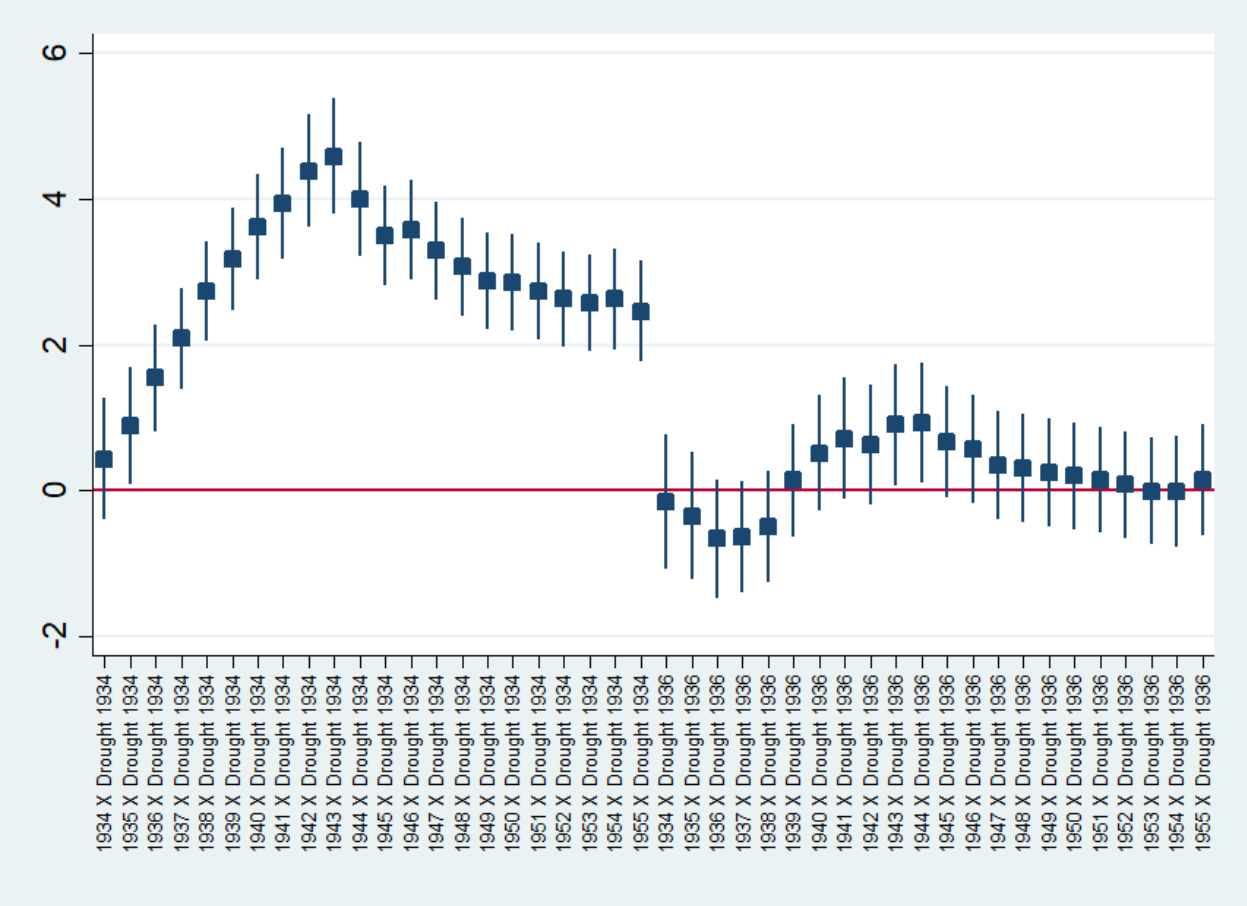



Figure A17: Robustness, CRD FE. Effect of 1934 and 1936 Drought Indicator X Year Indicator on ln hybrid odds radio.

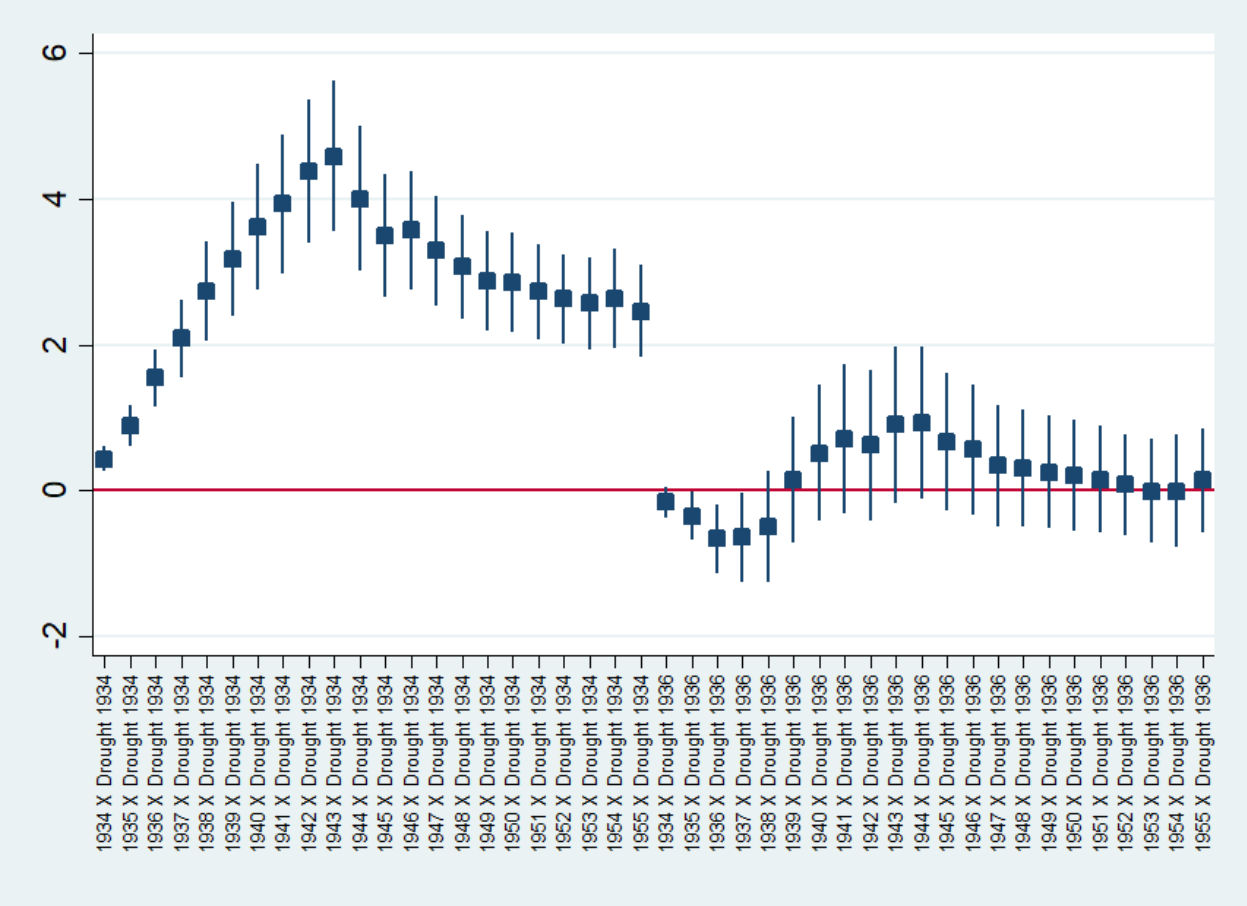



Figure A18: Robustness, CRD FE. SE clustered by CRD. Effect of 1934 and 1936 Drought Indicator X Year Indicator on ln hybrid odds radio.

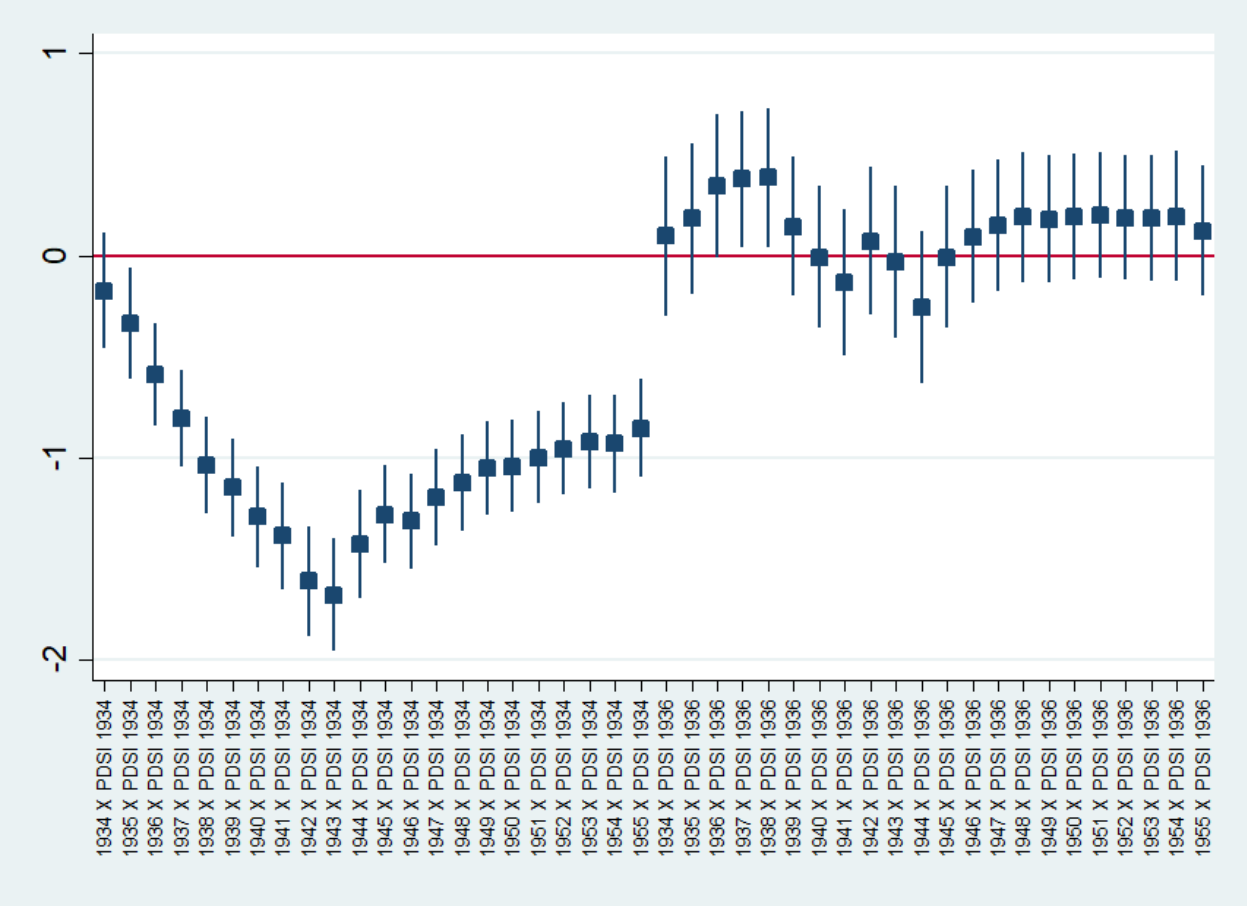



Figure A19: Robustness, CRD FE. Effect of 1934 and 1936 PDSI X Year Indicator on ln hybrid odds radio.

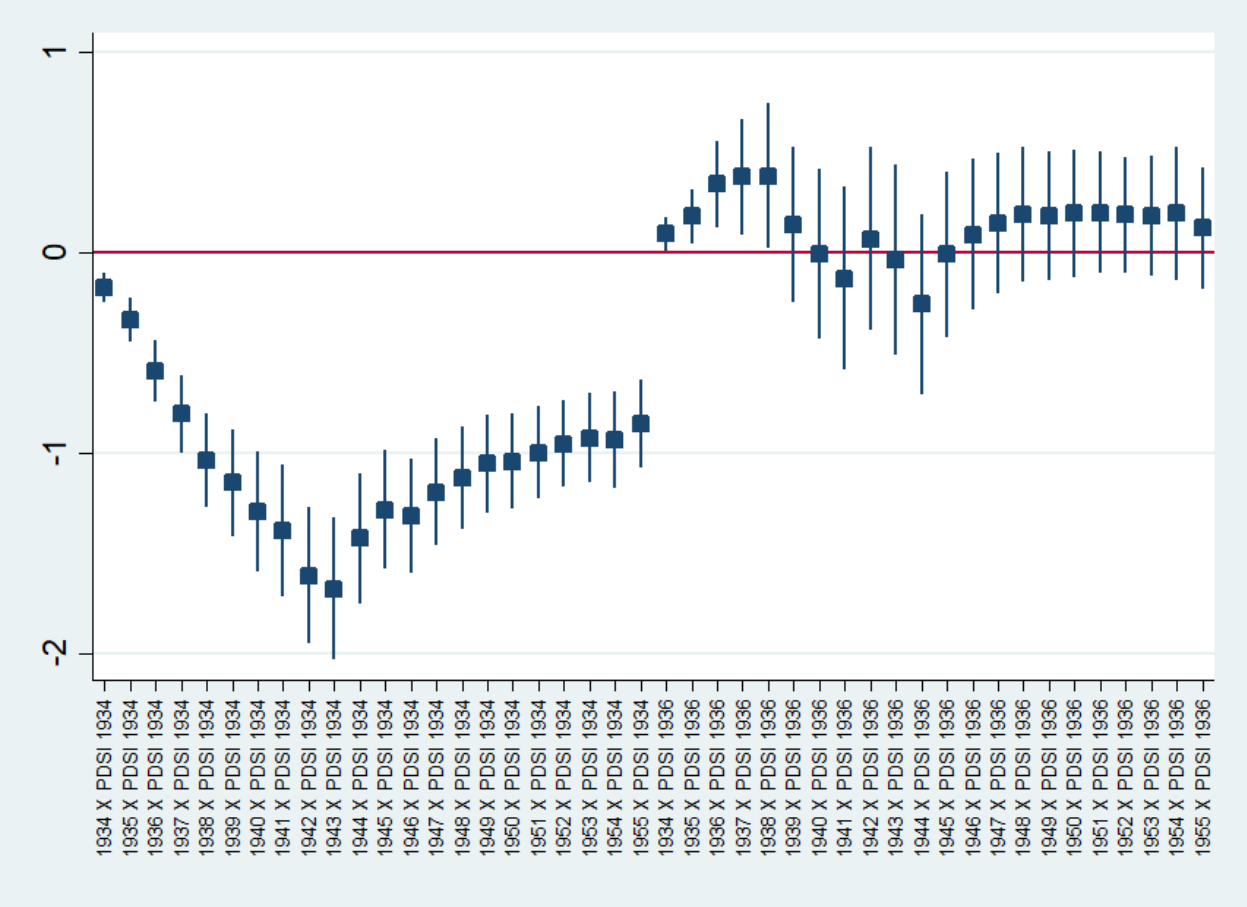



Figure A17: Robustness, CRD FE. SE clustered by CRD Effect of 1934 and 1936 Drought Indicator X Year Indicator on ln hybrid odds radio.