Exploring the Causes Driving Hybrid Corn Adoption from 1933 to 1955

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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 accelerating effect occurred several years after the initial shock.

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1 Introduction

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 et al., 1994; Schlenker et al., 2005, 2006; Deschênes and Greenstone, 2007) Recent research by Schlenker and Roberts (2009) 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 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, 2001; 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]

Hornbeck (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 onward 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. 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

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

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.

2 Literature Review

The story of hybrid corn has been told many times (Crabb, 1947; Fitzgerald, 1990; Kloppenburg Jr, 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

[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.

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. 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 (2010) 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 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

[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.)

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.

3 Conceptual Framework

The innovation and rapid expansion of commercial hybrid corn seeds occurred during a period of extreme farm distress. Financial pressures such as debt and low commodity prices were further compounded by successive waves of drought throughout the 1930s. Borrowing from Hornbeck's (2012) framework we discuss the agent farmer's hybrid seed adoption decision as a constrained optimization problem. In Equation 1, the farmer has a single unit of land, θ, that must be divided between two potential seed technologies, open pollinated (op) and hybrid (hy).

$$f_{op}(1-\theta) + \delta(D) f_{hy}(\theta) - C_{op}(1-\theta) - C_{hy}\theta \tag{1}$$

Let $f(.)$ denote concave and twice differentiable production functions and $C_{.}$ denote the cost of seed. For simplicity, suppose the relative (or perceived) difference in productivity between open pollinated and hybrid seeds can be represented by $\delta(.)\epsilon[0,\infty)$. If farmers are

[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.

unconstrained then θ is weakly increasing with δ and factors such as drought, denoted by D, can shape this value of δ. If drought shocks destroy open pollinated seed stocks, then the implicit relative prices of hybrids to open pollinated corns will drop. This would make it less expensive for farmers to change technologies. In order to see hastening (or slowing) of hybrid adoption, either preferences towards hybrids need to change (i.e. an increasing value of δ each subsequent year until θ equals one) or the cost of adoption needs to decrease. Finally, liquidity constraints induced by drought shocks might hinder switching towards hybrid corns even if farmers find them more attractive than open pollinated seeds. Such constraints might suggest that drought experience or a history of drought is more important than a recent a more recent bout of drought.

To show how hybrid seed adoption affects corn yields (reported as bushels per acre harvested) we use data from the National Agricultural Statistics Service from 1931 to 1941 to plot the relationship between yields, rate of hybrid adoption, and drought. Figure 1 plots average crop reporting district yields vs percent hybrid adoption for drought and non-drought years. As hybrid adoption increases the gap between drought and non-drought yields decreases and highlights the drought tolerant characteristics attributed towards hybrid corns in the literature. If these qualities did effect preferences towards hybrids then it's plausible that drought accelerated adoption. In Figures 2 and 3, we plot hybrid adoption "S" curves and group adoption based on the initial level of hybrid adoption observed in a crop reporting district in 1934 or 1936. In both 1934 and 1936, large waves of drought stretched across the agricultural heartland of the United States. These figures suggest that regions with some hybrid seed endowment during these Dust Bowl waves experience more rapid hybrid adoption relative areas with little to no hybrid adoption during these drought waves.

Figures 4 and 5 plot average seed prices (and see price ratio) of open pollinated and hybrid corns across states.[5] The dashed lines denotes a two standard deviation band around these

[5]Seed prices are available in Table A.8.

averages. The price of hybrid seeds was many times more expensive than open pollinated varieties with the price difference peaking in 1939. Reductions in relative prices plausibly helped encourage late adopters to switch over towards hybrids. Nevertheless, high prices in the 1930s suggests that nascent adoption was not a cost/price driven process early on. The destruction of seed corn during the previous year might make hybrid corns more attractive as this would lower the relative cost of switching to hybrids that year. If such a shock induced switching for one growing season, then experience with hybrids could have shifted preferences and induced further hybrid adoption in subsequent years.

4 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.[6] 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

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.[7] In addition, the records of Griliches include

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

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

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 6 maps out the AMS diffusion data used in this paper from 1933 onward and reports the year in which hybrid corns exceed 10 percent of planted acreage.[8]

Griliches tabulated but did not use USDA data on the prices (per bushels) of hybrid and open-pollinated seed by state (Box 59).[9] 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 A.8.) Griliches tabulated but did not use state-level data on seeding rates (Box 59).[10] 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

[8]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.

[9]Griliches relied on a USDA publication entitled "Seed Crops." These are essentially the same as in USDA (1963).

[10]These data were based on USDA, Agricultural Statistics, 1945, 1949, 1950.

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) [11] 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 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 7 maps the number of years crop reporting districts experienced moderate or worse drought (PDSI $\leq$ -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.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 zero hybrid adoption in a CRD in 1935 but

[11] We thank Price Fishback and Alex Hollingsworth for proving these data at the county level.

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. With this panel, we can study the dynamics through which drought influences the adoption of hybrid corns.

5 Empirical Strategy and Result

To analyze the relationship between drought experience and hybrid adoption decisions we regress drought status measures against the natural log of the hybrid adoption ratio. Following the framework established in Griliches' analysis of technological adoption curves, we perform a linearized version of the logic model. We include drought as a shifting variable for adoption. Equation 2 describes the main panel regression specification employed in our empirical analysis.

$$Y_{c,t} = \theta D_{c,t-1} + \alpha_c + \gamma_t + X_{c,1930} * \phi_t + \epsilon_{c,t} \tag{2}$$

The natural log of the odds ratio, $Y_{c,t}$, in crop reporting district c in year t is regressed against the drought measure $D_{c,t-1}$. $D_{c,t-1}$ includes drought status in the previous year, drought status over the previous five years, cumulative years of drought status since 1931, and cumulative drought status over the previous five years. These different measures allow us study how drought in the short and longer-run shape hybrid adoption. All drought measures indicated moderate or worse drought as reported by the Palmer Drought Severity Index over the April to September growing season for corn. 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 denote severe drought, and extreme drought is denoted by values -4 (and greater in non-top-coded data).[12] Crop reporting district fixed effects denoted by α_c control for common time invariant factors within crop reporting districts that may affect hybrid adoption. Year fixed effects γ_t control for common annual shocks that influence hybrid adoption throughout the sample (in some alternative specifications we include state by year fixed effects.) We also flexibly control for measures of agricultural development, population, and corn production from the 1930 Agricultural Census. These controls, $X_{c,1930}$, are interacted with year indicator variables [13]. All regressions cluster standard errors, $\epsilon_{c,t}$, at the crop reporting district level.

Summary statistics describing the sample and drought variables are available in Table 1. Table 2 reports the full specification for each drought variable. Sensitivity analyses for each drought variable are reported in Tables 3 through 6. Specification (1) uses a single lag of drought as a transitory shock. The coefficient of -0.155 is statistically significant at the 5% level and suggest that drought last year reduces the probability an acre of land is planted as hybrid corn next year by 14.3%. In contrast, cumulative years of drought stress from 1931 onward finds that an additional year of drought hastens hybrid adoption. The coefficient for specification (2) of 0.193 is statistically significant at the 1% level and suggests that an additional year of drought increases the probability an acre of land is planted with hybrid seed next year by 21.3%. Specifications (3) and (4) look at drought history over five year windows and both measures of drought suggest that recent drought experience drought experience hinders adoption of hybrid corns. These two contrasting results are consistent with a scenario where drought shocks both increase the salience of hybrid seed adoption and cause financial distress for farmers. To understand how drought experiences during the Dust Bowl affect the adoption of hybrid seeds, we perform an event study using the 1934 and 1936 waves of drought.

[12] Alternative specifications using the Palmer Drought Severity Index provides similar results though complicate the cleanness of empirical interpret ion of the results.

[13] These 1930 Census controls include ln population, ln number of farms, ln acres of corn, ln number of corn farms, ln value of total, ln value of farm products, share of county land as farmland, average farm size, land value per acre, and average corn yield per acre harvested.

The role of Dust Bowl drought waves on hybrid adoption suggests that these specific events may have made hybrid adoption more salient. The S-curves in Figures 2 and 3 suggest that crop reporting districts with some hybrid endowment during these drought waves had accelerate hybrid adoption relative to crop reporting districts with less hybrid endowment. The drought resistant qualities of hybrid seeds became apparent in the 1934 early in the period of hybrid adoption. The second major wave of the Dust Bowl arrived in 1936 and the narrative literature argues that this particular drought led farmers to hasten their adoption of hybrids. These droughts may have served as informative shocks where farmers would observe hybrid performance relative to open pollinated performance. We perform an event study analysis and adjust Equation 2 to trace out the effects of these drought experiences on hybrid adoption over time.

$$Y_{c,t} = D_{c,1934}\theta_t + D_{c,1936}\sigma_t + \alpha_c + \gamma_t + X_{c,1930} * \phi_t + \epsilon_{c,t} \quad (3)$$

In Equation 3 time invariant time indicators $D_{c,1934}$ and $D_{c,1936}$ are interacted with time indicator variables denoted by θ_t and σ_t. Figure 8 plots out the regression coefficients and a 99% confidence interval for the 1934 drought and the full set of controls. We exclude 1934 as the base reference year. In the years following 1934, crop reporting districts that had moderate or worse drought though the 1934 corn growing season had increased adoption of hybrid corn seeds. Figure 9 measures adoption patterns after the 1936 drought and exclude the 1936 interaction as the base year. There is a similar pattern in increased hybrid adoption but the effect is smaller in magnitude relative to the 1934 drought. Figure 10 includes both the 1934 and 1936 interactions into the same model. Both the 1934 and 1936 waves of Dust Bowl drought accelerated hybrid adoption. The hastening of adoption in response to drought stress in 1934 is more pronounced, immediate, and prolonged than the response to the 1936 drought. Many crop reporting districts experienced the 1934 drought but did not have hybrids present in the local region. This result suggests that farmers' preferences towards hybrid seeds were driven by drought stress and a desire to mitigate that stress. This result is consistent with narrative evidence that farmers learned about hybrid seeds many years before adopting them. If observational learning about hybrids during drought made such seeds more salient, then the 1936 drought should have a greater hastening effect on the ln odds ratio.

6 Robustness and Additional Information

In the Appendix, we present several robustness checks and additional information. This includes Table A.7 which report the correlation of annual drought from 1931 to 1940. There is generally a positive and non-trivial relationship between drought starting in 1933 and drought status in subsequent years. Table A.8 provides average seed prices for open pollinated and hybrid varieties. Table A.9 details information from the Pioneer seed company regarding hybrid seed prices. According to these archival prices, hybrid seeds were often three to four times more expensive than open pollinated varieties in the 1930s. Tables A.10 through A.13 report the regression results without the recoding of missing (omitted) observations from 1933 to the first year of Griliches' data as zero. This change makes statistical significance and magnitude of the coefficients more sensitive to the inclusion of controls and state by year fixed effects.

Tables A.14 through A.17 replace the outcome ln odds ratio with a level measure of hybrid adoption. This change in outcome variable finds results consistent with those in the main analysis. Figures A.11 to A.13 perform the event study analysis using levels of hybrid adoption rather than the ln odds ratio. These plots reveal that the 1934 drought hastened adoption much more than the 1936 drought. These plots also suggest that in the years immediately after the 1936 drought that drought hindered the adoption of hybrid seeds and that the hybrid adoption in response to the 1936 drought hastened starting in the 1940s.

7 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) andCulver and Hyde (2001) 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. Interestingly, when we allow drought experience to accumulate year to year we find that an additional year of drought hastens hybrid adoption. 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 and before most crop reporting districts had any measurable level of hybrid adoption, had a more pronounced effect on the speed of 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 (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 drought 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 A.9.)

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)).

8 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 hastening 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.

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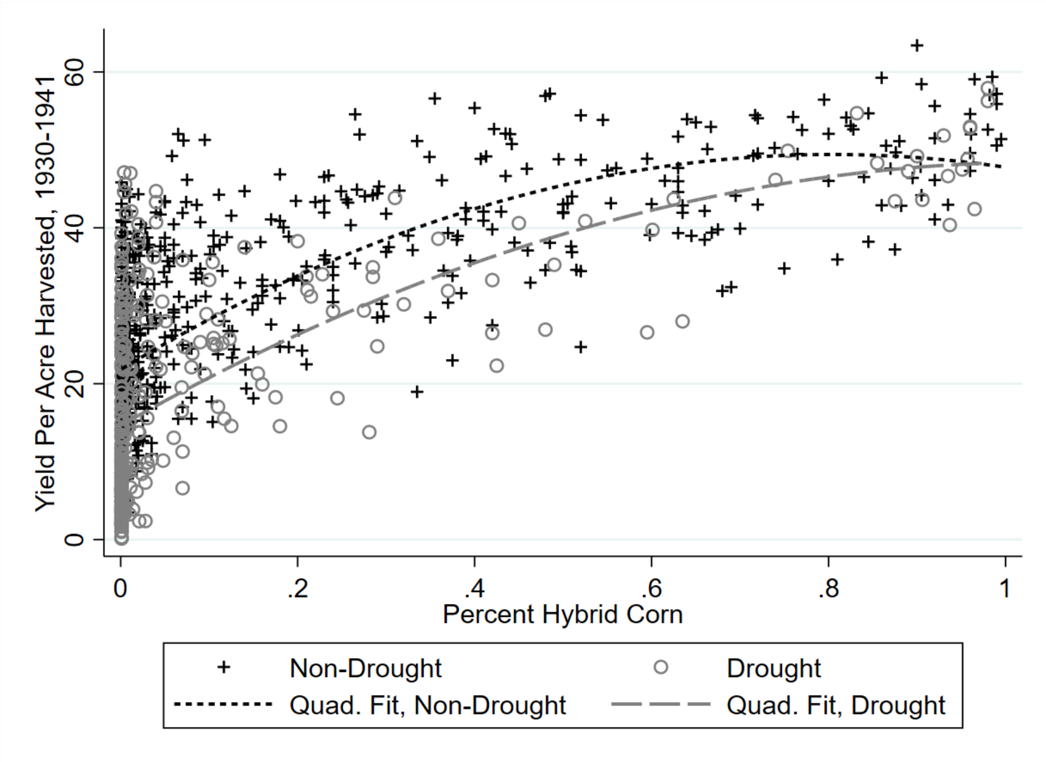

Figure 1: Relationship between Corn Yields, Hybrid Adoption, and Drought, 1930 to 1941

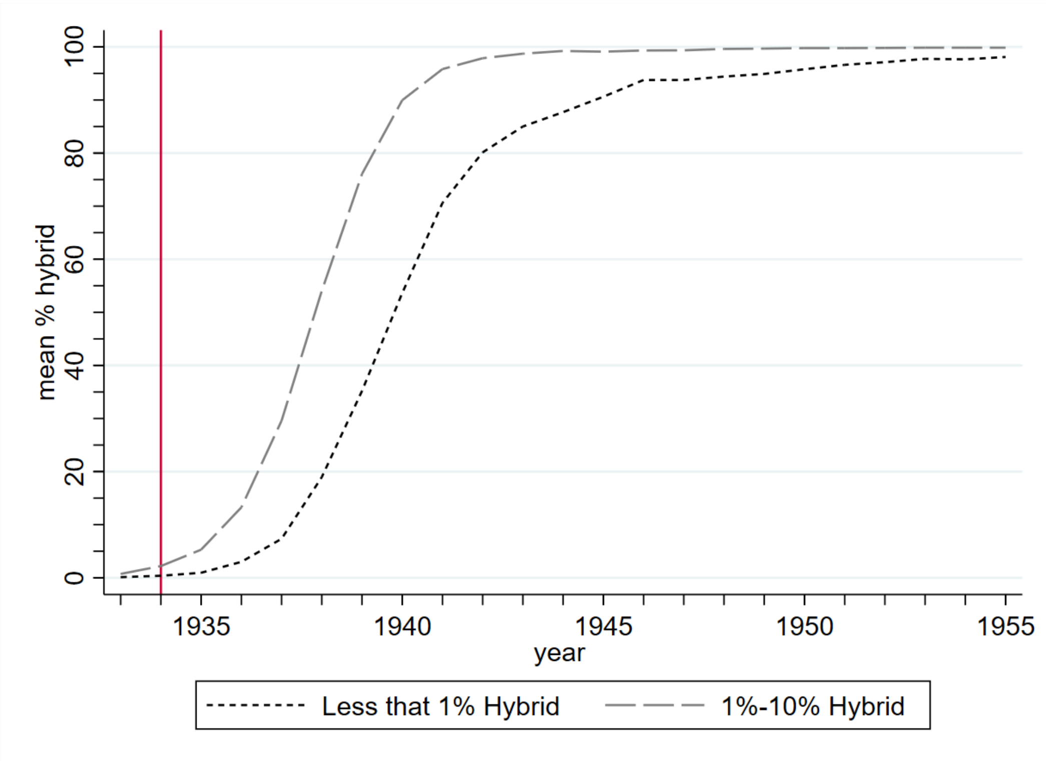

Figure 2: Hybrid Growth Rates of Crop Reporting Districts by % Hybrid in 1934

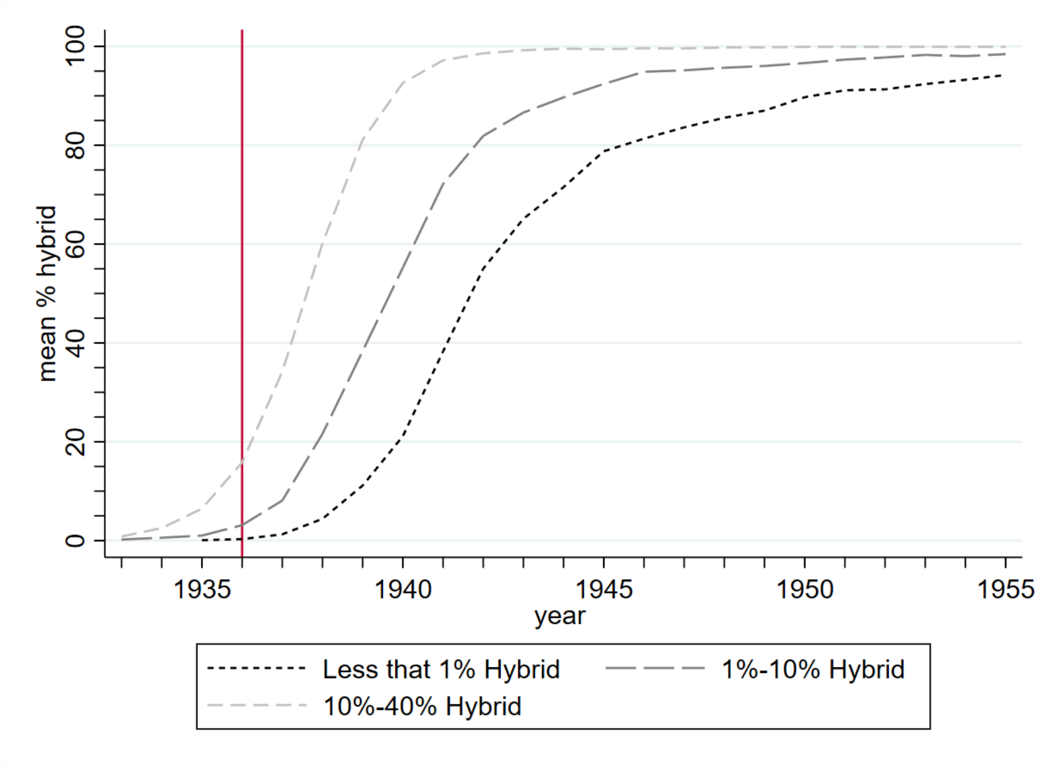

Figure 3: Hybrid Growth Rates of Crop Reporting Districts by % Hybrid in 1936

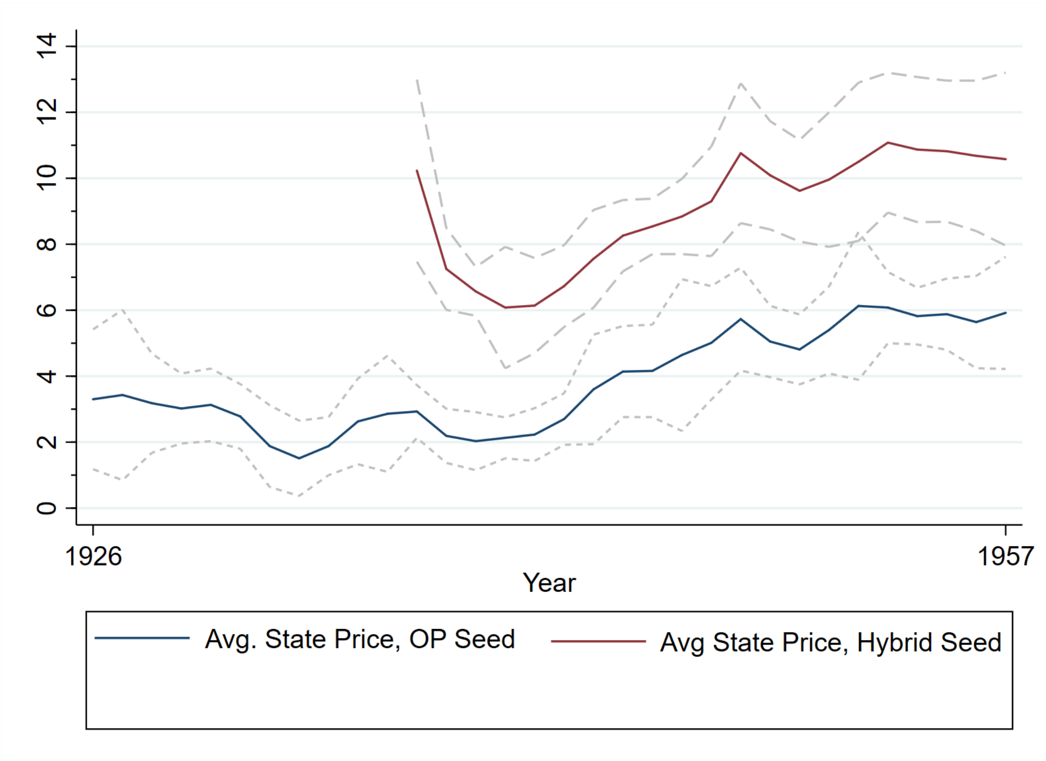

Figure 4: Open Pollinated vs Hybrid Corn Seed Prices, nominal $, 1926-1957. Source: USDA (1963). Prices paid by farmers for seed: spring season averages, 1926-1961: September 15 prices, 1949-1961, by states and United States. Statistical Bulletin No. 328. GPO: Washington, DC.

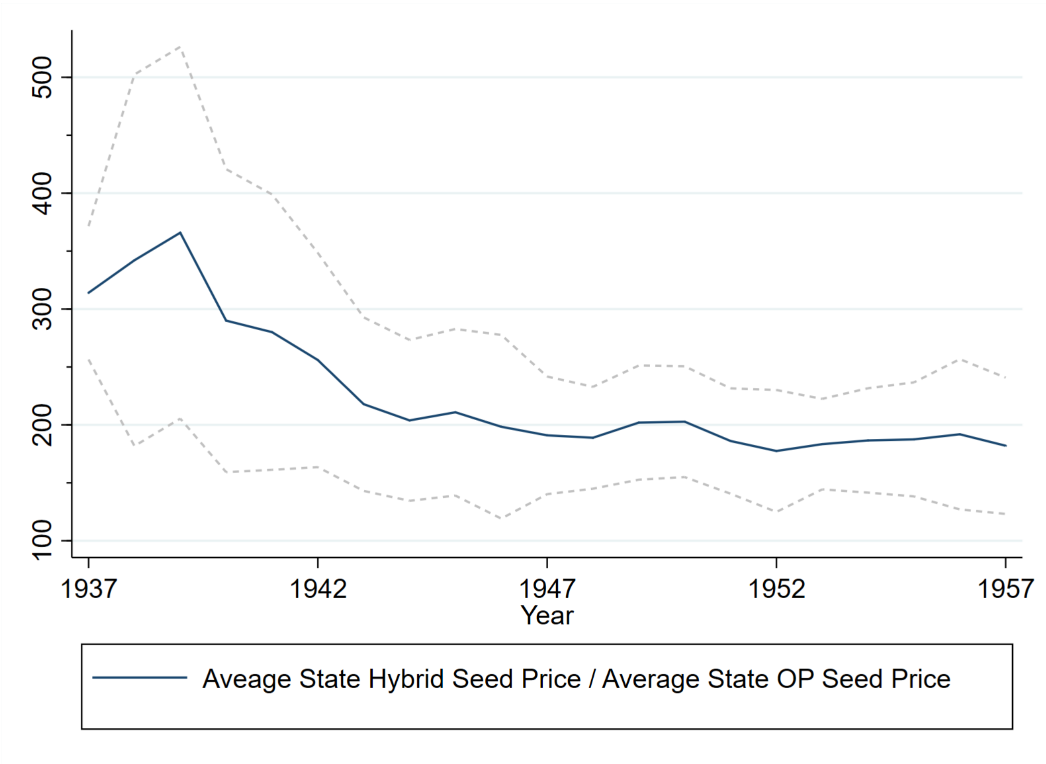

Figure 5: Open Pollinated vs Hybrid Corn Seed Price Ratio, 1937-1957. Source: USDA (1963). Prices paid by farmers for seed: spring season averages, 1926-1961: September 15 prices, 1949-1961, by states and United States. Statistical Bulletin No. 328. GPO: Washington, DC.

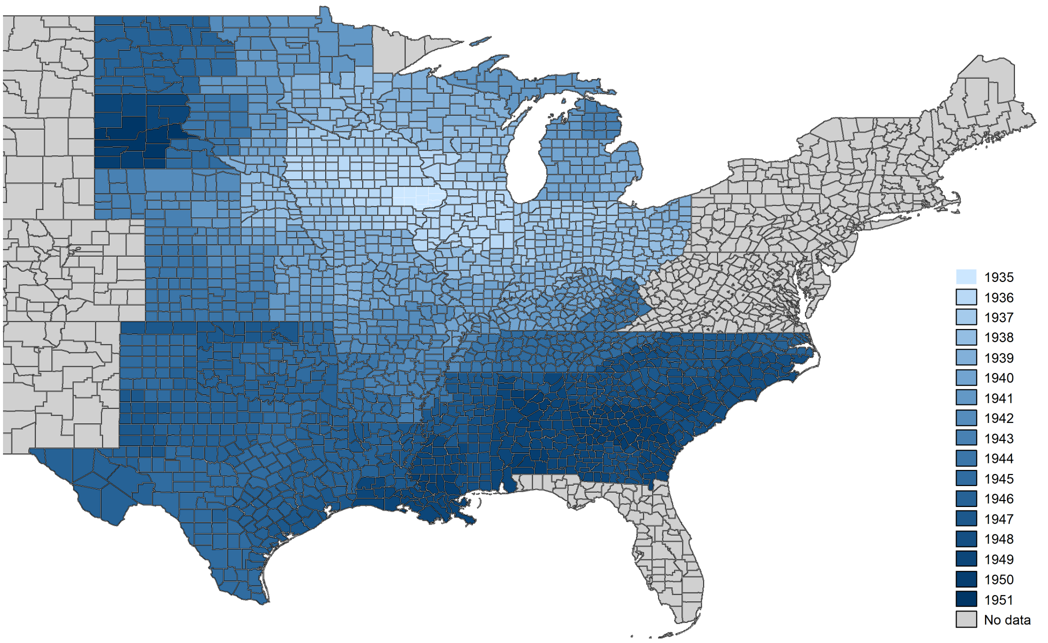

Figure 6: Year Hybrid Adoption Exceeds 10%

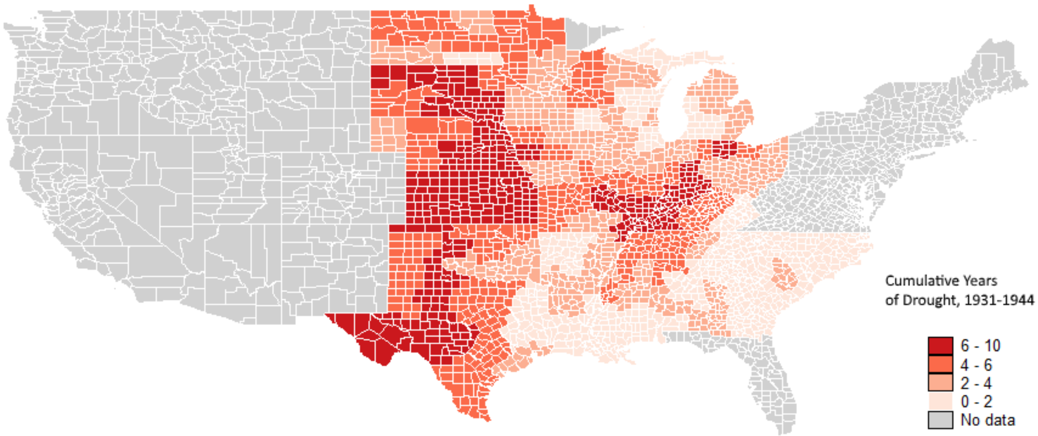

Figure 7: Total Number Years of Moderate or Worst Drought from 1931 to 1955

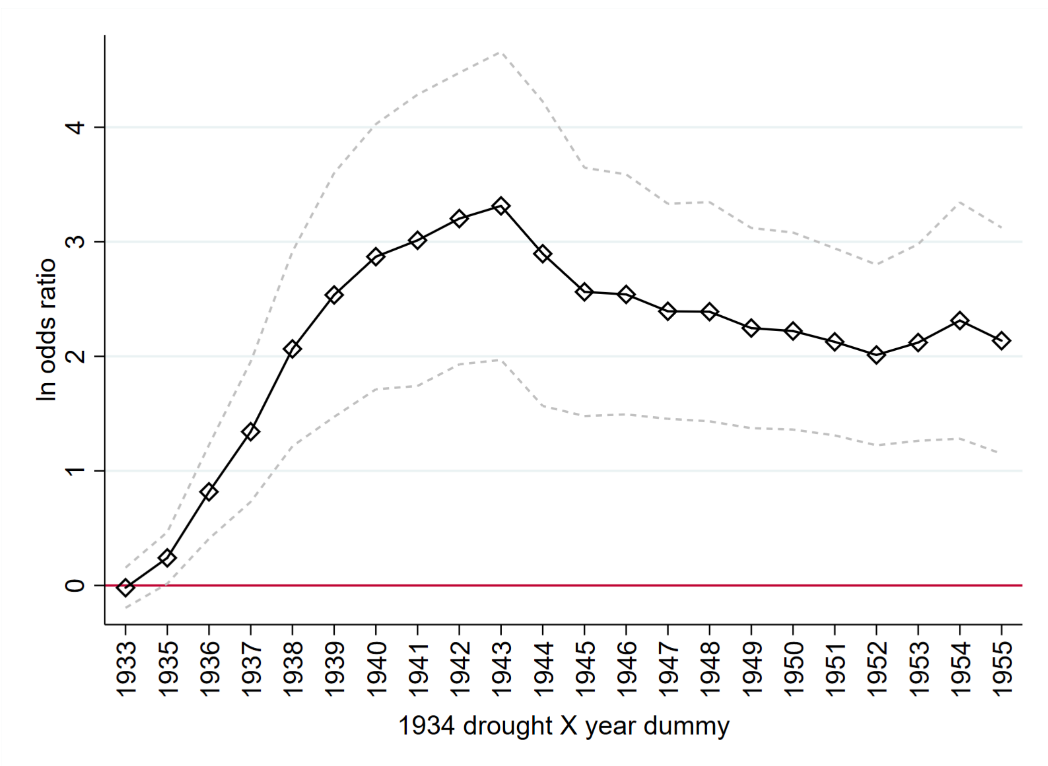

Figure 8: Effect of 1934 Drought on Hybrid Adoption, Regression Coefficients of 1934 Drought Status X Year.

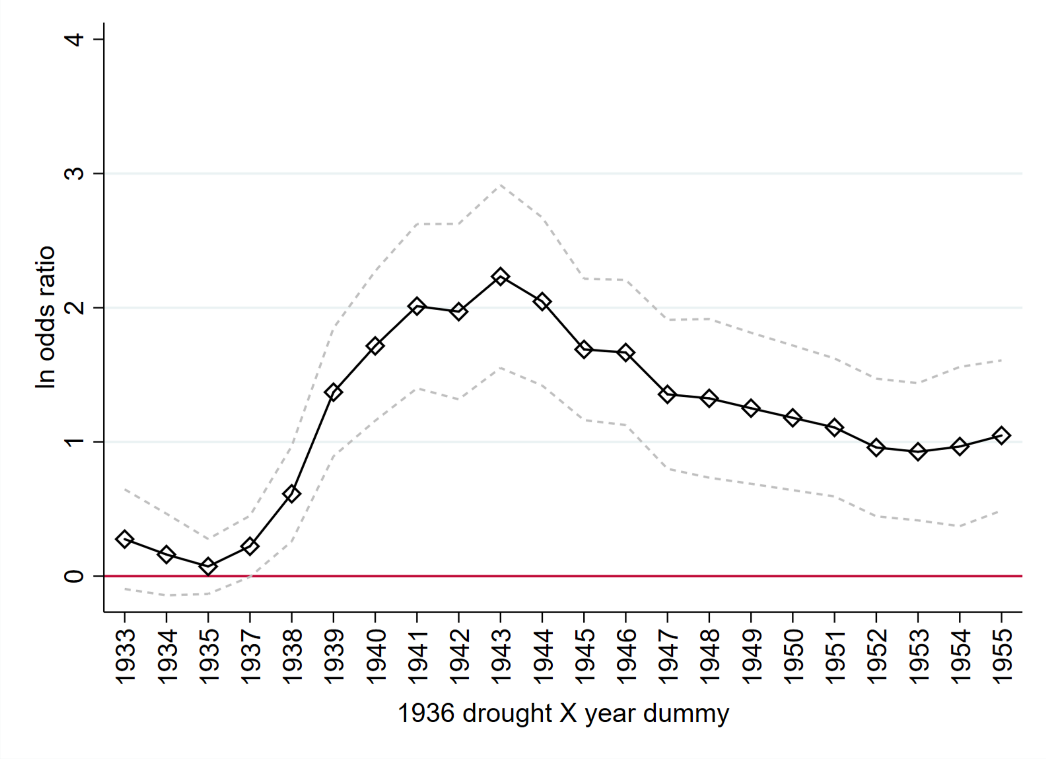

Figure 9: Effect of 1934 Drought on Hybrid Adoption, Regression Coefficients of 1936 Drought Status X Year.

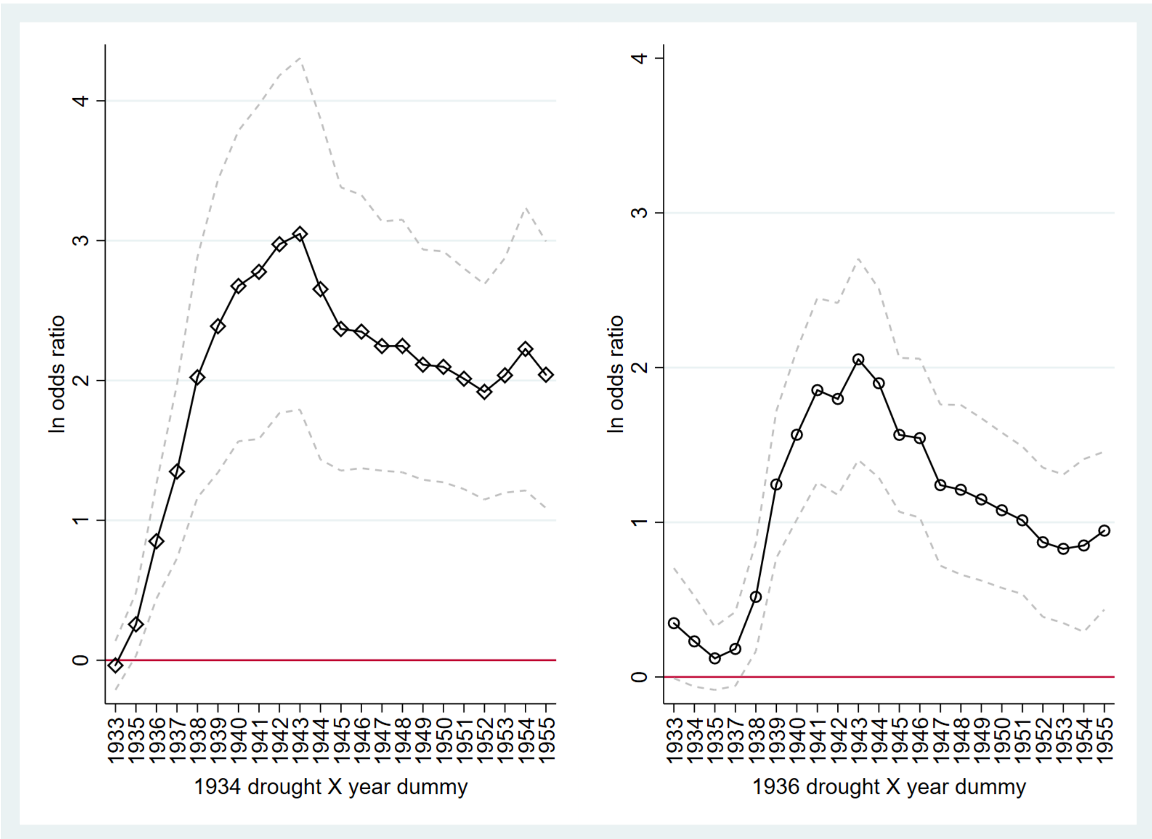

Figure 10: Effect of 1934 and 1936 Droughts on Hybrid Adoption, Regression Coefficients of Drought Status X Year.

Table 1: Summary Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
Percent Hybrid Corn	4516	0.376	0.39	0	1
ln Odds Ratio	4516	-1.581	4.158	-6.907	6.907
PDSI	4516	-0.291	1.709	-4	4
Drought	4516	0.165	0.371	0	1
Cumulative Years of Drought	4516	2.658	2.117	0	10

Table 2: Main Regression Specifications

	(1)	(2)	(3)	(4)
Drought, t-1	-0.155**		-0.135**	
	(0.065)		(0.060)	
Drought, t-2			-0.218***	
			(0.056)	
Drought, t-3			-0.163***	
			(0.057)	
Drought, t-4			-0.078	
			(0.055)	
Drought, t-5			-0.014	
			(0.056)	
Cum. Yrs of Drought		0.193***		
		(0.060)		
Cum. Yrs of Drought past 5 Yrs				-0.126***
				(0.045)
Year FE	Yes	Yes	Yes	Yes
CRD FE	Yes	Yes	Yes	Yes
1930 Census X Year Controls	Yes	Yes	Yes	Yes
N	4516	4516	4516	4516
adj r^2	0.956	0.956	0.956	0.956

All Standard Errors are Clustered by Crop Report District.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 3: Alternative Specifications: Effect of Drought Last Year on ln Odds Hybrid Ratio

	(1)	(2)	(3)	(4)
Drought, t-1	-0.324***	-0.091*	-0.155**	-0.083**
	(0.074)	(0.050)	(0.065)	(0.042)
Year FE	Yes	No	Yes	No
CRD FE	Yes	Yes	Yes	Yes
State X Year FE	No	Yes	No	Yes
1930 Census X Year Controls	No	No	Yes	Yes
N	4516	4516	4516	4516
adj r^2	0.923	0.982	0.956	0.986

All Standard Errors are Clustered by Crop Report District.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 4: Alternative Specifications: Effect of Lagged Drought on ln Odds Hybrid Ratio

	(1)	(2)	(3)	(4)
Drought, t-1	-0.240***	-0.088*	-0.135**	-0.082**
	(0.065)	(0.049)	(0.060)	(0.041)
Drought, t-2	-0.388***	-0.113**	-0.218***	-0.095**
	(0.058)	(0.050)	(0.056)	(0.040)
Drought, t-3	-0.141***	-0.040	-0.163***	-0.066
	(0.046)	(0.048)	(0.057)	(0.044)
Drought, t-4	0.025	-0.061	-0.078	-0.090**
	(0.048)	(0.042)	(0.055)	(0.042)
Drought, t-5	0.145**	-0.066	-0.014	-0.084*
	(0.058)	(0.045)	(0.056)	(0.045)
Year FE	Yes	No	Yes	No
CRD FE	Yes	Yes	Yes	Yes
State X Year FE	No	Yes	No	Yes
1930 Census X Year Controls	No	No	Yes	Yes
N	4516	4516	4516	4516
adj r^2	0.924	0.982	0.956	0.986

All Standard Errors are Clustered by Crop Report District.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 5: Alternative Specifications: Effect of Cumulative Drought on ln Odds Hybrid Ratio

	(1)	(2)	(3)	(4)
Cumulative Yrs Drought, t-1/t=1931	0.327***	0.098*	0.193***	0.117**
	(0.060)	(0.052)	(0.060)	(0.047)
Year FE	Yes	No	Yes	No
CRD FE	Yes	Yes	Yes	Yes
State X Year FE	No	Yes	No	Yes
1930 Census X Year Controls	No	No	Yes	Yes
N	4516	4516	4516	4516
adj r^2	0.926	0.983	0.956	0.986

All Standard Errors are Clustered by Crop Report District.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 6: Alternative Specifications: Effect of Cumulative Drought over Past 5 Yrs on ln Odds Hybrid Ratio

	(1)	(2)	(3)	(4)
	ln_odds	ln_odds	ln_odds	ln_odds
Cumulative Yrs Drought, t-1/t-5	-0.130***	-0.074*	-0.126***	-0.083**
	(0.035)	(0.038)	(0.045)	(0.032)
Year FE	Yes	No	Yes	No
CRD FE	Yes	Yes	Yes	Yes
State X Year FE	No	Yes	No	Yes
1930 Census X Year Controls	No	No	Yes	Yes
N	4516	4516	4516	4516
adj r^2	0.923	0.982	0.956	0.986

All Standard Errors are Clustered by Crop Report District.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

A Appendix

Table A.7: 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 A.8: Seed Prices in Dollars per Bushel, 1926-57

	Open Pollinated				Hybrid				Hybrid-OP Ratio			
	National Average	State Average	St Dev	Coeff. Of Variation	National Average	State Average	St Dev	Coeff. Of Variation	National Average	State Average	St Dev	Coeff. Of Variation
1926	3.39	3.30	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	1.7	1.88	0.44	0.24								
1935	2.47	2.63	0.65	0.25								
1936	2.6	2.86	0.88	0.31								
1937	2.85	2.93	0.4	0.14	10	10.23	1.38	0.13	350.9	314	28.76	0.09
1938	2	2.19	0.41	0.19	7.3	7.25	0.62	0.09	365	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	2.13	0.31	0.15	6.1	6.08	0.92	0.15	305	290	65.37	0.23
1941	2.02	2.23	0.4	0.18	6.2	6.14	0.72	0.12	306.9	280.1	59.43	0.21
1942	2.5	2.7	0.39	0.14	6.9	6.73	0.62	0.09	276	256	46.22	0.18
1943	3.28	3.6	0.83	0.23	7.67	7.56	0.74	0.1	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	0.7	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	8.8	8.84	0.57	0.06	203.7	198.4	39.64	0.2
1947	4.7	5.01	0.86	0.17	9.35	9.3	0.83	0.09	198.9	191	25.38	0.13
1948	5.57	5.73	0.78	0.14	11.1	10.76	1.06	0.1	199.3	188.9	21.98	0.12
1949	4.79	5.05	0.54	0.11	10.5	10.09	0.82	0.08	219.2	202	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	5.4	0.66	0.12	10.3	9.96	1.02	0.1	199.2	186.1	22.72	0.12
1952	5.73	6.13	1.12	0.18	11	10.5	1.2	0.11	192	177.5	26.31	0.15
1953	5.97	6.08	0.54	0.09	11.2	11.08	1.06	0.1	187.6	183.4	19.53	0.11
1954	5.58	5.82	0.43	0.07	11	10.87	1.1	0.1	197.1	186.6	22.53	0.12
1955	5.54	5.88	0.54	0.09	11	10.82	1.07	0.1	198.6	187.5	24.6	0.13
1956	5.06	5.64	0.7	0.12	10.9	10.68	1.14	0.11	215.4	191.9	32.42	0.17
1957	5.15	5.92	0.85	0.14	10.7	10.58	1.31	0.12	207.8	182	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 A.9: Pioneer Prices, Yields, Costs, and Sales

Year	Seed Price $/bu	Seed Yield Bu/acre	Unit Production Cost,$/bu	Sales Bushels Customers	Source and Notes
1926-27		20		605	History of Pioneer's First Ten Years
1927-28	7.2	24		928	"
1928-29		25.2		2,055	"
1929-30	10.43	31		2,281	"
1930-31	10.6	18		1,870	" Realized price=$7.83
1931-32	6.5	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		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	7.3	41.9	5.66	152,157	1940 Annual Report
1939-40	7.2	34.9	7	160,127	1940 Annual Report
1940-41	7.01	36	6.29	166,503	1942 Annual Report
1941-42	7.73	35.4	6.85	192,700	1942 Annual Report
1942-43	8.4	56.1	6.62	269,378	1944 Annual Report
1943-44	8.84	47.7	7.22	292,113	1944 Annual Report

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

Table A.10: Robustness: Effect of Drought Last Year on ln Odds Hybrid Ratio, no re-labeling missing pre-adoption values as zero

	(1)	(2)	(3)	(4)
Drought, t-1	-0.032	-0.146**	-0.009	-0.143***
	(0.060)	(0.058)	(0.052)	(0.052)
Year FE	Yes	No	Yes	No
CRD FE	Yes	Yes	Yes	Yes
State X Year FE	No	Yes	No	Yes
1930 Census X Year Control	No	No	Yes	Yes
N	3200	3198	3200	3198
adj r^2	0.949	0.974	0.965	0.978

All Standard Errors are Clustered by Crop Report District.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A.11: Robustness: Effect of Lagged Drought on ln Odds Hybrid Ratio, no re-labeling missing pre-adoption values as zero

	(1)	(2)	(3)	(4)
Drought, t-1	-0.012	-0.144**	-0.005	-0.141***
	(0.050)	(0.057)	(0.050)	(0.051)
Drought, t-2	-0.106*	-0.165***	-0.056	-0.154***
	(0.055)	(0.056)	(0.045)	(0.046)
Drought, t-3	-0.050	-0.080	-0.013	-0.059
	(0.046)	(0.054)	(0.047)	(0.047)
Drought, t-4	0.004	-0.021	0.014	-0.039
	(0.048)	(0.052)	(0.049)	(0.046)
Drought, t-5	-0.002	-0.053	-0.022	-0.071
	(0.043)	(0.047)	(0.050)	(0.046)
Year FE	Yes	No	Yes	No
CRD FE	Yes	Yes	Yes	Yes
State X Year FE	No	Yes	No	Yes
1930 Census X Year Control	No	No	Yes	Yes
N	3200	3198	3200	3198
adj r^2	0.949	0.974	0.965	0.978

All Standard Errors are Clustered by Crop Report District.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A.12: Robustness: Effect of Cumulative Drought on ln Odds Hybrid Ratio, no re-labeling missing pre-adoption values as zero

	(1)	(2)	(3)	(4)
Cumulative Yrs Drought, t-1/t=1931	0.145***	0.128*	0.032	0.122**
	(0.047)	(0.066)	(0.045)	(0.057)
Year FE	Yes	No	Yes	No
CRD FE	Yes	Yes	Yes	Yes
State X Year FE	No	Yes	No	Yes
1930 Census X Year Control	No	No	Yes	Yes
N	3200	3198	3200	3198
adj r^2	0.950	0.974	0.965	0.978

All Standard Errors are Clustered by Crop Report District.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A.13: Robustness: Effect of Cumulative Drought over Past 5 Yrs on ln Odds Hybrid Ratio, no re-labeling missing pre-adoption values as zero

	(1)	(2)	(3)	(4)
Cumulative Yrs Drought, t-1/t-5	-0.034	-0.091**	-0.016	-0.090**
	(0.038)	(0.044)	(0.037)	(0.036)
Year FE	Yes	No	Yes	No
CRD FE	Yes	Yes	Yes	Yes
State X Year FE	No	Yes	No	Yes
1930 Census X Year Control	No	No	Yes	Yes
N	3200	3198	3200	3198
adj r^2	0.949	0.974	0.965	0.978

All Standard Errors are Clustered by Crop Report District.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A.14: Alternative Specifications: Effect of Drought Last Year on Percent Hybrid

	(1)	(2)	(3)	(4)
Drought, t-1	-0.050***	-0.012	-0.037***	-0.013*
	(0.013)	(0.008)	(0.009)	(0.007)
Year FE	Yes	No	Yes	No
CRD FE	Yes	Yes	Yes	Yes
State X Year FE	No	Yes	No	Yes
1930 Census X Year Control	No	No	Yes	Yes
N	4516	4516	4516	4516
adj r^2	0.818	0.948	0.901	0.961

All Standard Errors are Clustered by Crop Report District.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A.15: Alternative Specifications: Effect of Lagged Drought on Percent Hybrid

	(1)	(2)	(3)	(4)
Drought, t-1	-0.033***	-0.011	-0.033***	-0.013*
	(0.011)	(0.008)	(0.008)	(0.007)
Drought, t-2	-0.061***	-0.015**	-0.048***	-0.014**
	(0.009)	(0.007)	(0.008)	(0.007)
Drought, t-3	-0.056***	-0.005	-0.055***	-0.010
	(0.008)	(0.007)	(0.008)	(0.007)
Drought, t-4	-0.046***	-0.000	-0.050***	-0.006
	(0.008)	(0.007)	(0.008)	(0.006)
Drought, t-5	-0.034***	0.005	-0.041***	-0.001
	(0.009)	(0.008)	(0.008)	(0.007)
Year FE	Yes	No	Yes	No
CRD FE	Yes	Yes	Yes	Yes
State X Year FE	No	Yes	No	Yes
1930 Census X Year Control	No	No	Yes	Yes
N	4516	4516	4516	4516
adj r^2	0.826	0.948	0.905	0.961

All Standard Errors are Clustered by Crop Report District.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A.16: Alternative Specifications: Effect of Cumulative Drought on Percent Hybrid

	(1)	(2)	(3)	(4)
Cumulative Yrs Drought, t-1/t=1931	0.035***	0.009	0.030***	0.013*
	(0.010)	(0.009)	(0.010)	(0.008)
Year FE	Yes	No	Yes	No
CRD FE	Yes	Yes	Yes	Yes
State X Year FE	No	Yes	No	Yes
1930 Census X Year Control	No	No	Yes	Yes
N	4516	4516	4516	4516
adj r^2	0.822	0.948	0.902	0.961

All Standard Errors are Clustered by Crop Report District.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A.17: Alternative Specifications: Effect of Cumulative Drought over Past 5 Yrs on Percent Hybrid

	(1)	(2)	(3)	(4)
Cumulative Yrs Drought, t-1/t-5	-0.047***	-0.006	-0.046***	-0.009
	(0.007)	(0.007)	(0.007)	(0.006)
Year FE	Yes	No	Yes	No
CRD FE	Yes	Yes	Yes	Yes
State X Year FE	No	Yes	No	Yes
1930 Census X Year Control	No	No	Yes	Yes
N	4516	4516	4516	4516
adj r^2	0.826	0.948	0.905	0.961

All Standard Errors are Clustered by Crop Report District.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

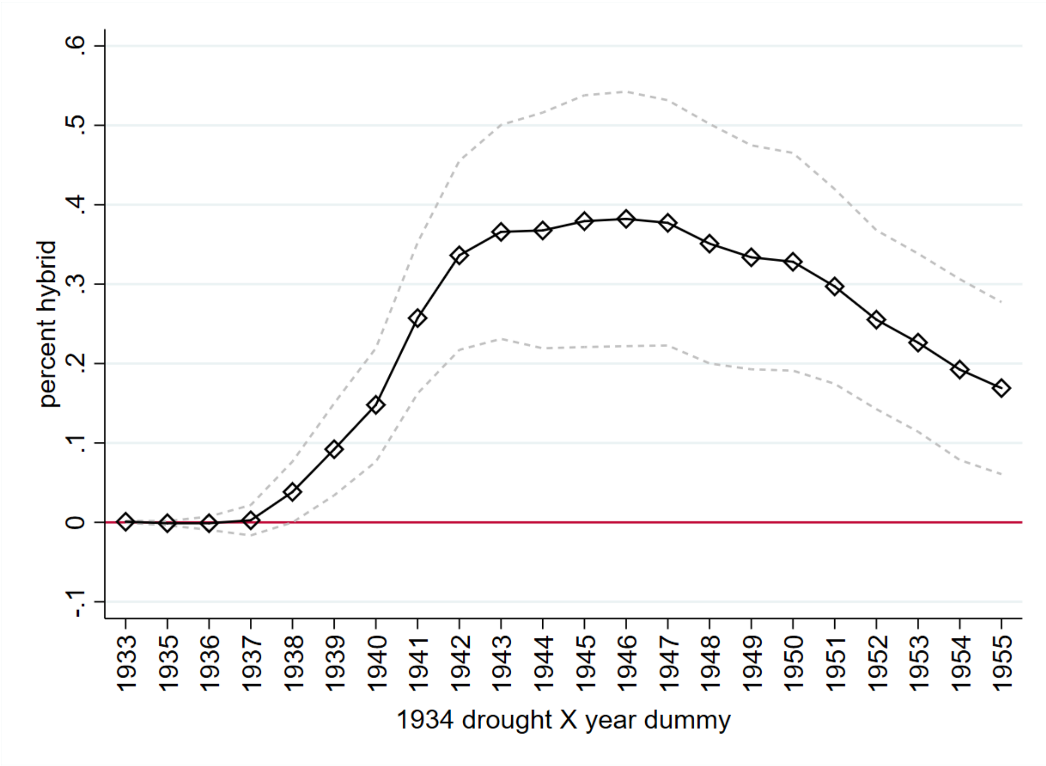

Figure A.11: Effect of 1934 Drought on Hybrid Adoption, Regression Coefficients of 1934 Drought Status X Year.

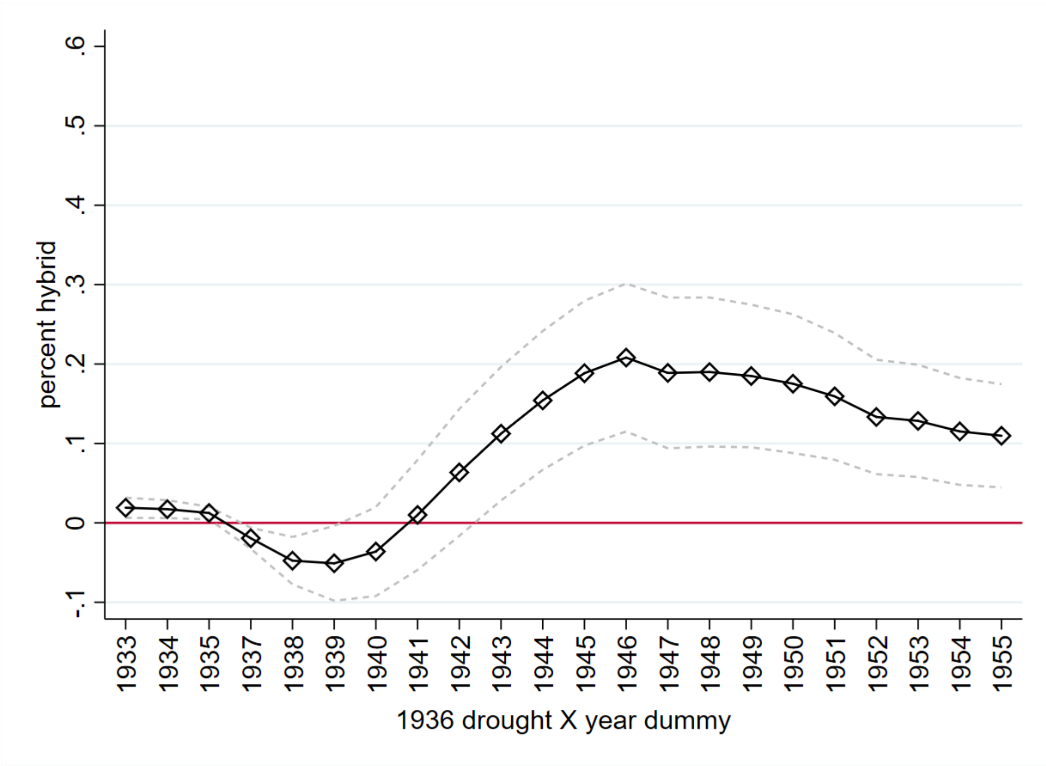

Figure A.12: Effect of 1934 Drought on Hybrid Adoption, Regression Coefficients of 1936 Drought Status X Year.

Figure A.13: Effect of 1934 and 1936 Droughts on Hybrid Adoption, Regression Coefficients of Drought Status X Year.