Quantifying Long-term Adjustment to Environmental Change: Evidence from the American Dust Bowl

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Abstract

This paper analyzes the impact of the 1930's American Dust Bowl and, in particular, investigates how much the short-term costs from erosion were mitigated by long-term adjustments. Exploiting new data collected to identify low, medium, and high erosion counties, estimates indicate that the Dust Bowl led to substantial immediate decreases in agricultural land values and revenues. Until at least the 1950's, however, there was limited reallocation of farmland away from activities that became relatively less productive due to erosion. Relative changes in agricultural land values and revenues indicate that the annualized long-term cost (in present discounted value) was 86% of the short-term cost to agriculture. Labor was reallocated, primarily through immediate migration and continued population declines into the 1950's. Substantial migration reflects the large cost of the Dust Bowl, and was an important channel through which short-term costs were partly mitigated.

JEL: J6, N32, N52, O1, Q1, Q5

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One recurrent theme within economics is that production adjusts more to a shock in the "long-run" than in the "short-run" (e.g., Samuelson's Le Chatelier principle). The short-run costs from a shock may be mitigated in the long-run by economic agents' adjustments. This is a central issue in the context of global climate change and local environmental collapse (Diamond 2005). While short-run costs from weather fluctuations may be large, the implied effect for a permanent change in climate may be an overestimate if agents are able to adjust (Deschenes and Greenstone 2007, Dell et al. 2008, Guiteras 2008).

Similar issues motivate work by Blanchard and Katz (1992) and others on regional economic adjustment to labor demand shocks and the resulting geographic allocation of labor. This relates to a general question of how quickly resources can be reallocated in response to changes in prices or relative productivity. While such responses may be slow and difficult to observe in response to modern shocks, historical shocks provide settings in which to identify economic adjustments that occur over a long period of time (Carrington 1996, Margo 1997, Duflo 2004).

Empirical challenges arise in isolating the effect of an historical shock from other economic changes. The shock must be large and observable to people at the time, but to allow identification of its effects it must also be differential across areas. Large geographically-differentiated shocks are rare, and there is typically not detailed data on what happened in the immediate aftermath of the shock. This makes it difficult to study the specific adjustment strategies that might have been adopted in reaction to the shock. This data scarcity explains why the historical literature has generally focused on long-run changes in population (Davis and Weinstein 2002, Miguel and Roland 2006, and Redding and Sturm forthcoming).

This paper analyzes the aftermath of tremendous permanent soil erosion during the 1930's American Dust Bowl. The Dust Bowl erosion was quite damaging, and its effects varied across counties within a state. Detailed data allow for an examination of many dimensions of adjustment over more than 60 years. This paper focuses on the speed and magnitude of adjustment in the agricultural sector, the resulting difference in short-run and long-run costs, and the reallocation of labor.

The Dust Bowl was a period of extreme soil erosion on the American Plains, unexpectedly brought about by the combination of severe drought and intensive land-use. Strong winds swept topsoil from the land in massive dust storms, and occasional heavy rains carved deep gullies in the land. By the 1940's, many Plains areas had cumulatively lost more than 75% of their original topsoil.

The paper begins by setting out a model of agricultural production in the short-run and long-run. The model highlights that the cost of the Dust Bowl will be immediately capitalized into land values. In the long-run, land allocations adjust toward less-affected

activities. In general equilibrium, adjustment may also occur through out-migration and an expansion of local industry. Thus, there are multiple potential margins of adjustment, and this paper examines many of them.

The key to this analysis is the existence of substantial local variation in erosion following the Dust Bowl. In particular, the empirical analysis is based on a comparison of areas that became severely, moderately, or lightly eroded. Erosion levels are combined with Census data to form a balanced panel of counties from 1910 to the 1990's. The regressions compare changes in more-eroded and less-eroded counties within the same state, after adjusting for differences in pre-Dust Bowl characteristics.

The Dust Bowl imposed substantial costs on Plains agriculture. From 1930 to 1940, immediately following the Dust Bowl, more-eroded counties experienced substantial and permanent relative declines in agricultural land values. The per-acre value of farmland declined by 28% in high erosion counties and 16% in medium erosion counties, relative to changes in low erosion counties. Assuming that the low erosion counties were not affected, the decline in land values indicates a total capitalized economic loss from the Dust Bowl of $153 million in 1930 dollars ($1.9 billion in 2007 dollars). Given average land values in 1930, this is the total value of farmland equal to an area roughly the size of Oklahoma.

More-eroded counties also experienced substantial immediate declines in agricultural revenues per-acre of farmland. Under strong theoretical assumptions, the relative percent changes in agricultural land values and revenues imply that the annualized long-term cost, in present discounted value, was 86% of the short-term cost to agriculture. That is, for each 1% that revenue declined from 1930 to 1940, land values declined by 0.86%. Similar levels of cost persistence are implied by the estimated path of recovery in revenues.

One potential margin of adjustment to the Dust Bowl was in land-use decisions, but there was limited and slow adjustment. Total farming experienced little decline, consistent with an inelastic demand for land in non-agricultural sectors. Within the agricultural sector, adjustment appears to have been possible: there was a decrease in the relative productivity of land for crops (compared to animals) and for wheat (compared to hay). Until at least the 1950's, however, there was little adjustment of land from crops to pasture or from wheat to hay.

The paper then examines why land-use adjustment was slow. Credit constraints may have been important, and adjustment was greater in the more-eroded areas that had more banks prior to the 1930's, compared to those with few banks. Evidence is mixed on the role of tenant farming in slowing land-use adjustment. Government programs do not appear to have discouraged adjustment, at least not in more-eroded counties relative to less-eroded counties, as payments were not targeted toward more-eroded counties.

A second potential margin of adjustment was labor, through migration or movement between sectors. Consistent with contemporary and historical accounts, there was a substantial population decrease from 1930 to 1940 in more-eroded counties relative to less-eroded counties, at the same time as substantial out-migration from the entire region. By 1940, unemployment was slightly higher and proxies for wages were lower. Equilibrium was reestablished through further declines in population, rather than an increase in local industry.

One caveat of examining within-region variation from a shock is the inability to observe aggregate adjustment through technological innovation. Instead, this paper analyzes changes in technology choice, treating the technological possibility frontier as common to all areas.

Overall, this paper finds that the Dust Bowl imposed substantial costs on Plains agriculture. Immediate adjustment took place mainly through decreased land values and population, while agricultural land-use only adjusted slowly. There was limited mitigation of short-run agricultural losses. Migration reflected these large losses, and was an important channel through which economy-wide consequences were mitigated, both in the short-run and long-run.

The paper is organized as follows. Section I provides historical background on the Dust Bowl and aggregate trends over the 20th century. Section II models the short-run and long-run response of agricultural production to the Dust Bowl, and discusses how population, industry, and other locations might also change. Section III describes the measurement of erosion levels and presents baseline summary statistics by erosion level. Section IV outlines the empirical methodology, Section V presents the results, and Section VI concludes.

I Historical Background

I.A The Dust Bowl and Massive Soil Erosion: 1931 to 1938

Since the late 19th century, agricultural activity had increased substantially on the Plains. World War I then increased demand for American agricultural goods, leading to high prices and a boom period in Plains agriculture. Farming continued to expand and European production recovered after WW1, contributing to low prices for agricultural goods in the 1920's. Thus, despite high yields, farms were struggling even prior to the Great Depression.

By the time moderate drought began on the Plains in 1931, farms had increasingly plowed up native grasslands. Dry conditions persisted, contributing to a loss in ground cover that made the land susceptible to self-perpetuating dust storms (wind erosion). The hardened bare ground also experienced substantial runoff during the occasional heavy rain storm (water erosion).

In 1934 and 1936, there were devastating droughts and widespread crop failure. From 1934 to 1936, especially large dust storms blew topsoil across the Plains. The occasional fierce rain, especially in 1935, carved deep gullies in farmland. This period of massive erosion (the Dust Bowl period) is considered to have ended by 1941 at the latest, along with the US entry into WW2, the end of the Depression, and the return of generally wetter weather.

There is limited precise information, however, on when erosion occurred in particular areas, as the stock of topsoil was not recorded in comparable units at different points in time. The Soil Erosion Service (SES), established in 1933 and expanded to become the Soil Conservation Service (SCS) in 1935, published erosion maps from 1933 to December 1937, at which point there is a gap in the National Archives collection of soil erosion maps until the late 1940's. The SCS marked a very general boundary for which areas experienced severe wind erosion from 1935 to 1936, in 1938, and from 1935 to 1938. There are few historical accounts or references to severe erosion occurring after 1938, despite some incorrect information that has circulated.[1] Thus, I consider the Dust Bowl erosion to have occurred between 1931 and 1938, i.e., between the collection of census data in 1930 and 1940.

I.B Causes of the Dust Bowl and Government Policy

The Dust Bowl was caused by a combination of prolonged severe drought and intensive land-use, though it is debated how much weight should be attributed to each factor.[2] New Deal government officials emphasized that an unsustainable amount of Plains land had been plowed for crops and that the remaining grassland was over-grazed by livestock. There was a fear that the region would become the once-imagined "American Desert" if private land-use practices were allowed to continue (Science 1934, News-week 1936). Attributing the Dust Bowl to unsustainable land-use became an important rationalization for New Deal agricultural policies.

[1] Worster (1979, p.30) presents a map of the SCS wind erosion regions (1935-1936, 1938, 1935-1938) that also adds a substantial wind erosion area in 1940. Geoff Cunfer discovered the source of this error: a 1940 USDA document, which cites a December 8, 1939 Washington Evening Star newspaper article, which in turn cites information provided by SCS technicians. The displayed 1940 wind erosion region was projected in 1939, and the 1940 USDA document states that these projections proved incorrect and that there turned out to be little blowing. The 1939 newspaper article map also displays how the Dust Bowl region evolved from 1935-1939. In addition to the common 1935-1936 and 1938 regions, this map shows a 1937 region that is similar to and contained within the 1935-1936 region and a 1939 region that is at the center of the 1938 region and is much smaller. Neither Cunfer nor I has found these 1937 and 1939 regions in other archived publications. My interpretation is that these regions were included by the newspaper to fill in the time series from 1935-1939, rather than as a reflection of particular new blowing in those years.

[2] The typical historical view emphasizes the over-exploitation of land (SCS 1955, Worster 1979, Hurt 1981), as did most contemporaries (SCS 1935 and 1939, Hoyt 1936, Wallace 1938). Cunfer (2005) emphasizes the impact of severe weather.

One explanation for the Depression was farmers' lack of purchasing power, due to low prices for agricultural goods. The 1933 Agricultural Adjustment Act was designed to raise prices by paying farmers to reduce planted acreages. The government also purchased livestock at above-market prices, canning some meat and destroying the rest (Leuchtenburg 1963, Saloutos 1982).

As these initial policies became less popular and the Supreme Court declared aspects unconstitutional, the policies' stated purpose shifted toward conservation. The 1935 and 1936 Soil Conservation and Domestic Allotment Acts were partly an effort to combat erosion and preserve the country's farmland resources, but they also represented the new banner under which to reduce agricultural production (Rasmussen and Baker 1979, Phillips 2007). The 1938 Agricultural Adjustment Act combined efforts to maintain higher prices with this new focus on erosion prevention, nominally making a portion of acreage reduction payments conditional on conservationist land-use adjustments. The SCS established soil erosion control projects, aimed at demonstrating the effectiveness of their recommended soil conservation techniques (SCS 1937). These adjustments were mainly plowing along contour lines, retaining crop residues to provide ground cover, fallowing land with protective cover, planting alternate strips of cash crops and drought-resistant crops, or converting cropland back to grassland.[3]

I.C Responses to the Dust Bowl

The Dust Bowl is associated with substantial out-migration, most famously described in Steinbeck's The Grapes of Wrath. There is little empirical evidence, however, that separates Dust Bowl migration from other sources of change in Plains states' population. All migrants from the region may have been inappropriately (and derogatorily) lumped together as "Okies."[4]

Most historical discussions of agricultural land-use have focused on its role in causing the Dust Bowl, but many give the impression that there was substantial adjustment following the Dust Bowl. Historical accounts of government programs generally suggest that these encouraged substantial land-use adjustment.[5]

[3]The SCS also took greater responsibility over the administration of Civilian Conservation Corps work camps, which employed workers on public projects to reduce unemployment. Some of this work focused on preventing erosion: terracing land, rehabilitating gullies, and planting trees as wind breaks.

[4]Worster (1979, p51) describes interviews with migrants registering at Federal Emergency Relief offices around the country: only 12% of families from Oklahoma attributed their migration to farm failure, 17% of families from Kansas, and 16% of families from Colorado.

[5]For example, see Hurt (1985). In contrast, Cunfer (2005) notes that overall land-use patterns appear surprisingly stable from 1920 to 2000. Yet Cunfer's aggregate analysis of land-use may overlook important adjustments within agricultural production (Hansen 2005).

Hansen and Libecap (2004) present evidence that externalities played an important role in causing the Dust Bowl. Farmers could discourage wind erosion by fallowing land or converting land to grasslands and pasture, but much of the benefit would be captured by neighboring farms. They argue that increased farm sizes and soil conservation districts lowered these coordination problems, and that resulting production adjustments prevented the Dust Bowl's reoccurrence.[6]

Agricultural adjustment to the Dust Bowl would be expected to reflect the substantial decrease in productivity due to soil erosion. In particular, erosion may have changed the relative returns to different productive activities. If the production of crops is more sensitive to soil quality, then farmers may shift more-eroded land into pasture for animals. Similarly, land may be shifted from soil-sensitive crops (wheat) to more erosion-resistant crops (hay/grass). Agricultural adjustment will also interact with migration and adjustment in non-agricultural sectors, as discussed later.

I.D Aggregate Trends in Agriculture and Population on the Plains

Figure 1 presents aggregate changes in agriculture and population on the Plains over the 20th century.[7] Panels A and B show changes in the per-acre value of farmland and farm revenue in logs.[8] Average farmland became less valuable and less productive from 1910 to the 1940's. This partly reflects an increase in total farmland (Panel C), which expanded into less valuable areas. Average land values and revenues rose after total farmland stabilized in the 1940's.

Panel D shows that the total amount of cropland, as a fraction of total farmland, was constant from 1925 to 1930, decreased from 1930 to 1945, and was then mostly constant. This decrease is consistent with accounts that Plains farming had become too intensive prior to the 1930's and then found it necessary to scale back cultivation. However, this decrease is also consistent with an expansion of farming from 1930 to 1945 into areas less-suited for growing crops.

[6]This is in line with much of the historical literature. However, Worster (1979) argues that the Dust Bowl did reoccur to some degree, and that conservation never replaced capitalism as the dominant farming mentality.

[7]Aggregate numbers are calculated by summing over the same 769 Plains counties in every reported period. The only exception is in Panel E. Data on land fallowing are available from 1925 to 1945 for all 769 counties, when fallow land is defined as cropland left idle or in cultivated summer fallow. In 1950 and after, data are only available in 587 counties for land in cultivated summer fallow. Following Hansen and Libecap (2004), this series is treated as comparable and the sample is restricted to the 587 counties over the entire period.

[8]The value of farmland is divided by the CPI, as land is an asset whose value will change with the price of consumption. The value of revenue is divided by the PPI for all farm products, to focus on changes in productivity rather than output prices.

Panel E shows that there was a substantial increase from 1930 to 1940 in the proportion of cropland kept fallow. Much of this increase was short-lived, but fallowing remained above its level in 1930. Panel F shows that there was a gradual increase in average farm sizes after 1930. The aggregate changes in panels E and F are consistent with results presented by Hansen and Libecap (2004): increased farm sizes may have allowed farmers to internalize the positive externalities from preventing wind erosion by fallowing land and decreasing cultivation shares.

Panel G shows that total population grew at a roughly constant rate from 1910 to 2000, with somewhat slower growth from 1930 to 1950. Note that, from 1930 to 1940, total population declined in the five central Plains states (Oklahoma, Kansas, Nebraska, South Dakota, North Dakota) between 3% and 7%. Panel F shows that the fraction of population in rural areas declined at a constant rate from 1910 to 1940, and a somewhat quicker rate from 1940 to 1970. Some of this decline is mechanical: as population grows, more people will be in non-rural areas (places with more than 2,500 inhabitants).

Figure 1 provides an overall empirical context in which to interpret the estimated relative changes. However, it is difficult to isolate the effect of the Dust Bowl in these aggregate changes. Even relative to other areas of the country, other shocks may substantially affect these outcomes (e.g., WW1, the Great Depression, WW2, technological change, price changes). The empirical analysis that follows will attempt to isolate the effects of the Dust Bowl, controlling for state-specific changes over each time period.

II Theoretical Framework

This section outlines a model in which permanent erosion during the Dust Bowl may affect agricultural production differently in the "short-run" and "long-run." In the short-run, farmers can only adjust variable inputs. In the long-run, farmers can adjust product choices or fixed inputs at some cost. This model helps to interpret the speed and magnitude of adjustment in agricultural production decisions, and to compare short-run and long-run costs using observed changes in land values, revenue, and inputs.

The effects on agriculture are then interpreted within a basic model of long-run supply and demand across locations, sectors, and factor inputs. This model guides the empirical analysis of migration and non-agricultural outcomes, and informs how cross-county spillovers influence the estimated relative effect of the Dust Bowl within states.

II.A A Model of Agricultural Production

Assume perfectly competitive markets, in which a farmer chooses production decisions in every period to maximize the present discounted value of profits. The farmer produces one good and allocates a share θ of land between two production technologies, $\mathrm{F}_1(\theta, V_1)$ and $\mathrm{F}_2(1-\theta, V_2)$, that are each a function of variable input choices V. The variable inputs reflect factors that can be adjusted quickly, such as labor, and are purchased in each period at a constant price.[9] The two technologies reflect different production methods or choices of fixed inputs that can only be adjusted slowly, such as land characteristics (cropland vs. pasture) or product choices (wheat vs. hay).

For any given land allocation, the farmer chooses variable inputs to maximize profits. Define $\Pi_1(\theta)$ and $\Pi_2(1-\theta)$ as the maximum obtainable profit after allocating land to each technology. Given these maximum obtainable profits, the farmer chooses θ to maximize total profits: $\Pi_1(\theta)+\Pi_2(1-\theta)$. Assuming that these two functions are differentiable and concave, an optimal interior $\overline{\theta}$ is chosen such that $\Pi_1'(\overline{\theta}) = \Pi_2'(1-\overline{\theta})$.[10]

The farmer obtains an initial profit $\pi^I = \Pi_1(\overline{\theta})+\Pi_2(1-\overline{\theta})$. The value of land is assumed to equal the present discounted value of profits, $\frac{\pi^I}{1-\beta}$, where β is a constant discount factor. This assumption is consistent with competition and free entry in land markets, with the marginal land buyer having access to credit at a fixed interest rate.[11]

II.B Agricultural Production After a Permanent Shock

An unexpected and permanent shock at $t = 0$ is assumed to decrease the relative profitability of the first technology. Define periods $t < T$ as the "short-run" when variable inputs can adjust but the land allocation is constrained at its previous level ($\theta = \overline{\theta}$). The land allocation is then completely adjusted when $t = T$, after which is the "long-run." Assume initially that adjusting the land allocation is costless, but the model will then highlight the impact of adjustment costs.

This artificial distinction between the "short-run" and "long-run" can be interpreted as a simplified case of an unconstrained optimal adjustment model in which several factors

[9] This baseline model assumes that variable inputs are supplied in competitive markets, in which agriculture is only a small part. This rules out general equilibrium effects where input prices depend on agricultural production.

[10] This analysis will focus on interior solutions, where technological change is simply an adjustment along an existing production possibility frontier. If the initial equilibrium were a corner solution and only one technology were used, then subsequent adoption of the other technology could be interpreted as technological growth.

[11] If this assumption were relaxed and the Dust Bowl temporarily lowered the discount factor, then land values would decline more in the short-run and increase more in the long-run.

could delay adjustment. First, adjustment costs could be convex, e.g., if needed capital or other inputs have an upward sloping supply curve in each period. Second, adjustment costs could decline over time due to learning-by-doing or other positive spillovers in technological adoption (Griliches 1957, Foster and Rosenzweig 1995). Third, the potential for learning to resolve uncertainty about optimal adjustments could delay investment responses (Dixit and Pindyck 1994, Bloom et al. 2007). Fourth, the original land allocation could have required fixed investments that depreciate over time, and would be lost during adjustment (Chari and Hopenhayn 1991).

Change in Profits. By assumption, the relative profitability of the first technology decreases in the short-run, given the new optimal choice of variable inputs. For analytical convenience, assume that it decreases by a constant percentage: $\Pi_1(\theta)$ decreases to $\delta\Pi_1(\theta)$, where $\delta \in (0,1)$. The land allocation constraint binds because $\delta\Pi_1'(\overline{\theta}) < \Pi_2'(1-\overline{\theta})$. The farmer earns a short-run profit $\pi^{SR} = \delta\Pi_1(\overline{\theta}) + \Pi_2(1-\overline{\theta})$. In the long-run, a new optimal $\widehat{\theta}$ is chosen such that $\delta\Pi_1'(\widehat{\theta}) = \Pi_2'(1-\widehat{\theta})$. The farmer earns a long-run profit $\pi^{LR} = \delta\Pi_1(\widehat{\theta}) + \Pi_2(1-\widehat{\theta})$.

Given an initially binding land allocation constraint, it must be that $\widehat{\theta} < \overline{\theta}$ and $\pi^{SR} < \pi^{LR} < \pi^{I}$. Profit increases from the short-run to the long-run by $\int_{\widehat{\theta}}^{\overline{\theta}} \Pi_2'(1-x) - \delta\Pi_1'(x)dx$; intuitively, the difference in marginal profit is regained for each unit adjusted. Taking a first-order Taylor expansion of each marginal profit function around $\overline{\theta}$, this term simplifies to $\frac{1}{2}(\overline{\theta}-\widehat{\theta})(1-\delta)\Pi_1'(\overline{\theta})$. The value of this "adjustment triangle" corresponds to one-half the change in land allocation multiplied by the initial decrease in marginal return. The approximation is exact if $\Pi_2'(1-\overline{\theta})$ and $\Pi_1'(\overline{\theta})$ are linear. As one would expect, profits fall in the short-run and partially recover in the long-run as the land allocation adjusts.

Change in Land Values. Land values are derived as the net present value of profits, given a profit stream of π^{SR} until period T and π^{LR} thereafter. In each period $0 \leq t \leq T-1$, the value of land is $\sum_{i=t}^{T-1} \pi^{SR}\beta^i + \sum_{i=T}^{\infty} \pi^{LR}\beta^i$; for $t \geq T$, the value of land is $\frac{\pi^{LR}}{1-\beta}$.

This has three implications that will be estimated from the data. First, land values initially fall by a smaller percentage than profits. This is due to the expected long-run recovery in profits. Rearranging terms, the value of land at $t=0$ is $\frac{\pi^{SR}}{1-\beta} + (\pi^{LR} - \pi^{SR}) \sum_{i=T}^{\infty} \beta^i$. This expression is greater than the PDV of short-run profits (the first term) when the long-run recovery in profits is larger and the long-run is achieved sooner.

Second, land values recover somewhat over time as periods of short-run profits are past and periods of long-run profits become more immediate. Rearranging terms, the value of land in each period $0 \leq t \leq T-1$ is $\frac{\pi^{LR}}{1-\beta} - (\pi^{LR} - \pi^{SR}) \sum_{i=t}^{T} \beta^i$. Land values increase in each period, though by a smaller percent than profits increase when the long-run is reached.

Third, the value of land at $t = 0$ capitalizes the full PDV economic loss associated with the shock. Rearranging terms, the value of land at $t = 0$ is $\frac{\beta^T \pi^{LR} + (1-\beta^T)\pi^{SR}}{1-\beta}$. Intuitively, this is a weighted average of long-run profits and short-run profits, where the weights are the relative value of each.

Change in Land Allocation. In the long-run, land is allocated away from the production technology that experienced a relative decrease in profitability. Rearranging terms from the profit function Taylor expansion, the change in land allocation $(\widehat{\theta} - \overline{\theta})$ equals the initial decrease in marginal return $((1-\delta)\Pi_1'(\overline{\theta}))$, divided by the summed slopes of the two technologies' marginal returns at the initial equilibrium $(\Pi_2''(1-\overline{\theta}) + \Pi_1''(\overline{\theta}))$. The change in land allocation will be greater when there is a larger decrease in marginal return, and smaller when marginal returns are more sensitive to changes in land allocation.

Change in Revenue and Inputs. There are no general theoretical predictions about changes in revenue or inputs, because they depend on the functional form of the production function. However, a Cobb-Douglas functional form provides a useful benchmark: because factor shares are constant, there would be proportional decreases in profits, revenue, and inputs.

All major inputs are not reported in the data, so it will not be possible to analyze profits directly. Rosenzweig and Wolpin (2000) illustrate how unobserved inputs, particularly family labor, can bias estimates of the effect of environmental shocks on profits (revenues minus observed input costs). The analysis here will instead focus on percent changes in revenue, which would proxy for percent changes in profits assuming a Cobb-Douglas functional form. This assumption is quite strong, so an empirical analysis of observed inputs will explore the potential direction of bias.

The Effect of Adjustment Costs. Consider now the differences in these effects when the farmer must pay a non-recoverable cost $C_{12}(L)$ to shift land L from technology 1 to technology 2. For simplicity, assume that the farmer will pay this one-time cost in period T.

Assuming that some land adjustment is still optimal, the new long-run land allocation is chosen in period T to satisfy the condition: $(1-\delta)\Pi_1'(\widehat{\theta}) = \Pi_2'(1-\widehat{\theta}) - (1-\beta)C_{12}'(\overline{\theta} - \widehat{\theta})$. This condition assumes that the farmer has perfect access to credit so that only $(1-\beta)$ of the adjustment cost is paid in each period; if instead the farmer faces some capital constraints, then full initial adjustment will be more costly.

Compared to the model with no adjustment costs, there will be less adjustment in land allocation. Thus, there will be less long-run recovery in profit, in addition to the direct reduction in profits from the paid adjustment cost. The value of land will initially decrease by an additional term, equal to the PDV of the future adjustment cost. This additional term increases over time as the adjustment cost becomes more immediate. At $t = T$, the value of

land then increases by the full value of the adjustment cost.[12] The sum total of these effects is clear in the special case when the adjustment cost is only ϵ less than the PDV long-run recovery in profits: the value of land decreases at $t = 0$, remains constant, and then partially recovers at $t = T$ when it increases by the full amount of the adjustment cost.

If adjustment costs can be fully recovered, such as in purchasing general machinery or livestock, then the value of land follows the same pattern initially and does not increase at $t = T$ when these costs are paid. Thus, observed changes in land values can indicate whether adjustment takes place on margins that require fixed or mobile investments. Note, however, that this model assumes perfect foresight. Any systematic errors about the future costs of erosion, potential government subsidies, or other factors will also influence the evolution of land values.

II.C Empirical Predictions for Agricultural Production

(1) The immediate decrease in land values reflects the present discounted value of the economic cost to agriculture.

(2) Profits recover partially in the long-run, as fixed production decisions adjust.

(3) If profits are expected to recover in the long-run, then land values fall by a smaller percentage than profits in the short-run.

(4) Under strong functional form assumptions, percent changes in revenue may proxy for percent changes in profits. If revenue recovers due to an increase in inputs rather than technological adjustment, then the percent recovery in revenue will overstate the percent recovery in profits.

(5) Adjustment costs reduce or slow recovery in profits. If adjustment costs are fixed to the land, land values increase when the costs are paid.

II.D A Model of Adjustment Across the Broader Economy

If the Dust Bowl substantially affected agricultural production, this could have general equilibrium effects in non-agricultural sectors and non-Dust Bowl areas. This section outlines a basic model of supply and demand across locations, sectors, and factor inputs. This is a model of long-run supply and demand, in which many margins are free to adjust.

In this model, there are two locations (Dust Bowl and non-Dust Bowl). For example, this could be two counties within Oklahoma that are more- and less-eroded, or one eroded county in Oklahoma and one non-eroded county in California. There are two sectors (agriculture

[12] This refers to the gross value of land, which is reported in the data. The value of land, net of any mortgage debt incurred, would increase gradually as that debt is repaid.

and industry) that produce freely tradeable goods using two homogeneous factors (land and labor). The supply of land is fixed in each location. Labor is supplied by workers who pay a cost to change location or sector. Workers must supply labor in the same location that they live. Workers consume land (housing), agricultural goods, and industrial goods. Assuming perfectly competitive markets, all prices (land values, wages, and prices for agricultural and industrial goods) are set such that each market clears.[13]

For the comparative statics, assume that agricultural productivity declines in the Dust Bowl area. This decreases the demand for agricultural land. Consider the case in which the supply of land for agriculture is inelastic, i.e., workers and industrial firms (current or entering) have little use for additional marginal lands. In this case, adjustment in the land market mainly occurs through decreased land prices with little change in total farmland.

Assume further that the Dust Bowl decreases the productivity of agricultural labor. Workers then have an incentive to move to the non-Dust Bowl area and/or switch to the industrial sector. Equilibrium wages remain relatively lower in the Dust Bowl area (particularly in the agricultural sector) to the extent that there are costs to moving (and switching sectors). Workers consume some land that is now cheaper, so paid wages fall by more than local price-adjusted wages.

The industrial sector has an incentive to expand in the Dust Bowl area for two reasons. First, cheaper land is attractive if the sector has any use for additional lands. Second, the industrial wage would decrease to the extent that workers switched sectors or consumed cheaper land.[14] Lower wages encourage higher labor-capital ratios in the agricultural sector, and discourage adjustment toward production methods that use less labor (such as animals or hay, relative to crops or wheat).

In the non-Dust Bowl area, wages decrease in response to an in-migration of workers. Because the Dust Bowl area is less productive, agricultural output prices increase and the agricultural sector expands in the non-Dust Bowl area. As a result, land prices increase. The industrial sector contracts due to higher land prices and lower output prices.

II.E Empirical Predictions for the Broader Economy

(1) Workers migrate from the Dust Bowl area, though this incentive is tempered by lower housing prices and moving costs. If workers migrate to the compared non-Dust Bowl area, the relative comparison in population will overstate the number of migrants.

[13] This model is similar to that derived by Roback (1982), which focuses on urban amenities.

[14] The industrial sector could contract if it was supplied inputs by the local agricultural sector, or if it sold outputs locally to the agricultural sector. This is not captured in the model, but could be empirically relevant.

(2) A greater share of workers become employed in the industrial sector, which also expands due to lower land values and wages.
(3) If industry and workers have inelastic demand for agricultural land, then adjustment in land markets occurs mostly through lower prices rather than a contraction in total farmland.
(4) Lower wages encourage labor-intensive production in the agricultural sector.
(5) Decreased agricultural production in the Dust Bowl area raises land values in the non-Dust Bowl area, causing the relative comparison of land values to overstate the total cost of the Dust Bowl.
(6) Discouraged production activities in the Dust Bowl area are encouraged in the non-Dust Bowl area, due to increased output prices. Relative comparisons in production across sectors or agricultural products would overstate adjustment in the Dust Bowl area.

III Data and Summary Statistics

III.A Measuring Erosion

This paper uses new detailed data on which areas were most eroded after the 1930's, which I gathered by digitizing soil erosion survey maps currently in the National Archives. In response to the Dust Bowl, these maps were produced by the Soil Erosion Service (SES) and its successor, the Soil Conservation Service (SCS). The SES published the 1934 Reconnaissance Erosion Survey, which detailed the severity and type of erosion across the United States based on measurements taken during visits to each county (SCS 1935). In August 1936, the SCS published a map of which general areas had been affected to different degrees and a second more-detailed map in December 1937.

This first type of erosion map indicates whether areas were slightly, moderately, or severely eroded; whether it was wind erosion (topsoil being swept from the land) or sheet erosion (water generally shifting the topsoil off the land); and whether there were many gullies (formed by small streams of runoff carving paths in the land). There are two main limitations to this map type. First, it only reflects the stock of erosion at the time of the survey. Since there is no detailed baseline data and the erosion category definitions change over time, it is not possible to measure directly the erosion that occurred during the Dust Bowl. Second, it is difficult to compare erosion across categories and generate a single index for how much an area was affected.[15]

[15] Hansen and Libecap (2004) assigned erosion categories based on the 1936 map, as they are focused on specifically wind erosion.

The SCS prepared a second type of map that indicates dated regions of wind erosion on the Plains. These show broad areas that experienced blowing from 1935 to 1936 and in 1938, which correspond closely to areas with the highest wind speeds (Chepil et al. 1962). These regions have less local variation, however, and it is not clear how the exact areas were determined. There was substantial wind erosion at other times during the Dust Bowl, as well as water erosion, and these maps give little sense of the cumulative effect on the soil.

My analysis focuses on a third type of SCS erosion map, which shows cumulative erosion damage after the Dust Bowl. The map classifies areas as slightly eroded (less than 25% of topsoil lost), moderately eroded (25% to 75% of topsoil lost), and severely eroded (more than 75% of topsoil lost). Of all the SCS erosions maps, this map has the most detailed local variation in erosion. Documentation is sparse, but this map (along with most others) is recorded as "based on the 1934 Reconnaissance Erosion Survey and other surveys." The National Archives have three copies of this same map with publishing dates in 1948, 1951, and 1954 – prior to the next substantial period of erosion in the mid-1950's.

The main limitation of this cumulative erosion map is that it does not just reflect erosion that occurred during the 1930's Dust Bowl. Total erosion would have begun to increase along with the settlement of the Plains. Large-scale detailed erosion surveys only began in the 1930's, so there is no systematic baseline data on erosion and topsoil levels prior to the Dust Bowl. To focus on the change in erosion over the 1930's, the empirical analysis controls for a range of county characteristics in 1930, 1925, 1920, and 1910 that might predict baseline erosion levels.

To focus on the extreme erosion of the 1930's, the sample is restricted to counties within the 12 Plains states: Colorado, Iowa, Kansas, Minnesota, Montana, Nebraska, New Mexico, North Dakota, Oklahoma, South Dakota, Texas, and Wyoming.[16] In the cumulative erosion map, many areas in non-Plains states were also classified as moderately or severely eroded. Non-Plains states had only severe water erosion indicated in other maps, however, which is more likely to reflect gradual erosion over many previous decades. As a robustness check, the empirical analysis shows that more-eroded non-Plains counties did not experience the substantial relative drop in land values during the 1930's that occurred in more-eroded Plains counties. This suggests that the cumulative erosion measure is an effective proxy for the extreme Dust Bowl erosion on the Plains in the 1930's.

[16]The results are similar when the sample is restricted further to "Great Plains counties," as defined by the Great Plains Population and Environment Database (which provided additional historical data on these 12 states). This reduces the sample from 769 counties to 356 counties concentrated in western Kansas and Oklahoma, northwest Texas, central and western Nebraska, eastern Colorado, and the Dakotas.

III.B Combining County Outcomes with Erosion Data

The core dataset is compiled from US Census data on agriculture, population, and industry, aggregated to the county level. Among the key variables are the value and quantity of agricultural land, agricultural revenue, total cropland and pasture, revenue from crops or animals, production and acreage for a variety of crops, the number of farms, population, rural population, farm population, retail sales, manufacturing workers and value added, and unemployment.[17] Other data sources include banking data from the FDIC; New Deal expenditures from the Office of Government Reports; and drought data from the National Climatic Data Center.[18]

The data are combined into a panel of US counties, where the unit of observation is held fixed at 1910 county boundaries. Census data are used from 1910, 1920, and then approximately every 5 years through 1997, though data availability for some variables is more restricted. Data from 1935 is dropped, due to ongoing erosion from the Dust Bowl. When counties split or borders were otherwise adjusted in subsequent periods, the reported Census data are aggregated or adjusted to reflect the original 1910 county border (Hornbeck 2008). The base year was chosen as 1910 in a tradeoff between more sample counties and a longer pre-period for analysis: changing from 1900 to 1910 substantially increases the number of sample counties in Oklahoma and other areas, while moving beyond 1910 has less effect on sample size and the pre-period becomes less informative about differential trends.

The core results focus on the same sample of counties, for which data on key variables are available in every period of analysis.[19] This allows for a clearer interpretation of estimated changes over time and across specifications, because the sample composition is not also changing.

Figure 2 displays these 769 sample counties, along with the mapped cumulative erosion levels. The white area represents low erosion, the light gray is medium erosion, and the

[17] An unusual aspect of this data concerns the calculation of agricultural revenue in 1920, 1925, and 1930. In these periods, revenues from animals sold and animal products sold are not reported. Only the total value of animals is reported. In 1910 and 1940, both of these variables are reported. The ratio of revenue to stock is calculated for each county and used to impute the county's value of animal revenue in the intervening years. The results are not sensitive to using the revenue/stock ratio in 1910, 1940, or a weighted average of the two – the results presented here use a weighted average (with the 1910 ratio weighted by two-thirds in 1920, one-half in 1925, and one-third in 1930).

[18] I thank Price Fishback for providing the New Deal data (Fishback et al. 2005) and the drought data (Boustan et al. 2007).

[19] In a tradeoff between timespan and sample size, the sample is restricted to counties that have data on: land values, revenue, and farmland through 1992; cropland through 1974; population and rural population through 1969. The sample also excludes a small number of counties with less than 1000 acres of farmland and a few counties with extreme values due clearly to measurement error and/or the adjustment to maintain constant boundaries.

dark gray is high erosion (the crossed out areas are not in the sample).[20] The figure was constructed by overlaying the cumulative erosion map on a map of United States historical county borders using Arcview Geographical Information System (GIS) software. To create the data, the erosion areas were traced and merged with 1910 county borders to assign each county the percent of its area that falls within each erosion category.

III.C Summary Statistics, by Erosion Level

Table 1 presents baseline differences between sample counties in 1930, based on their assigned post-Dust Bowl erosion level.[21] For comparison, column 1 presents mean characteristics for all counties in 1930. Columns 2 and 3 report coefficients from a single regression of each outcome variable on the percent of a county in medium erosion and high erosion, controlling for state fixed effects.[22]

Counties with more erosion after the Dust Bowl tended to have previously: higher land values, denser population, more but smaller farms, a larger fraction of cropland in corn or cotton (as opposed to wheat and hay), and more animals. Column 4 reports the average difference between a county with high erosion and a county with medium erosion. These counties were more similar, though high erosion counties have more cropland allocated to corn.

Measured erosion levels are not randomly assigned for two reasons. First, part of this erosion occurred prior to the Dust Bowl and could be caused by, reflected in, or otherwise jointly determined with pre-Dust Bowl county characteristics. Second, the Dust Bowl's intensity was partly determined by the intensity of cultivation and other county land-use practices. The main empirical challenge is that counties with these different characteristics may have changed differently after the 1930's, even if the Dust Bowl had not occurred.

To address this issue, the empirical analysis will focus on specifications that control for differential changes over time that are correlated with state, county characteristics in 1930, and lagged values of those characteristics. The empirical analysis will not control for county

[20] The main reasons why areas are dropped from the sample are: the area was not sufficiently settled by 1910 for data to be reported; data are unavailable in 1925; agricultural revenue could not be imputed for 1920, 1925, or 1930; and border adjustments left data unavailable for any piece that made up more than 1% of the original county's total area.

[21] Given the construction of the sample, there are no missing values for panels A, B, and C. For panels D and E, missing values are assumed to be zero (generally in areas where these products are not produced).

[22] The means and regressions are weighted by county farmland levels, as the empirical analysis will be focused on the effect for an average acre of farmland. These variables will all be included as controls in later weighted regressions, so their weighted difference is more relevant to interpreting their importance as control variables.

characteristics after 1930, as these are potential outcomes of the Dust Bowl. A robustness check will instrument for county erosion levels using intensity of drought during the 1930's.

IV Empirical Framework

The empirical analysis is based upon comparing changes in outcomes for counties that experience different levels of erosion. For a graphical analysis of the data over the entire sample period, outcome Y_{ct} in county c and year t is regressed on the percent of the county in medium erosion (M_c) and high erosion (H_c) areas, a state-by-year fixed effect (α_{st}), linear functions of county characteristics (X_c), and an error term (ϵ_{ct}):

$$Y_{ct} = \beta_{1t} M_c + \beta_{2t} H_c + \alpha_{st} + \theta_t X_c + \epsilon_{ct}. \tag{1}$$

The effects of erosion and each county characteristic are allowed to vary in each year. The included county characteristics are each of the variables in panels B – E of table 1, and their lagged value from all available previous years. In each regression, every county included has data in every analyzed period.

This regression is a special case, in which each regressor is fully interacted with each time period. Thus, controlling for a county fixed effect would not change the difference between estimated β's; rather, it simply normalizes the β's relative to zero in some base period. County fixed effects are omitted in this regression in order to observe the pre-Dust Bowl difference in outcome levels across counties with different erosion levels, after controlling for the other pre-Dust Bowl characteristics.

Graphing the estimated β's shows how counties with each erosion level changed over the sample period, relative to a county with low erosion. To interpret these changes as the relative effect of the Dust Bowl, the primary identification assumption is that counties with different erosion levels would have changed the same if not for the Dust Bowl. In practice, this assumption must hold after controlling for differential changes over each time period that are correlated with each state and pre-Dust Bowl county characteristic.

From the estimation of equation (1), it is possible to observe whether counties with different erosion levels were on similar trends from 1910 to 1930 (after controlling for other covariates). Because counties may not be on the same trend prior to the Dust Bowl, the empirical analysis then controls for these differences in pre-trends.

For estimating the numerical results, two modifications are made to equation (1). First, the regression controls for the outcome level in all available pre-Dust Bowl periods, L_c. This is a flexible way to control for differential pre-trends, without assuming that trends prior to

the 1930's would have continued predictably – which is theoretically inappropriate for asset prices such as land values, and is empirically questionable for other outcomes.

Second, the outcome Y_{ct} is differenced from its value in 1930, so that each coefficient can be interpreted as the relative change since 1930. Differencing the data also improves the precision of the estimates by absorbing any fixed county characteristics; yet, as before, the estimated coefficients are not changed by differencing the data or by including a county fixed effect.[23] The regression is otherwise the same:

$$Y_{ct} - Y_{c1930} = \beta_{1t} M_c + \beta_{2t} H_c + \alpha_{st} + \theta_t X_c + \gamma_t L_c + \epsilon_{ct}. \tag{2}$$

As before, note that the effects of erosion and each county characteristic are allowed to vary in each year. In order to condense the results, a specification is sometimes estimated that pools the erosion variables for some combination of later time periods. The control variables are still allowed to vary in each year, so this amounts to averaging the estimated β's across years.

Regressions for agricultural outcomes are weighted by county farmland (or an analogous land measure) in 1930 in order to estimate the average effect for an acre of farmland. Regressions for labor outcomes are weighted by county population in 1930 in order to estimate the average effect for a person. Standard errors are clustered at the county level, to adjust for heteroskedasticity and within-county correlation over time. To check for spatial correlation among counties, Conley standard errors are estimated for changes in land values from 1930 to 1940 (Conley 1999). These standard errors are similar to standard errors clustered at the county level, indicating that the impact of the Dust Bowl was not highly spatially correlated.[24]

[23] Because the sample is balanced and the regressors are fully interacted with each time period, estimation of the regression is completely separable across year pairs. The methods are equivalent in the case of two time periods. While the coefficients are identical, the methods have slightly different standard errors. This differencing was done throughout for ease of interpretation and computational speed.

[24] The Conley method allows for outcomes to be correlated among nearby counties, with the degree of correlation declining linearly until some cutoff distance. Relative to when there is restricted to be no cross-county correlation, the percent increase in standard errors for changes in high erosion vs. low erosion counties is: 0% (50 mile cutoff), 5% (100 mile), 16% (300 mile), 30% (500 mile), 29% (700 mile), 23% (900 mile). For changes in medium erosion vs. low erosion counties, the Conley standard errors decline by 0% to 17%. The Conley specifications are not also weighted by county farmland levels, so the comparison in standard errors is relative to when not weighting the regression.

V Results

V.A Agricultural Land Value and Revenue

Agricultural Land Value. Figure 3 graphs the β's from estimating equation (1) for the per-acre value of farmland. High and medium erosion counties had slightly higher land values than low erosion counties in 1910, after adjusting for the control variables. These counties were more similar by 1920 and then trended similarly through 1930.

After the Dust Bowl, high erosion counties experienced an immediate, substantial, and persistent relative decrease in land values. Medium erosion counties experienced a smaller but substantial relative decrease. Comparing the two lines, high erosion counties also experienced a persistent decrease relative to medium erosion counties.

To account for differences in the level and trend of county land values prior to the 1930's, the numerical results are obtained by estimating equation (2). This regression controls for county land values in 1930, 1925, 1920, and 1910, interacted with each year.[25] These controls absorb the graphed pre-1930's differences by erosion level, and are a flexible way of adjusting for differential pre-trends in land values. Table 2, column 1, presents the results.

Panel A reports that, from 1930 to 1940, land values fell by 27.8% in high erosion counties relative to low erosion counties. Land values fell by 16.7% in medium erosion counties relative to low erosion counties. If we assume that low erosion counties were not affected by the Dust Bowl, the total capitalized cost can be approximated by multiplying the percent decline in land values by the original value of those acres. These estimates indicate that the Dust Bowl erosion imposed an economic cost on agriculture of \$153 million in 1930 dollars (\$1.9 billion in 2007 dollars).[26] If low erosion counties were also damaged by the Dust Bowl, this number would understate the total cost. If the Dust Bowl made less-affected land in the same state more valuable, e.g., through higher output prices, this number would overstate the total cost.[27] Given average 1930 land values, this reflects an area of farmland the size of Oklahoma becoming worthless.

[25] In this case, the regression also controls for agricultural revenues per-acre in each pre-period, as the later analysis will combine the specifications in a seemingly unrelated regression framework.

[26] By multiplying 1930 county farmland levels by the share of its area in each erosion category, there were approximately 51 million farm acres in high erosion areas and 170 million farm acres in medium erosion areas. The per-acre value of farmland was \$3.60 in high erosion counties and \$3.62 in medium erosion counties, weighting by farmland. The total cost is found by multiplying the acres affected, the value of the acres, and the percent decline in land values: \$51 million from high erosion and \$102 million from medium erosion.

[27] There is no obvious indication of higher prices from national trends in the ppi for farm products and the cpi for urban consumers: farm output prices were lower from 1938 to 1940 than in the 1920's – both absolutely and relative to the urban cpi. All prices declined in the 1930's and increased during WW2, while farm output prices increased during the severe droughts from 1934 to 1936.

Panel B reports the estimated change in land values from 1930 to 1945. Column 2 expresses this change as a fraction of the change in land values from 1930 to 1940. These numbers reflect the amount of decrease from 1930 to 1940 that persisted into 1945: 84% for high erosion and 61% for medium erosion. For changes in high erosion counties relative to medium erosion counties, the persistence was 119% (land values declined further). There is no strong *a priori* reason for one of these three relative comparisons to reflect a more or less persistent shock. Taking the efficient weighted average of these three parameters, the average persistence is 76.5%.[28]

Panels C, D, and E report later changes in land values, pooling the estimates over 2, 3, and 4 census periods. There is little indication of a systematic recovery in land values. This suggests that the overall percent recovery in profits is not large, and that adjustment did not take place through fixed improvements in land that would be capitalized in its value.

Agricultural Revenue. Figure 4, panel A, graphs the β's from estimating equation (1) for the per-acre value of farm revenue. From 1930 to 1940, more-eroded counties experienced substantial declines in farm revenue. Revenue recovered partly from 1940 to 1945 and then the paths diverge: high erosion counties have lower revenue compared to low erosion counties, while revenue gradually recovers in medium erosion counties. Revenue had been increasing in more-eroded counties from 1910 to 1925, and then decreased from 1925 to 1930. Table 2, column 3, presents the numerical results for farm revenue, controlling for these pre-1930 differences.

Panel A reports the relative decrease in farm revenue from 1930 to 1940: 31.6% for high erosion counties and 20.2% for medium erosion counties. Panels B to E report the changes for later periods, and column 4 expresses these changes as a fraction of the decrease from 1930 to 1940. From 1940 to 1945, more-eroded counties experienced a substantial recovery in revenues, though averaged levels were still lower than in 1930. Over later periods, however, only medium erosion counties experienced a substantial recovery in revenues. On average, approximately 70% of the initial decline in revenues persisted between 1950 and the 1990's.

One way of interpreting these results is to take the present discounted value of all lost revenue after 1940. This calculation assumes an interest rate of 5%, linearly interpolates annual values between each census period, and assumes that revenue is constant after 1992. To obtain a measure of cost persistence, this PDV is expressed as a fraction of the PDV

[28]The variance-covariance matrix for these three estimates is known, so the efficient average is estimated through GLS (regressing the three values on a constant). Intuitively, this procedure gives more weight to the more-precisely estimated coefficients, and less weight to those coefficients are are more correlated with each other.

of lost revenue assuming no recovery after 1940.[29] The estimated persistence in losses (and standard error) is: 0.762 (0.132) for high erosion relative to low erosion, 0.687 (0.152) for medium erosion relative to low erosion, and 0.896 (0.351) for high erosion relative to medium erosion. If percent changes in revenue were a proxy for percent changes in profits in every period, then these numbers represent the full economic loss as a fraction of the short-run loss. However, if the recovery in revenue is due to an increase in production inputs, then these numbers will understate the persistence in lost profit.

The value of capital machinery and equipment is the primary production input for which comparable data are available across periods in all sample counties. Figure 4, panel B, graphs the results from estimating equation (1) for the log value of capital per acre of farmland. Capital inputs fell substantially from 1930 to 1940, though not by as much as revenues.[30] Capital inputs partially recovered from 1940 to 1945 and then diverged: inputs increased over time for medium erosion counties and declined again for high erosion counties. Thus, part of the observed recovery in revenue may be due to greater inputs, overstating the recovery in profits – particularly for the medium erosion counties in which revenue recovered substantially.

Agricultural Land Value vs. Revenue. Comparing the relative changes in land values and revenues provides a second estimate of the persistence in short-run costs. The percent decline in land values should reflect the true economic loss from the Dust Bowl, anticipating and appropriately discounting the future recovery in profits. Under strong functional form assumptions, the immediate percent decline in revenue would proxy for the immediate percent decline in profits. The true economic loss (land value) can then be expressed as a fraction of the short-run economic loss (revenue or profit).

Column 5 of table 2 reports this ratio, estimated for each relative comparison between erosion levels.[31] If the theoretical assumptions hold, these ratios have a clear structural interpretation: for every 1% lost in the short-run (1940), the full economic loss is between 0.82% and 0.98%, with a weighted average of 0.86%. Theoretically, this ratio should be weakly less than one, though the estimated parameters need not be. Because none are statistically less than one, these estimates fail to reject the hypothesis that long-run adjustments did not mitigate the short-run costs. These coefficients are all statistically greater than zero, which rejects the hypothesis that short-run costs were associated with no PDV cost. If the

[29] To do this calculation, annual coefficients for column 4 are linearly interpolated. Given an interest rate r, the estimated persistence in year t is multiplied by $\frac{1}{(1+r)^t}$. These values are summed and divided by $\frac{(1+r)}{r}$.

[30] From estimating equation (2) for capital inputs, the decrease was 0.225 (0.055) for high erosion and 0.121 (0.037) for medium erosion, relative to low erosion.

[31] To obtain the standard error of this ratio, both coefficients are estimated through seemingly unrelated regression, where the same control variables are included in each regression.

theoretical assumptions fail to hold, these numbers still have an appealing reduced-form interpretation: the full economic loss (land value) is scaled by the magnitude of the shock (revenue).

The main limitations in interpreting this ratio are the strong assumptions required for immediate percent changes in revenue to proxy for immediate percent changes in profits. Capital inputs fell substantially from 1930 to 1940 but somewhat less than revenues, so profits may have fallen by a larger percent than revenues. In this case, the estimated ratios in column 5 would overstate the persistence in costs (the denominator should be larger). By contrast, the persistence in costs may have been understated by the estimated recovery in revenues because capital inputs increased after 1940. The difference between revenues and profits may then bias the two cost persistence estimates in opposite directions. The range of cost persistence estimates from the two approaches is: between 0.762 and 0.881 for high erosion vs. low erosion, between 0.687 and 0.824 for medium erosion vs. low erosion, and between 0.896 and 0.981 for high erosion vs. medium erosion.

V.B Measured Erosion as a Proxy for the Dust Bowl

The empirical analysis relies on mapped erosion levels indicating areas that were more or less eroded during the Dust Bowl, after adjusting for state fixed effects and pre-Dust Bowl county characteristics. This section presents further results on changes in land values, in order to explore the validity of these erosion measures.

Plains vs. Non-Plains. One concern is that some of the measured variation in erosion levels occurred prior to the 1930's. Indeed, the nationwide map of cumulative erosion indicates that there were many severely eroded areas in the Eastern United States, where the Dust Bowl did not cause additional erosion. If counties with different baseline erosion levels would have changed differently over the 1930's, this would be confounded with the impact of the Dust Bowl.

To explore this possibility, figure 5 compares estimated relative changes in land values for more-eroded counties in Plains and non-Plains states. For each year, panel A (panel B) graphs the estimated difference in land values between high and low erosion counties (medium and low erosion counties), controlling only for state-by-time fixed effects.[32]

Before 1930, more-eroded Plains counties have higher land values than less-eroded Plains counties; and this difference is greater than the difference between more-eroded and less-eroded counties in non-Plains states. One explanation is that "more-eroded" Plains counties

[32]The other control variables are not available for all non-Plains counties. The sample is expanded to include all Plains and non-Plains counties with available land value data in each period: 867 Plains counties and 1840 non-Plains counties.

had yet to experience much of that erosion prior to the Dust Bowl. Following the Dust Bowl, more-eroded counties on the Plains experience a large relative decrease in land values. By contrast, land values in more-eroded and less-eroded counties in non-Plains states were relatively unchanged. These counties are otherwise on similar relative trends before 1930 and after 1960, at which point the level differences are also similar.

These estimates have two implications. First, the cumulative erosion measure appears to proxy for the particularly destructive erosion on the Plains during the Dust Bowl. Second, differentially eroded counties experienced similar changes in land values over the 1930's when the Dust Bowl did not contribute to further erosion.

Instrumenting for Erosion with Drought. A related concern is that observed erosion levels partly reflect counties' land-use, both prior to 1930 and during the Dust Bowl. When analyzing the effect on land value, OLS estimates could be negatively biased if farmers in counties otherwise becoming less valuable did not protect their land from Dust Bowl erosion. OLS estimates could be positively biased if counties otherwise becoming more valuable were farmed more intensely and this caused greater Dust Bowl erosion. Measurement error in erosion levels could also attenuate the estimated effects.

Some portion of the Dust Bowl erosion was due to severe drought on the Plains during the 1930's. As a robustness check, the analysis instruments for erosion levels using the number of months during the 1930's that a county was in extreme drought, severe drought, moderate drought, and the average level of drought over the 1930's.[33] The analysis now also controls for these four drought variables from 1895 to 1929, in order to capture general differences in susceptibility to drought.

The identifying assumption is that 1930's weather was not systematically correlated with future changes in land values, aside from its impact through changing erosion. These drought variables are sometimes correlated with pre-1930's county characteristics, so the empirical analysis continues to control for these variables. Temporary weather shocks should not have a direct effect on land values, though fixed investments in land could decrease in response to drought if income falls and credit is difficult to obtain.[34]

Table 3, columns 1 and 2, report the first-stage results. Column 1 reports estimates from regressing the percent of a county in high erosion areas on the drought instruments, controlling for drought from 1895 to 1929, state fixed effects, and the same pre-1930's county

[33]Drought is measured by the Palmer Drought Index, which is defined on a running basis depending on the arrival of rainfall and the loss of moisture. Extreme, severe, and moderate reflect conventional cutoffs in this Index. The drought data were collected at weather stations, and the PDI is reported by state and district (10 districts to a state). Details are available at ftp://ftp.ncdc.noaa.gov/pub/data/cirs/

[34]This exclusion restriction appears more likely to be violated for other county outcomes, so the instrumental variables specifications are only estimated for changes in land values.

characteristics as before. There is more high erosion in counties with more months of extreme drought, and a weaker effect in counties with more severe drought. High erosion is not predicted by months of moderate drought or average drought over the 1930's. Column 2 reports analogous estimates for the percent of a county in medium erosion areas. Medium erosion is higher in counties with higher average drought levels and more moderate drought, with slightly weaker effects from severe and extreme drought. The instruments are jointly significant, but the overall explanatory power is low and raises weak instrument problems. Ongoing work is gathering additional potential instruments.[35]

Table 3, column 3, reports the estimated relative changes in land values from 1930 to 1940, instrumenting for erosion levels with the 1930's drought variables. As a basis for comparison, column 4 presents the OLS results for the same sample and control variables. When instrumenting, higher erosion counties experienced a larger relative decline in land values (63% instead of 28%) and medium erosion counties experienced a somewhat smaller relative decline (12% vs. 17%). The implied cost of the Dust Bowl increases from $153 million to $187 million (in 1930 dollars). These IV estimates are much less precise, but they are consistent with the previous OLS findings: measured erosion levels appear to proxy for the impact of the Dust Bowl and decreased land values.[36]

V.C Adjustment in Agricultural Production

Agricultural costs from the Dust Bowl were estimated to be persistent. There are three main interpretations for this finding. The first interpretation, which later estimates support, is that adjustment in agricultural production was possible but costly and slow. The second interpretation is that adjustment to the Dust Bowl was not possible. The third interpretation is that adjustment was fast and had already taken place by 1940.

This section attempts to identify examples of possible margins of adjustment, and then what adjustments occurred. Results from estimating equation (1) are graphed in Figures 6 – 9, in order to observe relative pre-trends in each agricultural outcome. Table 4 reports

[35] Average wind speeds may predict wind erosion, and slopes may predict water erosion. There are direct measures of soil characteristics and its susceptibility to erosion, but these data are only available in the modern era and may be an outcome of the Dust Bowl erosion. Hansen and Libecap (2004) use these average wind speeds and soil characteristics as instruments. The instruments could potentially be interacted with each other or pre-1930 county land-use. Because the instruments must predict the transition from low erosion to medium and then high erosion, non-linear functions of the instruments may be appropriate. In the case of the drought instruments, including their squared values yields similar 2SLS results.

[36] As a falsification test, the same specification can be used to examine pre-differences in land values: more-eroded counties have similar or lower land values than in 1930, instrumenting for erosion with 1930's drought. In periods after 1940, the estimates are quite variable but fluctuate around their value in 1940.

the numerical results from estimating equation (2), which controls for differences in relative pre-trends.

Total Farmland. Figure 6 graphs the estimated changes in total farmland. This extensive margin of farming is fairly stable: immediately after the Dust Bowl, there are no substantial or statistically significant relative changes in farmland. These small relative changes in total farmland suggest that the previous estimates of changing land values, revenue, and capital inputs do not reflect large changes in the underlying composition of farmland.

High erosion counties later experience a gradual small decline in farming, which by the 1950's is lower by a statistically significant 3% (table 4, column 1). These declines in farming are then largely reversed, however, and medium erosion counties are relatively unchanged.[37]

One explanation for the persistence in overall land allocation is that non-agricultural sectors of the local economy might have an inelastic demand for land, at least in the short-run. In this case, the supply of land to the agricultural sector would be relatively inelastic. When agricultural demand for land decreased following the Dust Bowl, we would then expect large declines in land values and little change in the extensive margin of farming.

After the original settlement of the Plains slowed, the aggregate allocation of land to agriculture was fairly constant (figure 1). Assume that aggregate demand for agricultural land is constant, and that county-level fluctuations are driven by county-specific demand shocks for non-agricultural land. If these demand shocks have little effect on the county allocation of land to agriculture, then the agricultural sector may face a relatively inelastic supply of land. Indeed, the standard deviation of county-level fluctuations is relatively small (0.057).[38] There may be something about these counties in the 1930's and 1940's that limited adjustment, and later analysis will explore the possibility of credit constraints and other factors.

Crops vs. Animals. Higher quality land is generally thought to have a comparative advantage for growing crops, as opposed to raising animals. There is a reasonable *a priori* expectation that erosion from the Dust Bowl would reduce the productivity of land for crops by more than for animals. Thus, we might expect long-run conversion of land from growing crops to raising animals. Indeed, these arguments were made strongly by contemporaries, and this land conversion was a major goal of government policy, advocated as both good for the farmer and good for society.[39]

[37] These estimates do not reflect an increase in abandoned farmland, proxied by the difference between total farmland and cropland or land in pasture. Relative changes in this measure are never greater than 1% of the total land in farms, in either direction.

[38] This is calculated by first-differencing county farmland shares from 1945 to 1992, and taking the standard deviation of these differences.

[39] The SCS in 1955 was still strongly advocating conversion of land from cropland to grassland (Allred and Nixon 1955).

To explore this potential margin of adjustment, it is possible to estimate relative changes in the productivity of land for crops and animals. This has three main limitations. First, changes in relative productivity need not imply changes in relative profitability if input quantities or prices also change. Second, it is only possible to estimate changes in the productivity of the average unit of land, whereas adjustment incentives depend on the marginal unit of land. Third, if land allocations adjust, then changes in land composition would be confounded with productivity changes.

Crop productivity is defined as the total value of crops sold, divided by acres of cropland. Animal productivity is defined as the total value of animals sold and animal products sold, divided by acres of pasture. These measures of productivity are problematic because some unknown portion of cropland would be used to grow crops that are fed to that farm's animals. The analysis would overstate the relative decline in crop productivity if farmers in higher erosion counties became more prone to use cropland to feed their own animals.

Figure 7, panels A and B, present the relative changes in crop and animal productivity for high erosion and medium erosion counties, respectively.[40] Both productivities are normalized to zero in 1930, in order to allow a clearer comparison between the relative changes. For both high erosion and medium erosion counties, crop productivity declined more than animal productivity from 1930 to 1940. This relative decrease only persists for medium erosion counties.[41] Table 4, columns 2 and 3, report the corresponding numerical results. Crop productivity appears to have been more sensitive to erosion than animal productivity. The exception is for high erosion counties after 1945, in which animal productivity also declined substantially.

However, farmers did not begin systematically shifting land from cropland to pasture until the 1950's (figure 7 panel C and D, table 4 column 4). High and medium erosion counties both then shifted land. These estimates are consistent with adjustment costs declining in the long-run. Counterintuitively, the largest shift occurred in high erosion counties, for which there were not estimated relative productivity differences in later periods. This may reflect poor quality land being shifted to pasture, which would account for the accompanying decrease in pasture productivity. Alternatively, the quality of the empirical comparison may be deteriorating over time.

[40] The crop and animal productivity regressions are weighted instead by 1930 levels of county cropland and pasture, respectively. This allows the estimates to be interpreted as the percent change for an average unit of that land.

[41] Note that there was no relative change in productivity for high erosion counties relative to medium erosion counties. This may reflect a particular functional form through which erosion affects crops. This is consistent with earlier results on land values and revenue, where the high vs. medium shock had more persistent costs – there may be fewer opportunities to adjust production.

Wheat vs. Hay. A similar empirical exercise compares relative changes in the productivity of wheat and hay, and the relative allocation of land to each. These are the two most widely grown crops for which comparable data are available over a long period of time. There is also an *a priori* expectation that erosion would discourage the production of wheat, relative to hay. Wheat production is more sensitive to soil quality and more likely to cause erosion, whereas hay is cultivated grass. Hay is less sensitive to soil quality, less prone to cause erosion, and an input in the production of animals. In contemporaneous and later writings, it was generally recommended that farmers shift land from wheat to hay (or to native grasslands and pasture).

Productivity for each crop is defined as the total quantity produced divided by the total acreage harvested. Because acreage is only available for harvested land, complete crop failure would cause the analysis to understate declines in productivity. Many counties do not report wheat data for 1940, but the reason is unclear.[42] The same caveats as before apply: productivity may not reflect changes in profitability; changes in the average acre may not proxy for changes in the marginal acre; and compositional changes may affect productivity.

Figure 8, panels A and B, present the relative changes in wheat and hay productivity for high erosion and medium erosion counties, respectively.[43] From 1930 to 1940, wheat productivity decreased substantially. In 1950, when both production and acreage data are again surveyed for hay, wheat productivity remains persistently less than hay productivity.[44] Columns 5 and 6 of table 4 report the numerical results. Wheat productivity recovers substantially after 1964, but it remains relatively lower than hay productivity.

Figure 8, panels Panels C and D, show that farmers did not begin systematically shifting land from wheat to hay until the 1950's or 1960's. Table 4, column 7, reports the numerical results. After 1964, there were substantial and statistically significant declines in the amount of land devoted to wheat, as a fraction of the total land devoted to wheat and hay. Much of this adjustment occurs after data is no longer available for cropland and pasture, so it is difficult to compare the amount of adjustment along each land-use margin.

Average Farm Size and Land Fallowing. Hansen and Libecap (2004) present evidence that the presence of small farms limited efforts to prevent wind erosion during the Dust Bowl, due to substantial externalities. If more-eroded counties remained more prone to wind erosion, one potential margin of adjustment would be the consolidation of land hold-

[42] Data are often unavailable in one of the analyzed periods, so restricting the analysis to a balanced panel reduces the sample size by roughly half.

[43] The wheat and hay productivity regressions are weighted by 1930 acres of land devoted to that crop. The other crop and animal variables are omitted as controls, as they directly change along with wheat and hay.

[44] As in the case for crop and animal productivity, there is not much relative change between high and medium erosion counties.

ings to internalize these externalities. Indeed, estimates indicate that more-eroded counties experienced greater increases in average farm size during the 1940's (figure 9 panel A, table 4 column 8). However, there may be other reasons for farm sizes to adjust.

If increased farm sizes primarily reflected a desire to incorporate these externalities, there should be a corresponding increase in efforts to prevent erosion. Previous estimates show that cropland did not decrease relatively in more-eroded counties during the 1940's. As another method of preventing erosion, Hansen and Libecap (2004) analyze the fraction of cropland kept fallow. More-eroded counties, however, experienced relative decreases in fallowing during the 1940's (figure 9 panel A, table 4 column 9). It does not seem that more-eroded counties relatively adjusted production to prevent future erosion.

These estimates imply that more-eroded counties became more intensely cultivated from 1940 to 1945, similar to the estimated increases in capital inputs. This would cause the observed percent recovery in agricultural revenues to overstate the percent recovery in profits.

V.D Why Was Adjustment in Agricultural Production Limited?

This section explores three possible explanations for the observed slow and limited adjustment in agricultural production: credit constraints, low incentives for tenants to adjust, and government payment programs that might discourage adjustment.

Credit Constraints. During the Great Depression, access to credit may have been generally restricted. In particular, counties with higher erosion experienced substantial decreases in land values, so land-owning farmers would have lost potential collateral. Poorly performing local mortgages may have restricted banks' ability to lend. The most-eroded counties also experienced more bank failures during the 1930's (figure 10). Bank weakness and bank failures can lead to persistent decreases in the supply of credit, especially during the 1930's (Bernanke 1983, Calomiris and Mason 2003, Ashcraft 2005).

Without easy access to credit, it may have been difficult for farmers to adjust agricultural production in response to the Dust Bowl erosion. Raising animals or shifting crops would require the purchase of livestock and perhaps different machinery. Other local sectors would require capital to shift land from agriculture to industrial uses or residential housing.

To explore whether restricted access to credit might explain the limited adjustment in agricultural land-use, I estimate whether counties affected by the Dust Bowl adjusted more if they had more banks prior to the 1930's.[45] The estimated equation is a modified version of equation (2). It adds interaction terms between the log number of banks (B) at the end of 1928 and the percent of a county in high and medium erosion areas. For ease of

[45] Subsequent banking is potentially an outcome of the Dust Bowl. The results are similar when using the amount of deposits prior to the Dust Bowl.

interpretation, the log number of banks is normalized to have a mean of zero and a standard deviation of one. The specification also controls for the main effect from banks, and an interaction between banks and each pre-Dust Bowl outcome level to allow for differential pre-trends by banking levels. The coefficients on these terms are allowed to vary over each time period.

$$
\begin{aligned}
(3) \qquad Y_{ct} - Y_{c1930} &= \beta_{1t} M_c + \beta_{2t} H_c + \beta_{3t} B_c \\
&+ \beta_{4t} B_c \times M_c + \beta_{5t} B_c \times H_c \\
&+ \alpha_{st} + \theta_t X_c + \gamma_{1t} L_c + \gamma_{2t} B_c \times L_c + \epsilon_{ct}.
\end{aligned}
$$

The coefficients of interest are β_{4t} and β_{5t}. These indicate whether counties with more banks adjusted differently over each time period than similarly eroded counties with fewer banks.

The main identification assumption is that counties with more original banks had better access to credit during and after the Dust Bowl, but would otherwise have adjusted agricultural land-use similarly. Pre-Dust Bowl banking levels may be correlated with other county characteristics (credit demand, education levels, overall financial development), so it must be assumed that these other characteristics do not predict differential responses to erosion.

Table 5, columns 1 to 3, presents the results. More-eroded counties with more banks immediately shifted toward greater pasture (column 1).[46] By contrast, there was no relative shift from wheat to hay (column 2). This could reflect increases in animal production requiring more credit than increases in hay production, due to large capital purchases of livestock. Estimated changes in total farmland are mixed (column 3). High erosion counties with more banks had greater declines in farmland over time, but medium erosion counties experienced some relative increases in farmland.

It is surprising that pre-1930's banking levels would continue to predict differential adjustment into the 1960's, presumably after the recovery of local credit markets. There may be lock-in effects once early adjustments differ, but the interaction effect is strengthening slightly. This highlights the possibility that banking levels may be correlated with other characteristics that predict adjustment to erosion.

Low Incentives for Tenants to Adjust. When land is rented with imperfect contracting, tenants may have inefficiently low incentives to make permanent investments in the land. Contemporaries emphasized that tenants' focus was on their crop rather than the land

[46] When estimating equation (4) without the interaction between banking and pre-Dust Bowl land allocation, there is no pre-trend toward greater pasture in more-eroded counties with more banks.

(McDonald 1938). Thus, the presence of tenant farmers may have reduced adjustments to restore land productivity or prevent future erosion.[47]

This hypothesis is tested by estimating equation (4), but replacing the number of banks with the share of farmland managed by tenants in 1930 (normalized to have a mean of zero and a standard deviation of one). Table 5, columns 4 to 6, present the results on the interaction term. There are few systematic patterns in the data, though there is some evidence of counties with less tenant farmland switching more from wheat to hay, which would also be less likely to worsen erosion.

For a narrow window around 1930 to 1950, there is data on tenants' land value, cropland, and equipment. Comparing counties with different erosion levels, tenants and non-tenants are estimated to have had similar changes in the per-acre value of farmland, the share of cropland in total farmland, and per-acre equipment. These estimates suggest that tenants may have had similar adjustment incentives.

If tenant contracts give inefficient adjustment incentives, then overall farming should adjust away from land being managed by tenants. Figure 11 presents the results from estimating equation (1) for the share of land farmed by tenants. Tenant shares did not decline immediately, but there is some indication of declines in the 1950's and after. This shift away from tenancy, along with the move toward larger farm sizes, could indicate that long-run adjustment in land-use required the reorganization of land ownership.

Government Payment Programs. There was a substantial increase in government payment programs during the 1930's, and many programs were targeted at the agricultural sector. To the extent that these payments were also targeted to higher erosion counties, they could have distorted farmers' incentives to adjust agricultural production. The New Deal agricultural payment programs tended to encourage the analyzed production adjustments, as well as the general continuation of farming.

Table 6, panel A, presents information on average payments for different New Deal programs, and the correlation between payments and county erosion levels, after controlling for state fixed effects and the usual county characteristics. There is little systematic relationship between program payments and erosion levels. It is possible, however, that farmers expected future payments.

Parts of the New Deal programs were temporary, but some parts were extended or changed into other forms of agricultural payments. Panel B of table 6 presents information on all government payments, beginning again in 1969. Higher erosion counties did not

[47]Tenant farmers could also be more credit constrained, but this is not obvious: land owners would have lost substantial capital from lower land values, while tenants' assets might have been more liquid and allowed greater adjustment.

receive more payments in 1969, but began to in 1974. Total agricultural payments were much higher in 1987, but higher erosion counties received substantially less. This is likely due to the 1985 introduction of the Conservation Reserve Program (CRP), which paid farmers to take low-quality and erosion-prone land out of production. This precluded other farm payments. In 1992 and 1997, the higher erosion counties receive more CRP payments.

Overall, government payments were not targeted to more-eroded counties, so these programs seem unlikely to have discouraged agricultural adjustment to the Dust Bowl erosion. However, these estimates are consistent with a persistent drop in land quality. In the 1990's, a higher fraction of government payments were through the CRP, which targets low-quality erodible lands. These lands were still disproportionally in those counties more eroded during the Dust Bowl.

V.E Adjustment in Population, Industry, and Wages

In response to the substantial costs of the Dust Bowl, there should be strong incentives to reallocate labor across locations and/or sectors. Given that the agricultural sector was slow to adjust, this may create extra pressure for adjustment along the available margin of labor. However, if the agricultural sector was slow to adjust away from labor-intensive activities, this persistence could slow the reallocation of labor.

Population. Panel A of figure 12 graphs changes in log population from estimating equation (1). Prior to the 1930's, population was increasing in high erosion counties relative to low erosion counties. In medium erosion counties, population increased relatively from 1910 to 1920 and then decreased from 1920 to 1930. Following the Dust Bowl, population decreased substantially in both high and medium erosion counties.

In order to control for pre-1930 differences in levels and trends, column 1 of table 7 presents the numerical results from estimating equation (2). During the 1930's, high erosion counties experienced an 8.1% decrease in population, relative to low erosion counties in the same state. Medium erosion counties had a 6.5% relative decrease in population. In both county types, population continued to decline through the 1950's. By comparison, state-wide populations decreased 3% - 4% in Oklahoma, Kansas, and Nebraska from 1930 to 1940.

To explore selection in which populations decreased, panel B of figure 12 graphs changes in the fraction of population in rural areas of the county (areas with fewer than 2,500 inhabitants) and column 2 of table 7 presents the numerical results. The fraction of population in rural areas was mostly unchanged, indicating that decreases in population did not occur predominately in rural areas. Similarly, estimates in column 3 of table 7 show that the de-

crease in population was not especially among those living on farms.[48] There was sometimes a smaller decrease among farm populations, which may otherwise be less likely to migrate. The widespread population decrease in these counties may also indicate important spillover effects between agriculture and industry, perhaps through locally supplied inputs.

Historical survey data provide some evidence on the selection of Dust Bowl migrants. Janow and McEntire (1940) describe results from a special survey of 1930's migrants to California, many of whom came from Oklahoma.[49] Comparing the distribution of migrants' original occupations in Oklahoma to the distribution of all Oklahoma residents occupations in 1930, there is only a small tendency for migration from the agricultural sector.[50] By contrast, migrants from other regions were less likely to be from the agricultural sector. The Dust Bowl may have shifted the typical selection of migrants toward the agricultural sector, but not much beyond proportional levels.

Unemployment and Manufacturing Employment. From 1930 to 1940, the overall unemployment rate increased by 0.71 percentage points in high erosion counties (column 1, table 8), and this increase was gone by 1950. Medium erosion counties had no relative increase in unemployment by 1940. These estimates suggest that surplus labor was reallocated relatively quickly.

For a restricted sample of counties, it is possible to analyze within-county shifts in labor toward the manufacturing sector. I focus on the manufacturing sector, instead of wholesale and retail, because it would tend to be less directly affected by local changes in demand. However, there may be important spillovers between agriculture and manufacturing, as suggested by the widespread decrease in population.

Column 2 of table 8 reports changes in the fraction of the labor force employed in manufacturing.[51] Column 3 reports changes in the fraction of the population employed in manufacturing. In high erosion counties, there were small increases from 1930 to 1940 in the proportion of workers or population employed in manufacturing, though these are not statistically significant. These estimates represent large percent increases in manufacturing

[48] Data on farm populations are not available before 1930.

[49] The survey was conducted by the Bureau of Agricultural Economics, in cooperation with the California Department of Education. They surveyed families with school children that had migrated to California in the 1930's. This survey covered 116,000 families with 187,000 school children, which the surveyors estimated to be 84% of all such families. The results are described by Janow and McEntire (1940). I have not found the original data, but have converted the published figures back to aggregated numerical data when possible.

[50] Comparing the fractions in each occupation for migrant male heads of families vs. all employed males: 31% vs. 28% farmer; 19% vs. 15% farm laborer; 13% vs. 6% semi-skilled laborer; 12% vs. 12% skilled laborers; 12% vs. 15% other laborer; 5% vs. 10% clerks; 5% vs. 8% owner/manager; 1% vs. 2% servant; 0.5% vs. 3% professional.

[51] The labor force is defined as all employed workers, laidoff workers, and unemployed workers searching for a job.

employment of 11% and 15%, but they do not account for much overall movement of labor because manufacturing was a small sector of the economy. In medium erosion counties, there was no immediate shift in labor, but there were some later increases.

Columns 4 and 5 of table 8 report that total manufacturing establishments and value added did not increase following the Dust Bowl, though the coefficients are imprecisely estimated. Manufacturing may have been too slow to expand, perhaps due to the Depression, to attract workers before they left the county. Even after the Depression, there was no increase in manufacturing and the reallocation of labor continued through population declines. This overall pattern of results is similar to that found by Blanchard and Katz (1992) for state-level responses to a labor demand shock in the second half of the 20th century.

Proxies for Wages. Completing the empirical picture of labor market adjustment requires knowledge of changes in wage rates. Micro data on changes in wages are not available, but per-capita retail sales may serve as a proxy for local income (Fishback et al. 2005). This measure would differ from wages if there is net savings or borrowing, and would more closely reflect income if individuals' labor supply changed.

Column 1 of table 9 reports that high erosion and medium erosion counties experienced a 9.8% and 6.3% decrease in per-capita retail sales from 1930 to 1940. If this were the decrease in total income, it would be partly offset by lower land prices. A rough calculation indicates that individuals spent about 1% of their budget on land for housing.[52] Decreased land values would then compensate workers for a decrease of 2.78% and 1.67% in high and medium erosion counties, respectively.

Per-capita retail sales recovered from 1940 to 1958, partially in high erosion counties and completely in medium erosion counties. If we assume that income or wages recovered by a similar percent, it is useful to check whether the magnitude of recovery would require relative changes in labor demand or if it could be explained by the observed decreases in population over the same time period. Reinterpreting estimates by Borjas (2003) on immigration would imply that a 10% decrease in population would increase wages by 3% to 4%, or increase income by 6.4% if individuals' labor supply is allowed to increase. In high erosion counties, the population decrease from 1940 to 1960 implies a 2% to 2.7% increase in wages and a 4.3% increase in income – compared to an observed 4% recovery in per-capita retail sales from 1940 to 1958. In medium erosion counties, the population decrease implies a 3.2% to 4.2% increase in wages and a 6.7% increase in income – compared to a 6.8% recovery in per-capita retail sales.

[52] Assume that annual rental rates on residential land are 7% of the average value of one acre of agricultural land. The budget share is found by dividing this number by average per-capita retail sales. The number is similar whether unweighted or weighting by farmland or population.

For a restricted sample of counties, additional data is available on total payroll and workers in the manufacturing, wholesale, and retail sectors. Columns 2 to 4 of table 9 report estimated changes in the log of payroll divided by workers, as a proxy for salary income. In the retail sector, for which most counties are available, there is an insignificant immediate decline in salary and the long-run declines are similar or more negative than for per-capita retail sales. In the wholesale and manufacturing sectors, there are greater long-run declines in salaries. Given the large decreases in population, this may reflect changes in the underlying skill distribution of the workforce. Otherwise, relative wages are at their lowest only when relative changes in population cease.

Interactions with Agriculture. Changes in the labor market potentially interact with adjustment incentives in the agricultural sector. There is some evidence that wages decreased in more-eroded counties, and this might be especially true in the agricultural sector if switching sectors is costly.

Consistent with temporarily lower wages, estimates indicate that the ratio of labor to capital machinery increased temporarily in the agricultural sector. This ratio is approximated by dividing the number of people living on farms by the value of equipment and machinery on farms. Changes in the log of this ratio are estimated by equation (2). For high erosion counties, the changes (and standard error) after 1930 are: 14% (4.8%) by 1940, 2% (4.8%) by 1945, and 9% (5.5%) by 1969. For medium erosion counties, the changes after 1930 are: 13% (4.1%) by 1940, 4.5% (4.1%) by 1945, and 2.4% (4.3%) by 1969.

Despite the immediate decreases in population, there may still have been surplus labor in 1940. This is reflected in somewhat higher unemployment and the subsequent decreases in population. Some of this surplus labor appears to have been absorbed in the agricultural sector. This may have discouraged switching land from crops to animals or from wheat to hay, which use less labor. It was in the 1950's, as population declines ceased, that agricultural adjustment began to appear along these margins.

VI Conclusion

The 1930's American Dust Bowl provides a unique context in which to examine economic adjustment to a permanent change in the environment. Dust Bowl erosion imposed substantial short-run costs on Plains agriculture. Adjustment in agricultural land-use was slow and limited, despite evidence of potentially productive adjustments. Estimates imply that the long-run cost to agriculture was 86% of the short-run cost.

In other settings where short-run production costs from a shock are substantial, slow and limited adjustment would imply that the long-run production costs may also be large.

This paper provides some evidence on the role of credit and land ownership in predicting adjustment, and an important area for further research is understanding what conditions facilitate long-run adjustment. Further research on historical shocks may help anticipate the long-run effects of modern shocks for which only short-run effects can be observed.

If long-run production costs are large, the overall welfare consequences may be partly lessened if people can leave the area. The Unites States is known to have high labor mobility, so migration may be more limited in response to shocks in other countries. In particular, cross-country migration may be severely restricted by political constraints. If short-run production costs persist and migration is limited, shocks that have large short-run costs may impose similarly large long-run costs.

References

Allred, B.W. and W.M. Nixon. 1955. "Grass for Conservation in the Southern Great Plains." Farmer's Bulletin No. 2093.

Ashcraft, Adam. 2005. "Are Banks Really Special? New Evidence from FDIC-induced Failures of Healthy Banks." *American Economic Review*, Vol. 95, No. 5, pp. 1712-1730.

Bernanke, Ben S. 1983. "Nonmonetary Effects of the Financial Crisis in the Propagation of the Great Depression." *American Economic Review*, Vol. 73, No. 3, pp. 257-276.

Blanchard, Olivier Jean, and Lawrence F. Katz. 1992. "Regional Evolutions." *Brookings Papers on Economic Activity*, Vol. 1992, No. 1, pp. 1-61.

Bloom, Nick, Stephen Bond, and John Van Reenen. 2007. "Uncertainty and Investment Dynamics." *Review of Economic Studies*, Vol. 74, pp. 391-415.

Borjas, George J. 2003. "The Labor Demand Curve *is* Downward Sloping: Reexamining the Impact of Immigration on the Labor Market." *Quarterly Journal of Economics*, Vol 118, No. 4, pp. 1335-1374.

Boustan, Leah Platt, Price V. Fishback, and Shawn E. Kantor. 2007. "The Effect of Internal Migration on Local Labor Markets: American Cities During the Great Depression." NBER WP#13276.

Calomiris, Charles W., and Joseph R. Mason. 2003. "Consequences of Bank Distress during the Great Depression." *American Economic Review*, Vol. 93, No. 3, pp. 937-947.

Carrington, William J. 1996. "The Alaskan Labor Market during the Pipeline Era." Journal of Political Economy, Vol. 104, No. 1, pp. 186-218.

Chari, V. V. and Hugo Hopenhayn. 1991. "Vintage Human Capital, Growth, and the Diffusion of New Technology." *Journal of Political Economy*, Vol. 99, No. 6, pp. 1142-1165.

Chepil, W.S., F. H. Siddoway, and Dean V. Armbrust. 1962. "Climatic Factor for Estimating Wind Erodibility of Farm Fields." *Journal of Soil and Water Conservation*, Vol. 17, pp. 162 – 165.

Conley, T.G. 1999. "GMM estimation with cross sectional dependence." *Journal of Econometrics*, Vol. 92, pp. 1-45.

Cunfer, Geoff. 2005. On the Great Plains: Agriculture and Environment. Texas A&M University Press, College Station.

Davis, Donald R., and David E. Weinstein. 2002. "Bones, Bombs, and Break Points: The Geography of Economic Activity." *American Economic Review*, Vol. 92, No. 5, pp. 1269-1289.

Dell, Melissa, Benjamin F. Jones, and Benjamin A. Olken. 2008. "Climate Change and Economic Growth: Evidence from the Last Half Century." NBER WP#14132.

Deschenes, Olivier, and Michael Greenstone. 2007. "The Economic Impacts of Climate Change: Evidence from Agricultural Output and Random Fluctuations in Weather." *American Economic Review*, Vol. 97, No. 1, pp. 354-385.

Diamond, Jared. 2005. Collapse: How Societies Choose to Fail or Succeed.

Dixit, A. and R. Pindyck. 1994. Investment Under Uncertainty. Princeton University Press. Princeton, New Jersey.

Duflo, Esther. 2004. "The medium run effects of educational expansion: evidence from a large school construction program in Indonesia." *Journal of Development Economics*, Vol. 74, pp. 163-197.

Fishback, Price V., William Horrace, and Shawn Kantor. 2005. "Did New Deal Grant Programs Stimulate Local Economies? A Study of Federal Grants and Retail Sales During the Great Depression." *Journal of Economic History*, Vol. 65, No. 1, pp. 36-71.

Foster, Andrew D., and Mark R. Rosenzweig. 1995. "Learning by Doing and Learning from Others: Human Capital and Technical Change in Agriculture." *Journal of Political Economy*, Vol. 103, No. 6, pp. 1176-1209.

Griliches, Zvi. 1957. "Hybrid Corn: An Exploration in the Economics of Technical Change." *Econometrica*, Vol. 25, No. 4, pp. 501-522.

Guiteras, Raymond. 2008. "The Impact of Climate Change on Indian Agriculture." Mimeo.

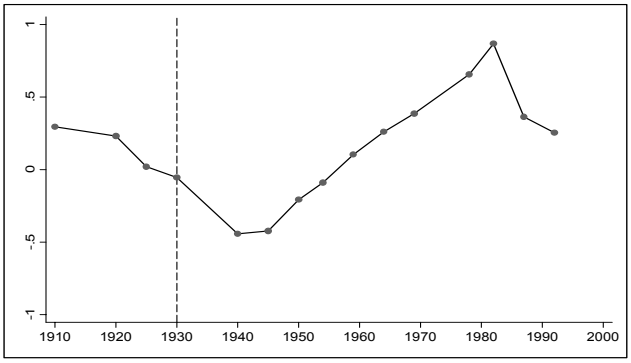
Hansen, Zeynep K. 2005. "Book Review of On the Great Plains: Agriculture and Environment by Geoff Cunfer." *Journal of Economic History*, Vol. 65, No. 4, pp. 1162-1163.

Hansen, Zeynep K. and Gary D. Libecap. 2004. "Small Farms, Externalities, and the Dust Bowl of the 1930s." *Journal of Political Economy*, Vol. 112, No. 3, pp. 665 – 694.

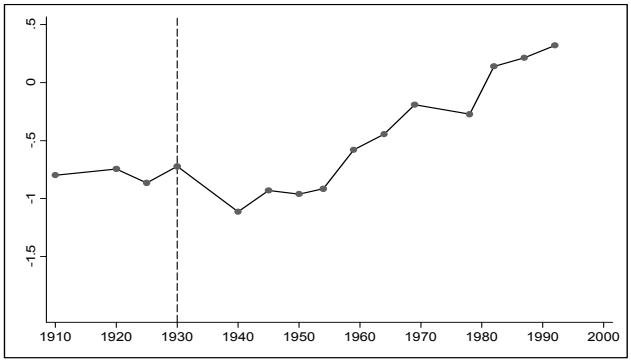
Hornbeck, Richard. 2008. "Good Fences Make Good Neighbors: Evidence on the Effects of Property Rights." Mimeo.
Hoyt, John C. 1936. "Droughts of 1930 – 1934." Water-Supply Paper 680, U.S. GPO.
Hurt, Douglas R. 1981. The Dust Bowl: An Agricultural and Social History. Nelson Hall, Chicago.
Hurt, Douglas R. 1985. "The National Grasslands: Origin and Development in the Dust Bowl," in The History of Soil and Water Conservation, eds. Douglas Helms and Susan L. Flader. The Agricultural History Society, Washington D.C., pp. 144 – 157.
Janow, Seymour J., and Davis McEntire. 1940. "The Migrants: Migration to California." *Land Policy Review*, July-August, pp. 24-36.
Leuchtenburg, William E. 1963. Franklin D. Roosevelt and the New Deal, 1932 – 1940. Harper & Row, Publishers, New York.
Margo, Robert A. 1997. "Wages in California during the Gold Rush." NBER WP on Historical Factors in Long Run Growth, Historical Paper 101.
McDonald, Angus. 1938. "Erosion and its Control in Oklahoma Territory." Soil Conservation Service, Miscellaneous Publication No. 301, GPO.
Miguel, Edward, and Gerard Roland. 2006. "The Long Run Impact of Bombing Vietnam." Mimeo.
National Archives (College Park, MD), Record Group 114, Cartographic Records of the Soil Conservation Service, Entry #149.
News-week. 1936. "Drought: A Merciless Sun and a Scourge of Insects Destroy Crops, Cattle and Men – Two-thirds of the Country Afflicted." July 18.
Phillips, Sarah T. 2007. This Land, This Nation: Conservation, Rural America, and the New Deal. Cambridge University Press.
Pressly, Thomas J. and William H. Scofield. 1965. Farm Real Estate Values in the United States by Counties, 1850 – 1959. University of Washington Press, Seattle.
Rasmussen, Wayne D. and Gladys L. Baker. "Price-Support and Adjustment Programs From 1933 Though 1978: A Short History." Agricultural Information Bulletin No. 424, U.S. Department of Agriculture, U.S. Government Printing Office.
Redding, Stephen J., and Daniel M. Sturm. Forthcoming. "The Costs of Remoteness: Evidence from German Division and Reunification." *American Economic Review*.
Roback, Jennifer. 1982. "Wages, Rents, and the Quality of Life." *Journal of Political Economy*, Vol. 90, No. 6, pp. 1257 – 1278.
Rosenzweig, Mark R., and Kenneth I. Wolpin. 2000. "Natural 'Natural Experiments' in Economics." *Journal of Economic Literature*, Vol. 38, No. 4, pp. 827-874.
Saloutos, Theodore. 1982. The American Farmer and the New Deal. Iowa State University Press.
Science. 1934. "The Recent Destructive Dust Cloud." New Series, Vol. 79, May 25, p. 473.
Soil Conservation Service. 1935. "Soil Erosion: A Critical Problem in American Agriculture." Part V of the Supplementary Report of the Land Planning Committee to the National Resources Board. US GPO.
Soil Conservation Service. 1937. "Soil Conservation Districts for Erosion Control." Miscellaneous Publication No. 293, GPO.
Soil Conservation Service. 1939. "Land Facts on the Southern Plains." Miscellaneous Publication No. 334, GPO.
Soil Conservation Service. 1955. "Facts About Wind Erosion and Dust Storms on the Great Plains." Leaflet No. 394. US Department of Agriculture.
US Department of Agriculture. 1940. "The Dust Bowl: Agricultural Problems and Solutions," Editorial Reference Series, No. 7, July 15.
Wallace, Henry A. 1938. "Forward" in Soils and Men: Yearbook of Agriculture. US Department of Agriculture, Washington D.C., Government Printing Office.
Worster, Donald. 1979. Dust Bowl: The Southern Plains in the 1930s. Oxford University Press, Oxford.

Figure 1. Aggregate Changes on the Plains in Agriculture and Population

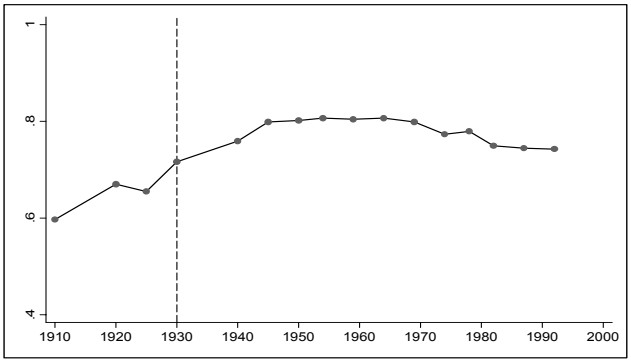
A. Farmland Value, per farm acre (Log/CPI)



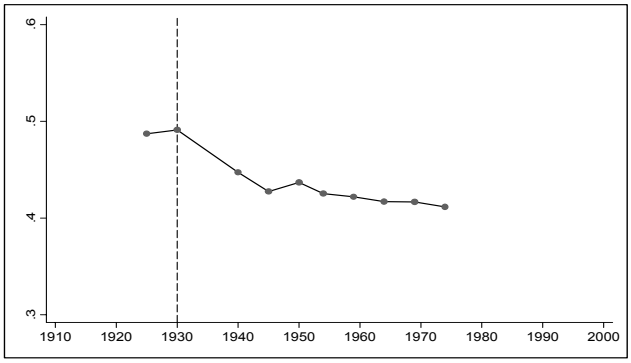
B. Agricultural Revenue, per farm acre (Log/PPI)



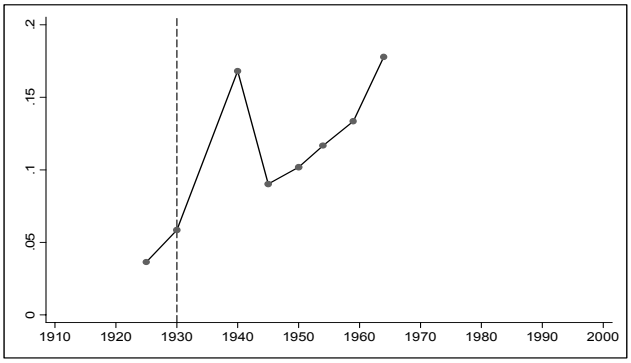
C. Farmland Acres, per county acre



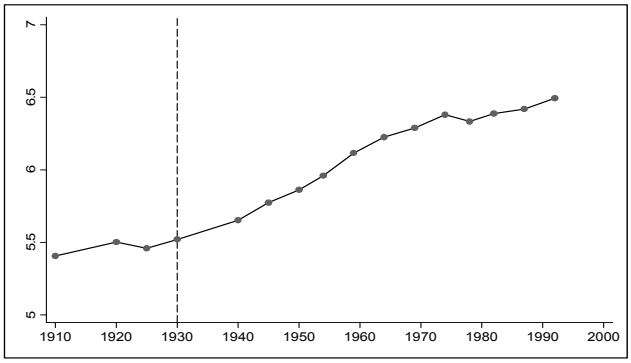
D. Cropland Acres, per farm acre



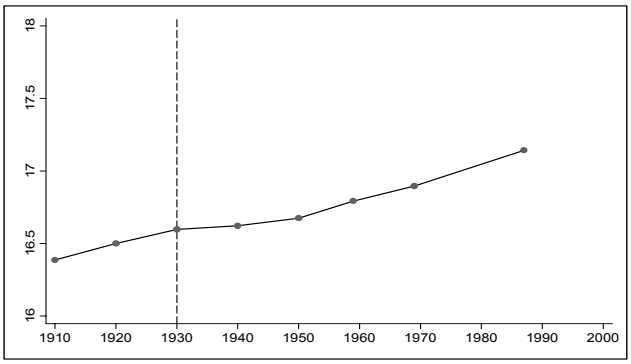
E. Fallow Acres, per cropland acre



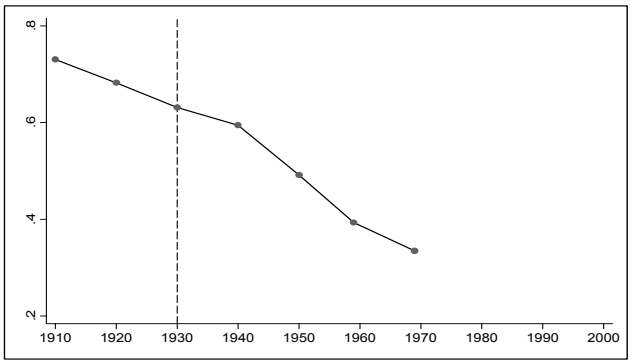
F. Average Farm Size (Log)



G. Population (Log)

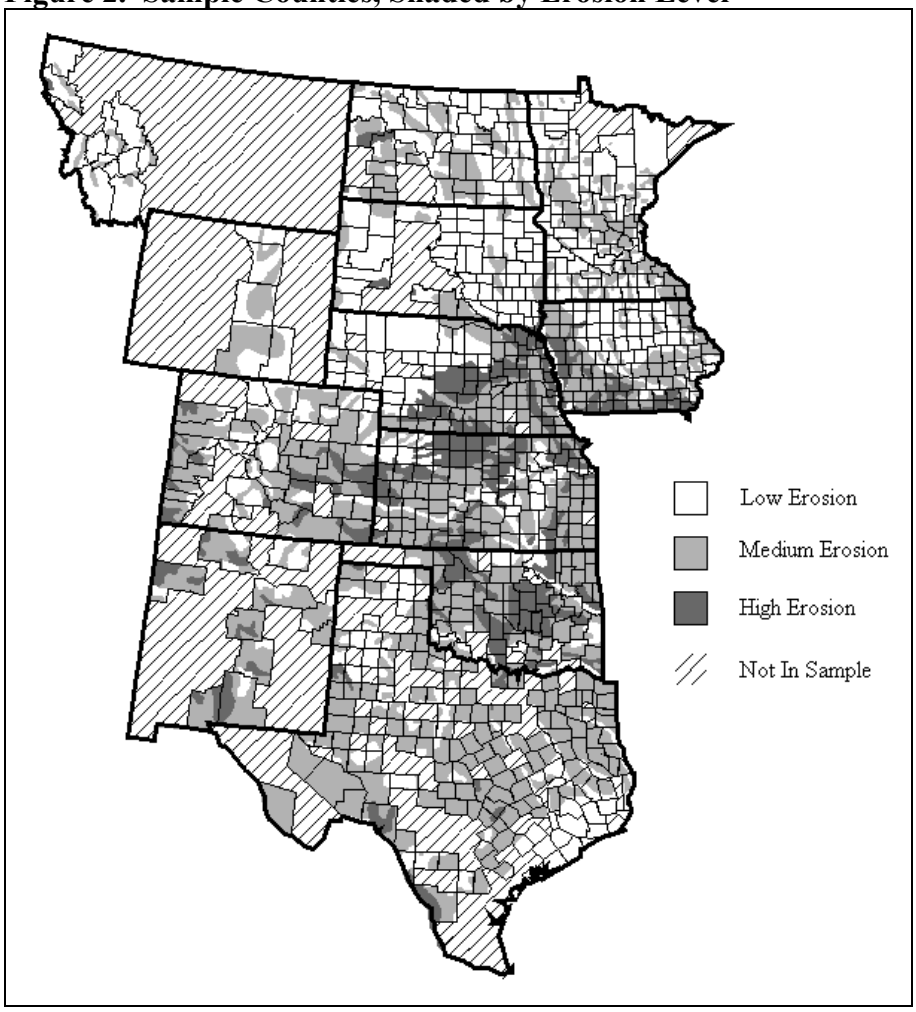


H. % Population in Rural Areas



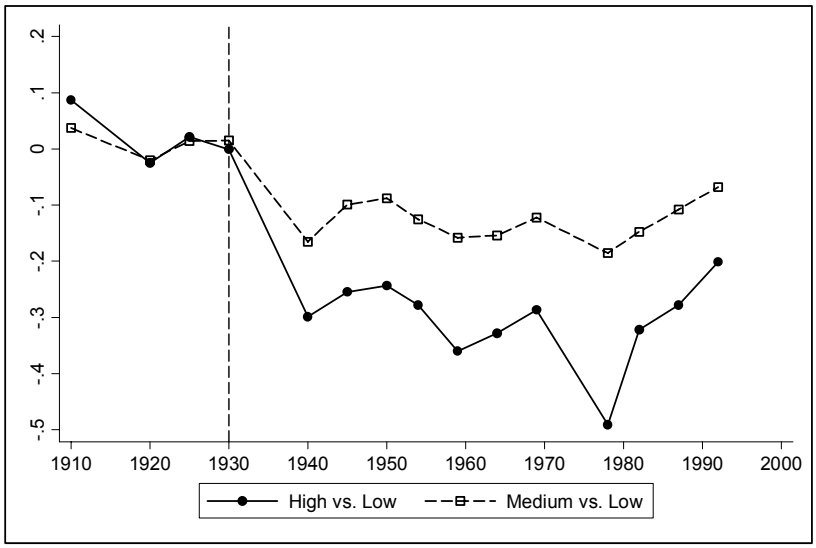
Notes: All panels (except E) report values aggregated over the same 769 Plains counties in every period for the following outcomes: Panel A, the log per-acre value of farmland divided by the consumer price index; Panel B, the log per-acre agricultural revenues divided by the producer price index for farm products; Panel C, the fraction of county land in farms; Panel D, the fraction of farmland that is cropland; Panel E, the fraction of cropland that is fallow (available for only 587 counties); Panel F, the log acres of farmland divided by the number of farms; Panel G, the log population; Panel H, the fraction of population living in areas with fewer than 2,500 inhabitants.

Figure 2. Sample Counties, Shaded by Erosion Level



Notes: Mapped erosion levels are indicated as low (less than 25% of topsoil lost), medium (25%-75% of topsoil lost and may have some gullies), or high (more than 75% of topsoil lost and may have numerous or deep gullies). Thin lines denote 1910 county borders, corresponding to the sample of 769 counties described in Table 1. Thick lines denote state boundaries. Crossed out areas are not in the sample.

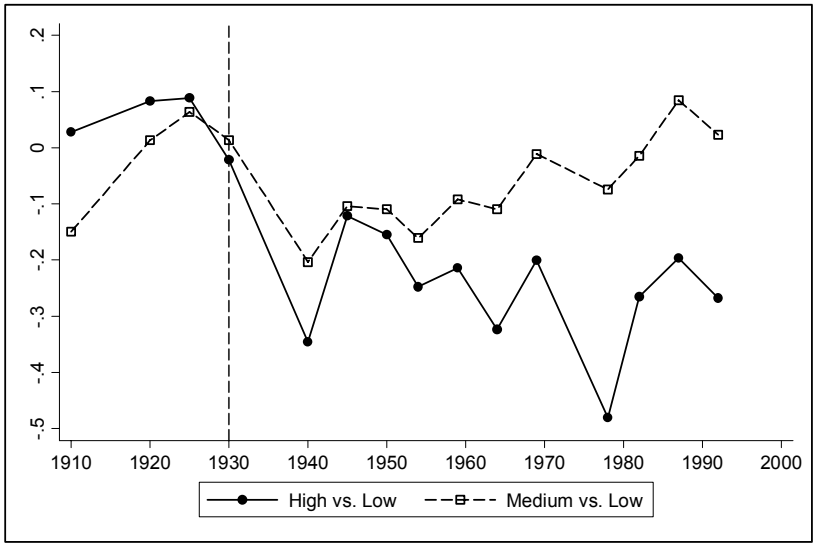
Figure 3. Log Changes in the per-Acre Value of Agricultural Land, by Erosion Level



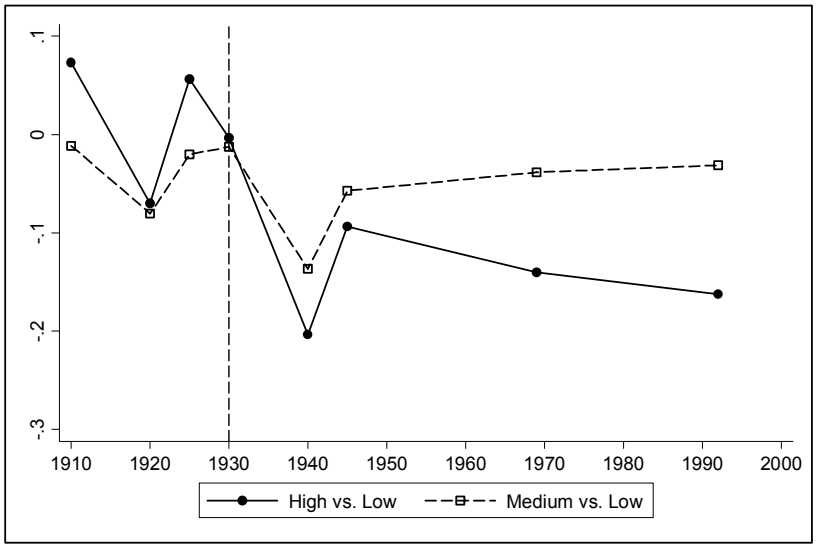
Notes: This figure graphs the estimated coefficients (β) from equation (1) in the text. For each year, the solid circles report differences in the log per-acre value of farmland for high erosion counties, relative to low erosion counties. The hollow squares report differences for medium erosion counties, relative to low erosion counties. These coefficients are estimated by regressing the per-acre value of farmland on the percent of a county in a high erosion area (solid circle) and the percent of a county in a medium erosion area (hollow square), controlling also for state-by-year fixed effects, the interaction between each year and each county characteristic in panels B – E of table 1, and the interaction between each year and the available lagged values of each county characteristic in panels B – E of table 1.

Figure 4. Log Changes in Agricultural Revenue and Capital, by Erosion Level

A. Agricultural Revenue, per Acre of Farmland



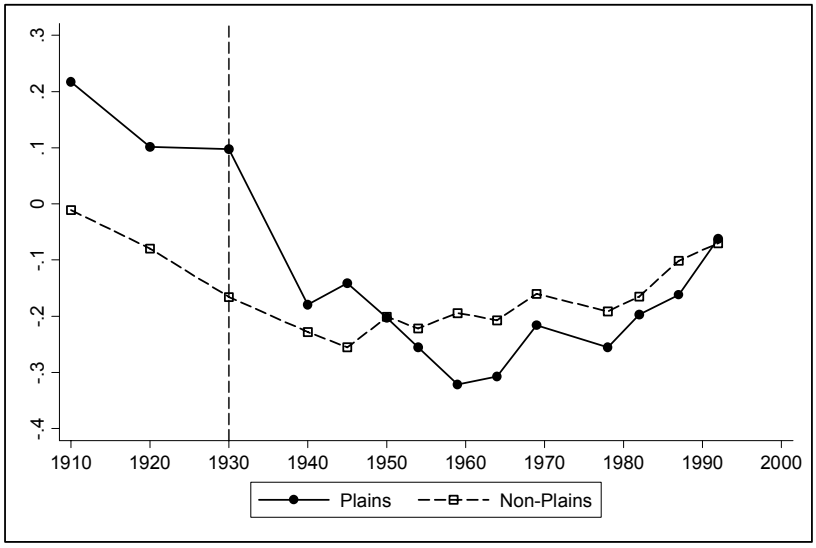
B. Value of Capital (Machinery & Equipment), per Acre of Farmland



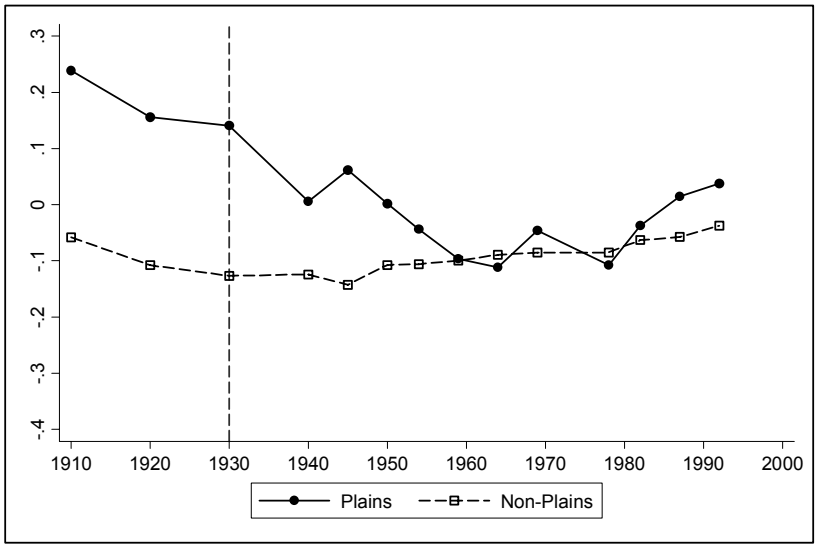
Notes: For the indicated outcome variable, each panel graphs the estimated coefficients (β) from equation (1) in the text, as described in the notes to Figure 3.

Figure 5. Log Changes in Land Value, Plains Counties vs. Non-Plains Counties

A. High – Low Erosion

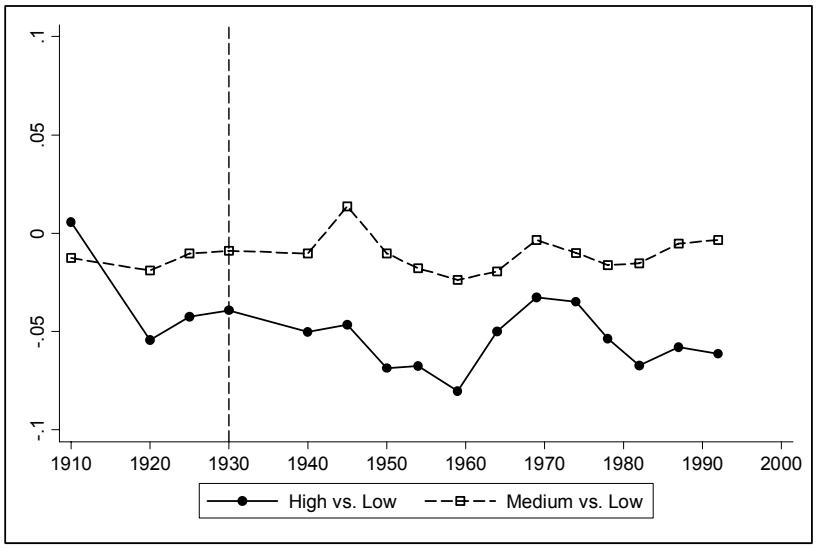


B. Medium – Low Erosion



Notes: The estimates in both panels are from a single regression of equation (1) in the text, modified to include only state-by-time fixed effects as controls. Panel A reports the difference between high and low erosion counties, for both Plains and non-Plains states. Panel B reports the difference between medium and low erosion counties, for both Plains and non-Plains states. Plains states are those depicted in Figure 2. The sample includes 867 Plains counties and 1840 non-Plains counties.

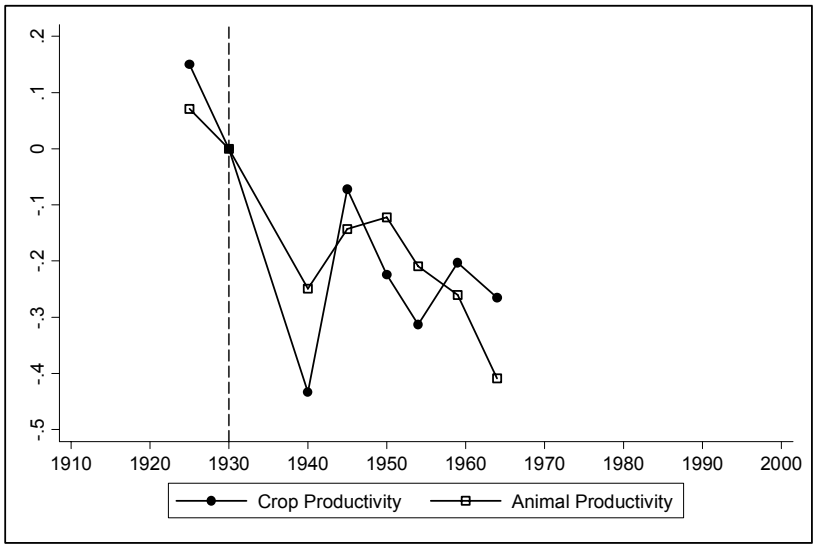
Figure 6. Changes in Farmland Acres per county acre, by Erosion Level



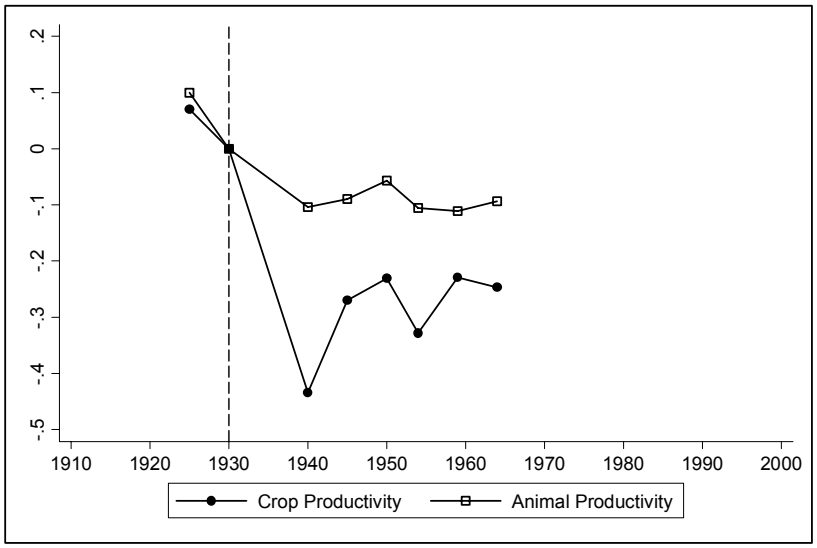
Notes: This figure graphs the estimated coefficients (β) from equation (1) in the text, as described in the notes to Figure 3. Omitted as controls are the 1930 and lagged values of farmland per county acre.

Figure 7. Log Changes in Crop & Animal Productivity, and Changes in Cropland as a Fraction of Cropland and Pasture

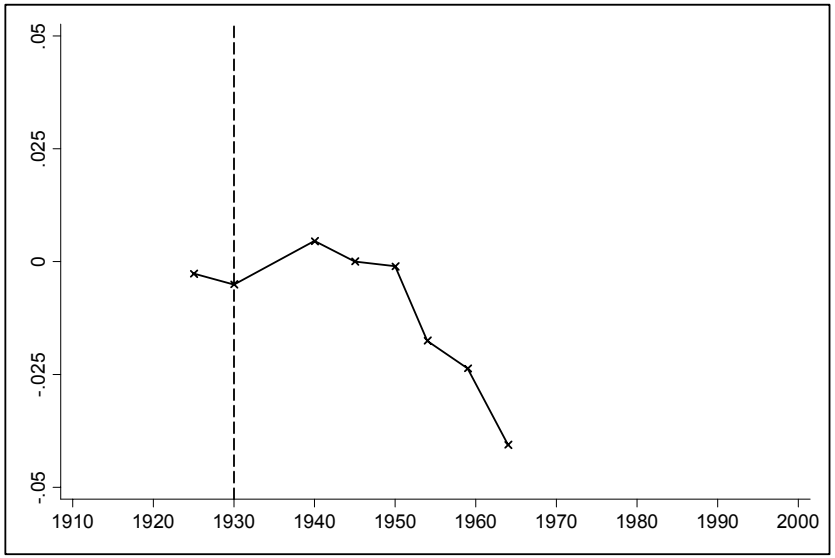
A. Crop and Animal Productivity: High – Low Erosion



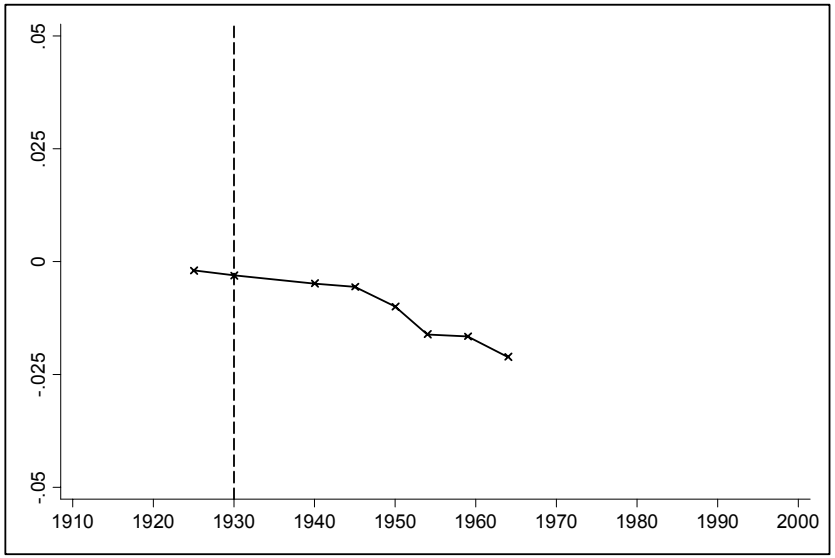
B. Crop and Animal Productivity: Medium – Low Erosion



C. Allocation of Land to Crops: High – Low Erosion



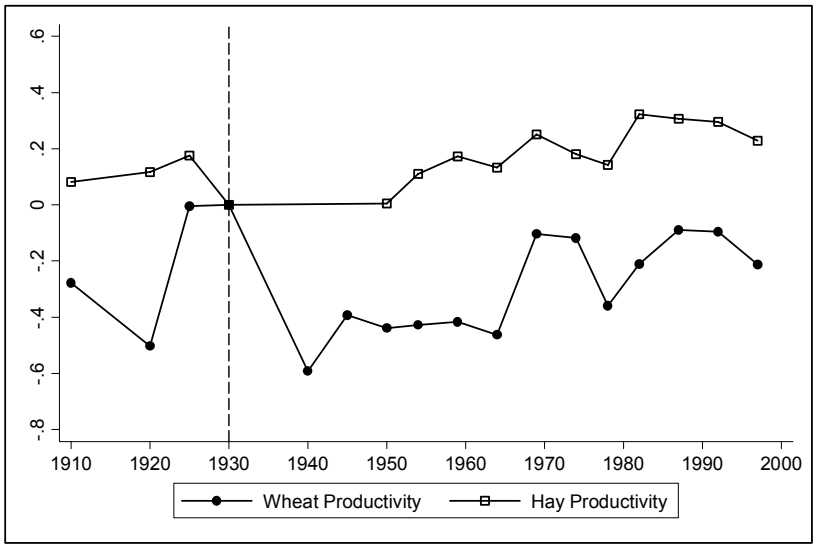
D. Allocation of Land to Crops: Medium – Low Erosion



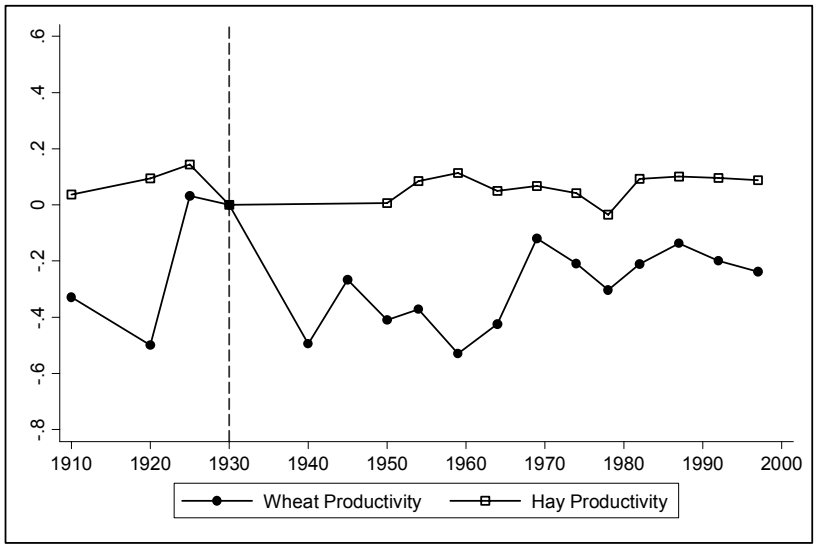
Notes: Panels A and C graph coefficients from equation (1), estimated separately for crop and animal productivity. Panel A reports the change in high erosion relative to low erosion, Panel B reports changes in medium relative to low erosion (normalized to zero in 1930). Panels C and D graph estimated changes in the relative fraction of land allocated to crops.

Figure 8. Log Changes in Wheat & Hay Productivity, and Changes in Wheat Land as a Fraction of Land in Wheat and Hay

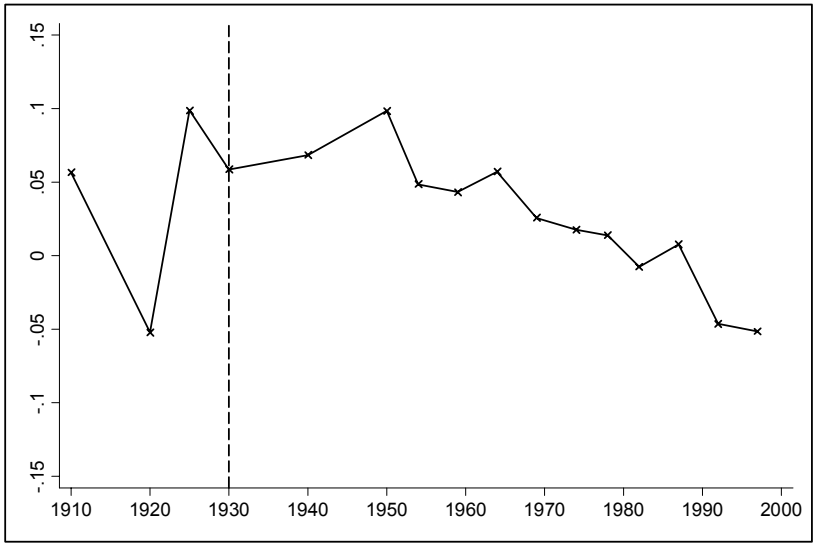
A. Wheat and Hay Productivity: High – Low Erosion



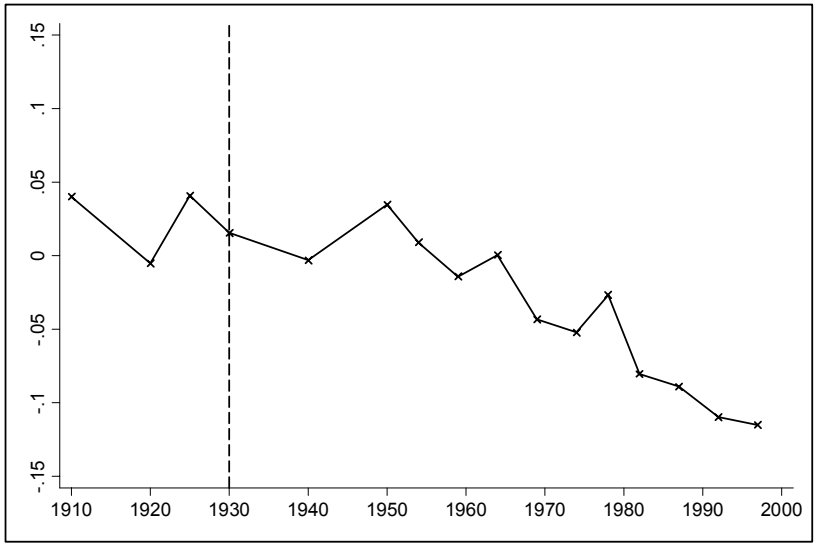
B. Wheat and Hay Productivity: Medium – Low Erosion



C. Allocation of Land to Wheat: High – Low Erosion



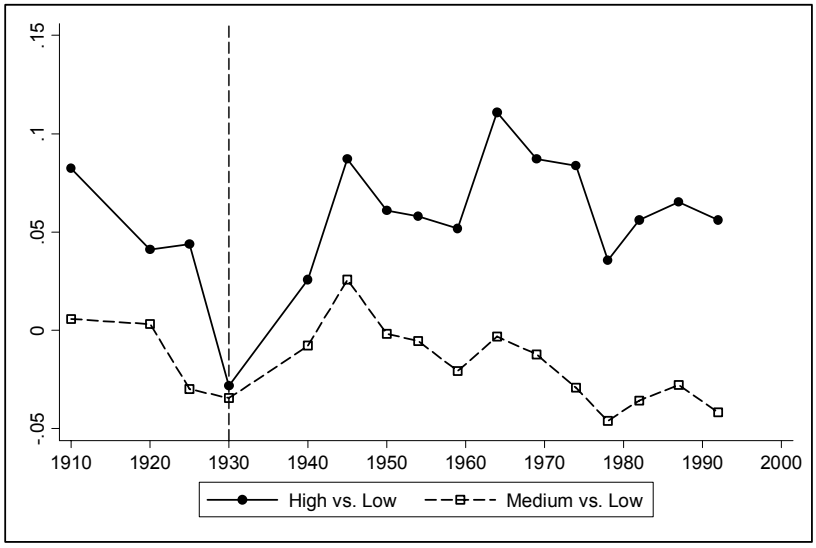
D. Allocation of Land to Wheat: Medium – Low Erosion



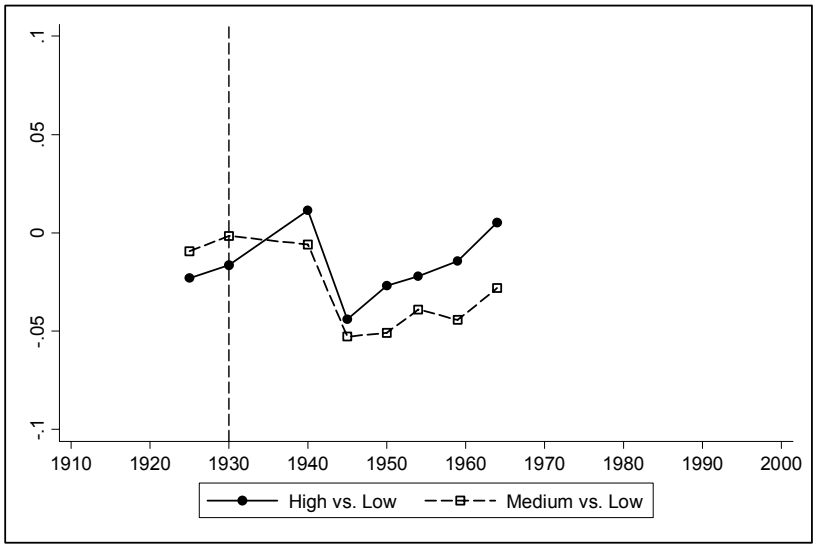
Notes: Panels A and C graph coefficients from equation (1), estimated separately for wheat and hay productivity. Panel A reports the change in high erosion relative to low erosion, Panel B reports changes in medium relative to low erosion (normalized to zero in 1930). Panels C and D graph estimated changes in the relative fraction of land allocated to wheat.

Figure 9. Changes in Average Farm Size and Land Fallowing, by Erosion Level

A. Log Average Farm Size

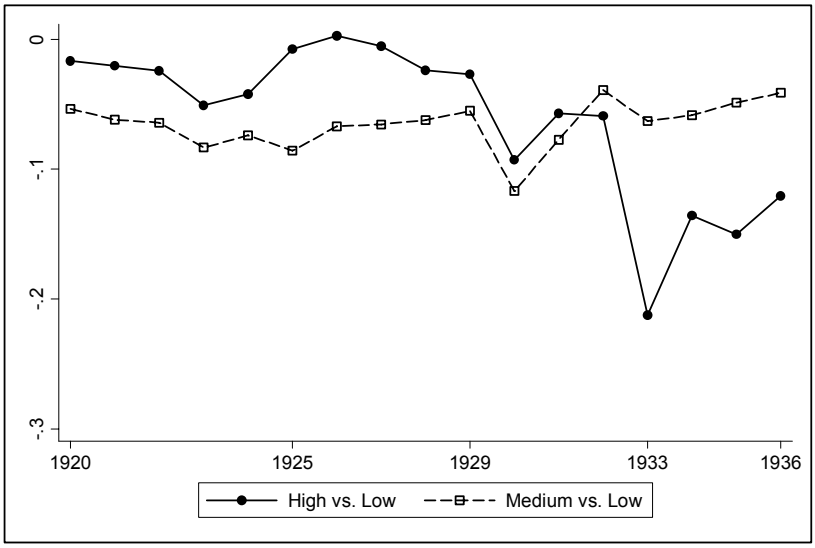


B. Acres of Fallow Land, per acre of cropland



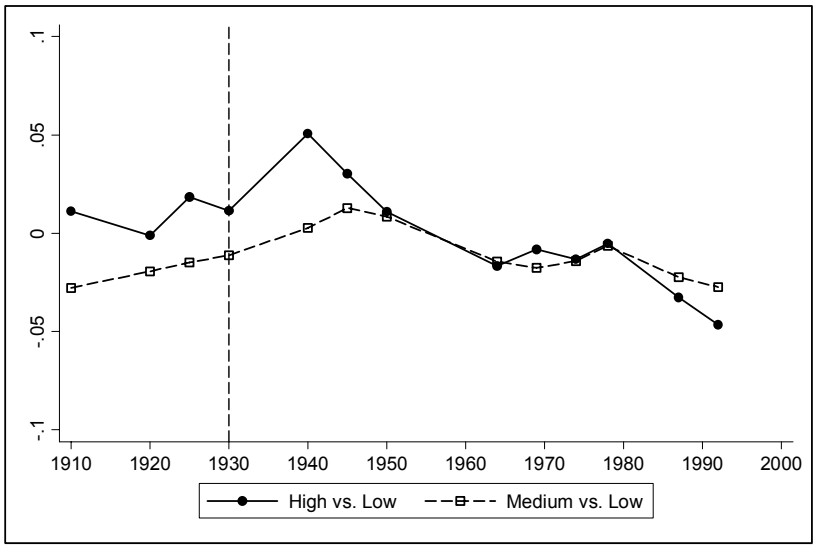
Notes: For the indicated outcome variable, each panel graphs the estimated coefficients (β) from equation (1) in the text, as described in the notes to Figure 3. Panel A omits 1930 and lagged values of average farm size as a control variable.

Figure 10. Log Changes in the Number of Active Banks, by Erosion Level



Notes: This figure graphs the estimated coefficients (β) from a modified version of equation (1), described in the notes to Figure 3. Banking data is available annually, so the regression controls for state-by-year fixed effects and county characteristics interacted with every year.

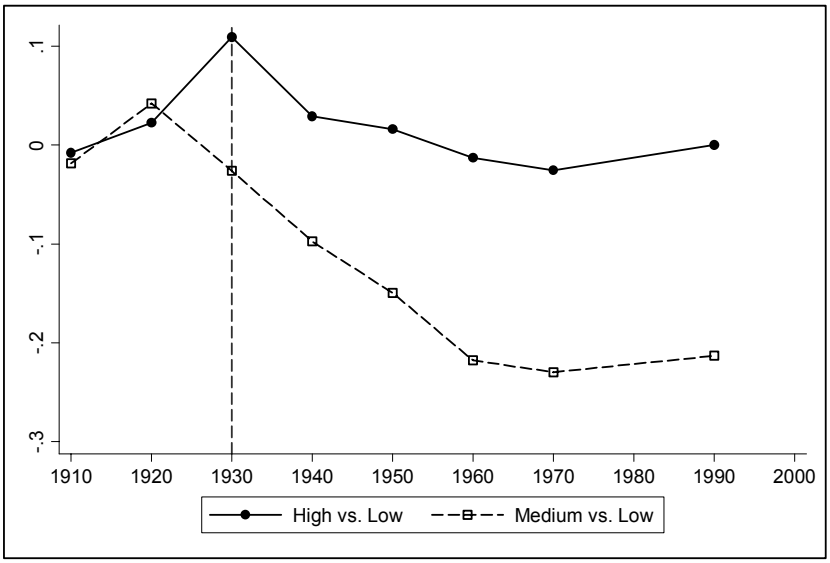
Figure 11. Changes in the Tenant Share of Farmland, by Erosion Level



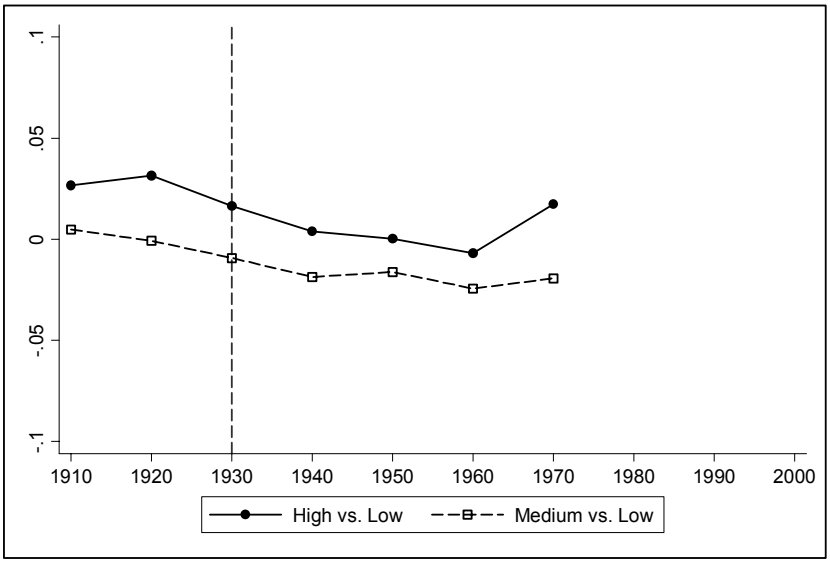
Notes: This figure graphs the estimated coefficients (β) from equation (1) in the text, as described in the notes to Figure 3.

Figure 12. Changes in Population and Rural Population, by Erosion Level

A. Log Population



B. Fraction of Population in Rural Areas of County



Notes: For the indicated outcome variable, each panel graphs the estimated coefficients (β) from equation (1) in the text, as described in the notes to Figure 3. In panel A, the 1930 and lagged values of population per acre are omitted as controls. In panel B, omitted controls are the 1930 and lagged values of fraction of population in rural areas.

Table 1. County Characteristics in 1930, by Post-Dust Bowl Erosion Level

	All Counties	Relative to Low Erosion: Medium Erosion	High Erosion	(3) – (2)
	(1)	(2)	(3)	(4)
Panel A: Value				
Value of farm land & buildings,	3.527	0.244*	0.225	-0.019
per acre in farms	[0.853]	(0.114)	(0.154)	(0.106)
Value of farm land,	3.309	0.217	0.202	-0.014
per acre in farms	[0.819]	(0.111)	(0.150)	(0.103)
Value of all farm products,	2.107	0.258**	0.202	-0.055
per acre in farms	[0.789]	(0.100)	(0.132)	(0.100)
Panel B: Land-use				
Acres of land in farms,	0.819	0.035	-0.004	-0.039
per county acre	[0.187]	(0.019)	(0.023)	(0.020)
Acres of cropland,	0.491	0.035	-0.008	-0.043
per acre in farms	[0.229]	(0.031)	(0.040)	(0.028)
Panel C: Population and Farms				
Population, per 100 county acres	3.524	1.289	1.262	-0.027
	[7.018]	(0.824)	(0.826)	(0.773)
Percent of population, rural areas	0.818	-0.022	0.034	0.057
	[0.221]	(0.030)	(0.043)	(0.042)
Percent of population, on farms	0.542	0.020	0.040	0.020
	[0.175]	(0.024)	(0.032)	(0.032)
Farms, per 100 county acres	0.328	0.163**	0.148**	-0.015
	[0.246]	(0.026)	(0.031)	(0.031)
Average farm size (acres)	613	-233	-307*	-74
	[1145]	(184)	(152)	(142)
Panel D: Cropland Allocation				
% Corn	0.188	0.070**	0.192**	0.122**
	[0.166]	(0.017)	(0.027)	(0.023)
% Wheat	0.181	-0.043	-0.102**	-0.059
	[0.214]	(0.027)	(0.035)	(0.034)
% Hay	0.157	-0.044	-0.099*	-0.056*
	[0.177]	(0.030)	(0.044)	(0.022)
% Cotton	0.104	0.053**	0.020	-0.033
	[0.209]	(0.017)	(0.019)	(0.019)
% Oats, Barley, and Rye	0.134	-0.005	-0.033*	-0.028
	[0.116]	(0.009)	(0.013)	(0.010)
Panel E: Animal Production				
Cows, per county acre	0.056	0.011**	0.013**	0.003
	[0.033]	(0.003)	(0.004)	(0.003)
Pigs, per county acre	0.066	0.040**	0.055**	0.015
	[0.096]	(0.008)	(0.012)	(0.011)
Chickens, per county acre	0.296	0.115**	0.116**	0.001
	[0.279]	(0.025)	(0.034)	(0.031)

Notes: Column 1 presents average values for the 769 sample counties, where counties are weighted by the acres of farmland in 1930 (counties based on 1910 borders; with at least 1000 acres of farmland in every period; and with data on each variable in Figure 1 for each period shown). The standard deviation is reported in brackets.

Columns 2 and 3 report coefficients from a single equation that regresses the indicated county characteristic in 1930 on the percentage of the county in a medium erosion area and in a high erosion area (low erosion is the omitted category), conditional on State fixed effects and weighted by acres of farmland in 1930. Column 4 reports the difference between the coefficients in columns 2 and 3. Robust standard errors are reported in parentheses. ** denotes statistical significance at the 1% level, * at the 5% level.

Table 2. Log Changes in Land Value and Revenue per farm acre, by Erosion Level

	Land Value		Revenue		
	Change After 1930	% Persisting After 1940	Change After 1930	% Persisting After 1940	Ratio of Change (1) / (3)
	(1)	(2)	(3)	(4)	(5)
Panel A. 1940					
High - Low	-0.278		-0.316		0.881
	(0.041)		(0.055)		(0.120)
Medium - Low	-0.167		-0.202		0.824
	(0.029)		(0.039)		(0.136)
High - Medium (calculated)	-0.111		-0.114		0.981
	(0.032)		(0.048)		(0.313)
Averaged Value (GLS)					0.861
					(0.112)
Panel B. 1945					
High - Low	-0.234	0.841	-0.122	0.386	
	(0.037)	(0.087)	(0.044)	(0.118)	
Medium - Low	-0.101	0.609	-0.131	0.648	
	(0.027)	(0.105)	(0.031)	(0.158)	
High - Medium (calculated)	-0.133	1.189	0.009	-0.081	
	(0.031)	(0.238)	(0.035)	(0.324)	
Averaged Value (GLS)		0.765		0.452	
		(0.080)		(0.114)	
Panel C. 1950 – 1954 (pooled)					
High - Low	-0.240	0.864	-0.208	0.658	
	(0.040)	(0.127)	(0.051)	(0.140)	
Medium - Low	-0.118	0.705	-0.183	0.904	
	(0.027)	(0.129)	(0.036)	(0.194)	
High - Medium (calculated)	-0.123	1.101	-0.025	0.220	
	(0.033)	(0.307)	(0.040)	(0.326)	
Averaged Value (GLS)		0.788		0.710	
		(0.112)		(0.135)	
Panel D. 1959 – 1969 (pooled)					
High - Low	-0.315	1.133	-0.255	0.807	
	(0.042)	(0.161)	(0.063)	(0.193)	
Medium - Low	-0.167	1.001	-0.130	0.643	
	(0.033)	(0.196)	(0.044)	(0.217)	
High - Medium (calculated)	-0.148	1.331	-0.125	1.099	
	(0.036)	(0.401)	(0.050)	(0.531)	
Averaged Value (GLS)		1.094		0.746	
		(0.150)		(0.178)	
Panel E. 1978 – 1992 (pooled)					
High - Low	-0.298	1.072	-0.323	1.021	
	(0.057)	(0.197)	(0.092)	(0.308)	
Medium - Low	-0.100	0.603	-0.056	0.276	
	(0.045)	(0.249)	(0.066)	(0.321)	
High - Medium (calculated)	-0.198	1.773	-0.267	2.347	
	(0.051)	(0.557)	(0.076)	(1.110)	
Averaged Value (GLS)		0.935		0.693	
		(0.184)		(0.272)	
R-squared	0.9496		0.8925		
Sample Counties	769		769		

Notes: Columns 1 and 3 report the results from estimating equation (2) in the text, for the value of land and revenue per-acre of farmland, weighting by county farmland in 1930. This estimates the change after 1930, controlling for the same variables as in Figure 3 as well as the values of both land values and revenue in 1930, 1925, 1920, and 1910. The indicated multiple year periods are pooled, such that the estimate is an average over those years. Columns 2 and 4 report the estimated change, as a proportion of the initial change from 1930 to 1940. Column 5 reports the change in land value as a proportion of the change in revenue from 1930 to 1940. Reported in parentheses are robust standard errors clustered by county.

Table 3. Instrumental Variables Estimate of the Change in Land Value from 1930 to 1940

	First-Stage:		2SLS:	OLS:
	% of County in High Erosion	% of County in Medium Erosion	Change in Land Value, 1930 – 1940	Change in Land Value, 1930 – 1940
	(1)	(2)	(3)	(4)
Erosion Level:				
High - Low			-0.631**	-0.277**
			(0.219)	(0.041)
Medium - Low			-0.125	-0.165**
			(0.154)	(0.030)
Drought Instruments:				
Months in Extreme	0.0061**	0.0057		
Drought, 1930s	(0.0021)	(0.0032)		
Months in Severe	0.0031	0.0069**		
Drought, 1930s	(0.0016)	(0.0022)		
Months in Moderate	-0.0014	0.0076**		
Drought, 1930s	(0.0016)	(0.0025)		
Average Palmer Drought	0.0487	0.1700**		
Severity Index, 1930s	(0.0334)	(0.0603)		
Controls:				
Drought Vars, 1895-1929	YES	YES	YES	YES
State Fixed Effects	YES	YES	YES	YES
County Characteristics	YES	YES	YES	YES
F-stat: Instruments	4.69	4.54		
P-value: Instruments = 0	0.0010	0.0013		
Sample Counties	766	766	766	766

Notes: Column 1 reports first-stage estimates from regressing the percent of a county in high erosion areas on the drought instruments, controlling for drought from 1895 to 1929, state fixed effects, and the same pre-1930's county characteristics as in table 2. Column 2 reports analogous estimates for the percent of a county in medium erosion areas. Column 3 reports two-stage least squares estimates of the relative change in land values by erosion level, controlling for the same variables as in columns 1 and 2 and instrumenting for erosion levels using the excluded drought variables. Column 4 reports OLS estimates of the relative change in land value (as in table 2), controlling for the same variables as in column 3 and for the same sample of counties. All regressions are weighted by county farmland in 1930. Robust standard errors are reported in parentheses. ** denotes statistical significance at the 1% level, * at the 5% level.

Table 4. Changes After 1930 in Agricultural Production, by Erosion Level

		Crops vs. Animals			Wheat vs. Hay			Hansen-Libecap Adjustments	
Erosion Level:	County Share in Farmland (1)	Log Crop Productivity (2)	Log Animal Productivity (3)	Land Share in Crops (4)	Log Wheat Productivity (5)	Log Hay Productivity (6)	Land Share in Wheat (7)	Log Average Farm Size (8)	Cropland Fallowed (9)
High - Low									
1940	-0.014	-0.489**	-0.246**	0.009	-0.263*		0.027	0.052	0.019
	(0.015)	(0.118)	(0.055)	(0.010)	(0.115)		(0.022)	(0.032)	(0.016)
1945	-0.012	-0.135	-0.158*	0.003	-0.215**			0.103**	-0.032*
	(0.017)	(0.078)	(0.064)	(0.011)	(0.073)			(0.034)	(0.013)
1950 - 1954	-0.032*	-0.332**	-0.184**	-0.007	-0.233**	-0.003	0.023	0.065	-0.018
	(0.014)	(0.067)	(0.068)	(0.013)	(0.058)	(0.051)	(0.020)	(0.034)	(0.015)
1959 - 1964	-0.025	-0.303**	-0.349**	-0.030*	-0.223**	0.090	0.003	0.084*	0.005
	(0.016)	(0.076)	(0.092)	(0.015)	(0.064)	(0.048)	(0.020)	(0.040)	(0.016)
1969 - 1974	0.003				0.012	0.149**	-0.039	0.081*	
	(0.016)				(0.060)	(0.045)	(0.022)	(0.041)	
1978 - 1992	-0.022				-0.035	0.199**	-0.067**	0.054	
	(0.018)				(0.043)	(0.046)	(0.025)	(0.046)	
1997					-0.067	0.141*	-0.110**		
					(0.048)	(0.063)	(0.032)		
Medium - Low									
1940	-0.002	-0.464**	-0.099**	-0.002	-0.165		-0.016	0.025	-0.005
	(0.010)	(0.086)	(0.038)	(0.006)	(0.091)		(0.016)	(0.021)	(0.010)
1945	0.021	-0.305**	-0.103*	-0.004	-0.102			0.063*	-0.050**
	(0.012)	(0.064)	(0.042)	(0.007)	(0.054)			(0.025)	(0.010)
1950 - 1954	-0.006	-0.310**	-0.095*	-0.012	-0.214**	0.001	0.005	0.034	-0.044**
	(0.010)	(0.054)	(0.046)	(0.008)	(0.054)	(0.047)	(0.020)	(0.028)	(0.011)
1959 - 1964	-0.015	-0.272**	-0.111	-0.018	-0.300**	0.033	-0.022	0.024	-0.034**
	(0.013)	(0.066)	(0.063)	(0.011)	(0.056)	(0.050)	(0.020)	(0.033)	(0.011)
1969 - 1974	-0.001				-0.075	0.002	-0.068**	0.014	
	(0.012)				(0.046)	(0.039)	(0.020)	(0.033)	
1978 - 1992	-0.004				-0.096*	0.009	-0.097**	-0.006	
	(0.013)				(0.033)	(0.042)	(0.021)	(0.037)	
1997					-0.128	0.014	-0.134**		
					(0.047)	(0.053)	(0.026)		
R-squared	0.6133	0.7877	0.8193	0.7254	0.8915	0.8094	0.4607	0.7473	0.8133
Sample Counties	769	769	769	769	388	388	388	769	587
Weighted by 1930 Value of:	Farmland	Cropland	Pasture	Cropland plus Pasture	Wheat	Hay	Wheat plus Hay	Farmland	Farmland

Notes: For each outcome variable, the column reports estimates from equation (2) in the text and described in notes to Table 2. Where indicated, the weights are adjusted to reflect the average change for the relative unit of land. Reported in parentheses are robust standard errors clustered by county. ** denotes statistical significance at the 1% level, * at the 5% level.

Table 5. Changes in Land-use after 1930, Interacted with County Pre-Characteristics

	Relative Adjustment in Areas with More Banks			Relative Adjustment in Areas with More Tenants		
	Land Share in Crops	Land Share in Wheat	County Share in Farmland	Land Share in Crops	Land Share in Wheat	County Share in Farmland
Erosion Level:	(1)	(2)	(3)	(4)	(5)	(6)
High - Low						
1940	-0.042**	0.015	0.008	-0.012	-0.020	0.005
	(0.014)	(0.018)	(0.014)	(0.010)	(0.018)	(0.017)
1945	-0.050**		0.025	-0.001		-0.004
	(0.017)		(0.022)	(0.012)		(0.022)
1950 – 1954	-0.071**	-0.016	-0.004	-0.013	0.048*	-0.016
	(0.019)	(0.021)	(0.015)	(0.015)	(0.020)	(0.016)
1959 – 1964	-0.074**	0.000	-0.030	-0.013	0.026	-0.013
	(0.020)	(0.021)	(0.018)	(0.017)	(0.021)	(0.018)
1969 – 1974		0.010	-0.039*		0.008	-0.035
		(0.023)	(0.018)		(0.022)	(0.018)
1978 – 1982			-0.038*			-0.023
			(0.017)			(0.020)
1987 – 1992			-0.044*			-0.025
			(0.019)			(0.022)
Medium - Low						
1940	-0.017**	-0.012	0.021*	-0.006	-0.009	0.007
	(0.006)	(0.012)	(0.009)	(0.006)	(0.014)	(0.011)
1945	-0.024**		0.007	0.008		-0.031*
	(0.007)		(0.012)	(0.008)		(0.015)
1950 – 1954	-0.013	-0.010	0.018	0.017	0.056**	0.008
	(0.008)	(0.018)	(0.010)	(0.010)	(0.018)	(0.011)
1959 – 1964	-0.021*	-0.007	0.026*	0.015	0.057**	0.027*
	(0.011)	(0.017)	(0.013)	(0.013)	(0.019)	(0.014)
1969 – 1974		0.001	0.026*		0.050*	0.024
		(0.019)	(0.012)		(0.020)	(0.013)
1978 – 1982			0.015			0.033*
			(0.011)			(0.013)
1987 – 1992			0.011			0.014
			(0.013)			(0.014)
R-squared	0.7488	0.4702	0.6180	0.7307	0.4844	0.6087
Sample Counties	696	696	696	696	696	696
Weighted by 1930 Value of:	Farmland	Wheat plus Hay	Farmland	Farmland	Wheat plus Hay	Farmland

Notes: For the indicated outcome variable, each column presents estimates from equation (3) in the text. For columns 1 – 3, the reported coefficients are the interaction term: the adjustment to erosion in areas with more banks in 1928, relative to the adjustment in areas with fewer banks. The log number of banks is normalized to have a mean of zero and a standard deviation of one. Columns 4 – 6 report the analogous coefficients, but for the normalized tenant share of farmland in 1930 (instead of the normalized log number of banks). Reported in parentheses are robust standard errors clustered by county. ** denotes statistical significance at the 1% level, * at the 5% level.

Table 6. Government Program Payments per farm acre, by Erosion Level

		Relative to Low Erosion:		
	All Counties	Medium Erosion	High Erosion	(3) – (2)
	(1)	(2)	(3)	(4)
Panel A. New Deal payments (1933-1939)				
AAA payments	0.489	0.001	-0.027	-0.028
	[0.327]	(0.017)	(0.023)	(0.021)
Public works spending	0.264	0.008	-0.033	-0.041
	[0.605]	(0.058)	(0.064)	(0.066)
Relief spending	0.508	0.110	0.142	0.032
	[2.435]	(0.100)	(0.129)	(0.118)
New deal loans	0.484	-0.090	-0.087	0.003
	[1.126]	(0.094)	(0.112)	(0.087)
Mortgage loans guaranteed	0.112	0.001	-0.103	-0.104*
	[0.792]	(0.040)	(0.059)	(0.042)
Panel B. Government payments				
All payments, 1969	3.323	-0.245	-0.159	0.086
	[2.646]	(0.256)	(0.284)	(0.254)
All payments, 1974	0.364	0.088	0.257**	0.169**
	[0.390]	(0.056)	(0.066)	(0.045)
All payments, 1987	16.040	-1.838*	-5.511**	-3.673**
	[13.631]	(0.866)	(1.076)	(1.075)
All payments, 1992	7.930	-0.887	-1.323*	-0.436
	[5.580]	(0.477)	(0.549)	(0.472)
All payments, 1997	8.060	-0.222	-0.523	-0.300
	[5.843]	(0.366)	(0.467)	(0.442)
CRP payments, 1992	1.571	0.750**	1.776**	1.026**
	[1.490]	(0.162)	(0.263)	(0.245)
CRP payments, 1997	2.094	1.186**	2.562**	1.376**
	[2.061]	(0.225)	(0.350)	(0.322)
Fraction of money from CRP, 1992	0.217	0.089**	0.185**	0.096**
	[0.149]	(0.018)	(0.027)	(0.023)
Fraction of money from CRP, 1997	0.289	0.105**	0.230**	0.125**
	[0.185]	(0.022)	(0.031)	(0.027)

Notes: Panel A reports differences in 1930's New Deal spending across counties, for a constant sample of 766 counties. Panel B reports later differences in government payments, conservation reserve program payments, and the fraction of payments through the conservation reserve program. Column 1 presents the mean for each variable and the standard deviation in brackets. Column 2 reports the average difference for a county with medium erosion relative to low erosion, controlling for state fixed effects, each characteristic in Panels B – E of Table 1, and the lagged values of those characteristics. Columns 3 and 4 report the same average differences comparing high erosion vs. low erosion and high erosion vs. medium erosion, respectively. All variables and regressions are weighted by county farmland in 1930. Robust standard errors are reported in parentheses. ** denotes statistical significance at the 1% level, * at the 5% level.

Table 7. Changes After 1930 in Population Outcomes, by Erosion Level

Erosion Level:	Log Population (1)	Fraction Rural (2)	Fraction on Farm (3)
High - Low			
1940	-0.081**	-0.0118	0.0159
	(0.021)	(0.0090)	(0.0095)
1950	-0.108**	-0.0115	0.0204*
	(0.041)	(0.0157)	(0.0095)
1960	-0.148*	-0.0165	
	(0.064)	(0.0199)	
1970	-0.157	0.0084	0.0334**
	(0.080)	(0.0225)	(0.0121)
1990	-0.127		0.0120
	(0.109)		(0.0081)
Medium - Low			
1940	-0.065**	-0.0102	0.0000
	(0.020)	(0.0075)	(0.0049)
1950	-0.108**	-0.0065	0.0077
	(0.035)	(0.0126)	(0.0070)
1960	-0.170**	-0.0144	
	(0.055)	(0.0157)	
1970	-0.180*	-0.0094	-0.0027
	(0.072)	(0.0181)	(0.0096)
1990	-0.160		0.0004
	(0.103)		(0.0065)
R-squared	0.5954	0.4558	0.9451
Sample Counties	769	769	769

Notes: For each indicated outcome variable, the column reports estimates from equation (2) in the text and described in the notes to Table 2. All regressions are weighted by county population in 1930. Reported in parentheses are robust standard errors clustered by county. ** denotes statistical significance at the 1% level, * at the 5% level.

Table 8. Changes After 1930 in Unemployment and Manufacturing

		Manufacturing			
	Unemployment Rate (1)	Workers per-labor force (2)	Workers per-capita (3)	Log Establishments (4)	Log Value Added (5)
1930 Mean:	0.0410	0.0628	0.0262		
	[0.0255]	[0.0629]	[0.0276]		
Erosion Level:					
High - Low					
1940	0.0071*	0.0072	0.0040	0.022	0.108
	(0.0034)	(0.0041)	(0.0021)	(0.069)	(0.145)
1945				-0.078	0.003
				(0.066)	(0.183)
1950	-0.0031				
	(0.0020)				
1954				-0.137	-0.138
				(0.078)	(0.247)
1958 (-1964)			0.0036	-0.126	-0.058
			(0.0061)	(0.080)	(0.261)
1967 (-1974)			0.0024	-0.014	-0.226
			(0.0093)	(0.099)	(0.259)
1978 (-1982)				-0.036	-0.443
				(0.110)	(0.494)
1987 (-1992)			0.0050	-0.044	0.157
			(0.0109)	(0.129)	(0.362)
Medium - Low					
1940	-0.0016	0.0000	0.0005	-0.080	-0.127
	(0.0025)	(0.0035)	(0.0020)	(0.049)	(0.111)
1945				-0.011	0.003
				(0.047)	(0.128)
1950	-0.0007				
	(0.0017)				
1954				-0.037	-0.041
				(0.058)	(0.182)
1958 (-1964)			0.0063	-0.100	-0.111
			(0.0047)	(0.062)	(0.178)
1967 (-1974)			0.0131	-0.060	-0.153
			(0.0076)	(0.079)	(0.187)
1978 (-1982)				-0.061	0.022
				(0.093)	(0.338)
1987 (-1992)			0.0250**	-0.045	-0.087
			(0.0075)	(0.109)	(0.263)
R-squared	0.8550	0.5803	0.9203	0.5754	0.9456
Sample Counties	769	550	336	551	275

Notes: For each outcome variable, the 1930 mean is reported at the top of the column and the standard deviation in brackets. The column reports estimates from equation (2) in the text and described in the notes to Table 2. In column 3, manufacturing worker data is only available for 1958, 1967, and 1987, and population data is taken from the nearest decennial. Reported in parentheses are robust standard errors clustered by county. ** denotes statistical significance at the 1% level, * at the 5% level.

Table 9. Log Changes After 1930 in Wage Proxies

		Payroll divided by Workers		
	Retail Sales per-capita	Retail Sector	Wholesale Sector	Manufacturing Sector
Erosion Level:	(1)	(2)	(3)	(4)
High - Low				
1940	-0.098**	-0.013	-0.035	-0.050
	(0.029)	(0.018)	(0.048)	(0.067)
1945				-0.049
				(0.062)
1954		-0.060**	-0.044	-0.095
		(0.022)	(0.051)	(0.069)
1958 (-1964)	-0.058	-0.030*	-0.050	-0.130*
	(0.031)	(0.015)	(0.032)	(0.060)
1967 (-1974)	-0.034	-0.041*	-0.048	-0.209*
	(0.039)	(0.016)	(0.035)	(0.104)
1978 (-1982)		-0.085*	-0.202**	-0.043
		(0.038)	(0.067)	(0.110)
1987 (-1992)	-0.059	-0.035	-0.104**	-0.077
	(0.053)	(0.018)	(0.039)	(0.065)
Medium - Low				
1940	-0.063**	-0.012	-0.048	-0.131**
	(0.022)	(0.014)	(0.034)	(0.049)
1945				-0.116**
				(0.040)
1954		-0.041**	-0.096**	-0.092*
		(0.013)	(0.032)	(0.045)
1958 (-1964)	0.005	-0.017	-0.079**	-0.106*
	(0.021)	(0.011)	(0.026)	(0.044)
1967 (-1974)	0.033	-0.016	-0.076**	-0.073
	(0.028)	(0.011)	(0.024)	(0.046)
1978 (-1982)		-0.041	-0.178**	-0.080
		(0.024)	(0.040)	(0.072)
1987 (-1992)	0.011	-0.014	-0.126**	-0.065
	(0.042)	(0.013)	(0.027)	(0.045)
R-squared	0.9749	0.9970	0.9921	0.9906
Sample Counties	758	748	495	257

Notes: For each outcome variable, the column reports estimates from equation (2) in the text and described in the notes to Table 2. In column 1, retail sales data is only available for 1958, 1967, and 1987, and population data is taken from the nearest decennial. Reported in parentheses are robust standard errors clustered by county. ** denotes statistical significance at the 1% level, * at the 5% level.