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THE ENDURING IMPACT OF THE AMERICAN DUST BOWL: SHORT AND LONG-RUN ADJUSTMENTS TO ENVIRONMENTAL CATASTROPHE

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The Enduring Impact of the American Dust Bowl: Short and Long-run Adjustments to Environmental Catastrophe
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ABSTRACT

The 1930's American Dust Bowl was an environmental catastrophe that greatly eroded sections of the Plains. Analyzing new data collected to identify low-, medium-, and high-erosion counties, the Dust Bowl is estimated to have immediately, substantially, and persistently reduced agricultural land values and revenues. During the Depression and through at least the 1950's, there was limited reallocation of farmland from activities that became relatively less productive. Agricultural adjustments, such as reallocating land from crops to livestock, recovered only 14% to 28% of the initial agricultural cost. The economy adjusted predominately through migration, rather than through capital inflows and increased industry.

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A recurrent theme in economics is that "short-run" impacts are mitigated in the "long-run" by economic agents' adjustments. The idea is central to the impact of global climate change (Mendelsohn et al. 1994; Deschenes and Greenstone 2007; Dell et al. 2009; Fisher et al. 2009; Guiteras 2009; Schlenker and Roberts 2009). Even small gradual changes in climate may trigger large and permanent local environmental collapse (Scheffer et al. 2001; Diamond 2005).

Theoretical differences between short-run and long-run effects are well-known, but empirical evidence is needed to gauge the speed and magnitude of long-run adjustment in different contexts (see, e.g., Blanchard and Katz 1992; Bresnahan and Ramey 1993; Foster and Rosenzweig 1995; Duflo 2004; Chetty et al. 2009). Historical settings provide a unique opportunity to identify adjustments that may occur over long periods of time (Carrington 1996; Margo 1997; Davis and Weinstein 2002; Miguel and Roland 2006; Collins and Margo 2007; Redding and Sturm 2008).

This paper analyzes the aftermath of large and permanent soil erosion during the 1930's that became widely known as the "American Dust Bowl." The Dust Bowl substantially reduced lands' potential for agricultural production, and erosion varied across counties even within a state. Detailed data allow for an examination of adjustment from 1940 to the present. The analysis here focuses on the speed and magnitude of adjustment in the agricultural sector, the resulting difference in short-run and long-run agricultural costs, and the geographic reallocation of labor and capital.

The 1930's Dust Bowl period was one 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 large 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 effects of the Dust Bowl are interpreted here within a model of agricultural production, in which land allocations are fixed in the short-run. Immediately following the Dust Bowl, the true cost is capitalized into land values. In the long-run, profits partly recover as land is reallocated toward activities less affected by erosion. Profits decrease by more than land values in the short-run, as land values anticipate the partial recovery in profits. Further, in a simple general equilibrium framework, adjustment may also occur through out-migration and an expansion of local industry.

Crucial for the empirical analysis is the existence of local variation in erosion following the Dust Bowl. In particular, the 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 land values and other outcomes in more-eroded and less-eroded counties within the same state, after adjusting for differences in pre-Dust Bowl characteristics.

The Dust Bowl is estimated to have imposed substantial long-run costs on Plains agriculture. From 1930 to 1940, more-eroded counties experienced large and permanent declines in agricultural land values. The per-acre value of farmland declined by 28% in high-erosion counties and 17% in medium-erosion counties, relative to changes in low-erosion counties. If low-erosion counties were not affected, either negatively by erosion or positively by general equilibrium spillovers, the land value declines indicate a total capitalized agricultural loss from the Dust Bowl of $153 million in 1930 dollars ($1.9 billion in 2007 dollars). Given average land values in 1930, the loss is represented by the value of farmland the size of Oklahoma.

Agricultural costs from the Dust Bowl appear to have been mostly persistent. More-eroded counties experienced substantial immediate declines in agricultural revenues per-acre of farmland, and lower revenues largely persisted. Two calculations, based on the persistence of lower revenues and a comparison between revenues and land values, imply that long-run adjustments recovered only 14% to 28% of the initial agricultural cost. Because the Dust Bowl permanently reduced the productive potential of a fixed factor, it might not be surprising that full recovery was not experienced in eroded areas.

Observed adjustments in agricultural land-use were limited and slow, consistent with the estimated persistent short-run cost. Total farmland remained similar, reflecting an inelastic demand for land in non-agricultural sectors. Within the agricultural sector, there were potentially productive adjustments: the relative productivity of land decreased for crops (compared to animals) and for wheat (compared to hay). Through the Great Depression and at least the 1950's, however, there was little adjustment of land from crops to pasture or from wheat to hay.[1]

The Great Depression itself may have partly accounted for limited agricultural adjustment and persistence in costs. In particular, credit constraints may have been important: more-eroded areas experienced more bank failures during the 1930's, and there was greater land-use adjustment in more-eroded areas that had more banks prior to the 1930's. In contrast, there is little evidence that tenant farming slowed land-use adjustment. New Deal government programs do not appear to explain the lack of adjustment, at least not in more-eroded counties relative to less-eroded counties, as payments were not targeted toward more-eroded counties.

Migration was the main margin of short-run and long-run economic adjustment. Population declined substantially from 1930 to 1940 in more-eroded counties relative to less-eroded counties, along with out-migration from the entire region. The Depression may have

[1] Overall technological innovation may have responded to the Dust Bowl, e.g., hybrid corn (Griliches 1957; Sutch 2008), but the within-region analysis is unable to identify aggregate shifts in the technological frontier. Aggregate technological change does not appear to have been substantially erosion-biased.

limited outside employment opportunities and, by 1940, labor adjustment remained incomplete: unemployment was higher, a proxy for wages was lower, and the labor-capital ratio in agriculture was higher. Equilibrium was reestablished by 1960 through further declines in population rather than through capital inflows and an increase in local industry.

Overall, the Dust Bowl is estimated to have imposed substantial and persistent costs on Plains agriculture. Adjustment took place mainly through decreased land values and population, while agricultural and industrial adjustments were limited and slow. The analysis helps in understanding a major episode in American economic history. The experience of the American Dust Bowl highlights that agricultural costs from environmental destruction need not be mostly mitigated by agricultural adjustments and that mass out-migration may result.

The paper is organized as follows. Section I provides historical background on the Dust Bowl. Section II presents a model of agricultural production in the short-run and long-run, and discusses in a simple general equilibrium framework how population, industry, and non-eroded locations may also adjust to the Dust Bowl erosion. 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

In the late nineteenth century, agricultural production began to expand substantially on the American Plains. World War I temporarily increased demand for American agricultural goods, and the Plains' native grasslands became increasingly plowed up for crops. Drought conditions during the 1930's, and especially severe Plains droughts in 1934 and 1936, led to widespread crop failure. The loss of ground cover made farmland susceptible to self-perpetuating dust storms (wind erosion) and substantial runoff during occasional heavy rains (water erosion).

Dust storms blew enormous quantities of topsoil off Plains farmland. On "Black Sunday" in 1935, one such storm blanketed East Coast cities in a haze. Due to repeated blowing soil on the Plains, some residents were afflicted with dust pneumonia.[2] The Dust Bowl period continued through 1938 and ended with the return of wetter weather and increased ground cover.[3]

The Dust Bowl was caused by a combination of prolonged severe drought and intensive land-use. Unsustainable exploitation of land is emphasized by most historical accounts (SCS

[2]Cutler et al. 2007 do not detect late-life health effects among cohorts from regions more exposed *in utero* to the Dust Bowl and drought (measured by crop yields).

[3]Worster (1979, p.30) reports a substantial wind erosion area in 1940, which Geoff Cunfer (since publishing) discovered to be erroneous: based on 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 the projections proved incorrect and that there turned out to be little blowing.

1955; Worster 1979; Hurt 1981) and contemporaries (SCS 1935 and 1939; Hoyt 1936; Wallace 1938).[4] Some feared that the region would become the once-imagined "American Desert" if private land-use practices were allowed to continue (Science 1934; News-week 1936). Hansen and Libecap (2004) present evidence that externalities contributed to the Dust Bowl: while farmers could discourage wind erosion by fallowing land or converting cropland to grasslands and pasture, much of the benefit would be captured by neighboring farms.

New Deal government programs attempted to restrict agricultural production, though the initial motivation was to raise prices, increase farm incomes, and stimulate the economy. The 1933 Agricultural Adjustment Act paid farmers to reduce planted acreages, and the government also purchased and destroyed livestock (Leuchtenburg 1963; Saloutos 1982).

When the Supreme Court declared aspects of New Deal policies unconstitutional, agricultural policy shifted toward "conservation" (Rasmussen and Baker 1979; Phillips 2007). Efforts to increase prices were combined with erosion control in the 1935 and 1936 Soil Conservation and Domestic Allotment Acts and the 1938 Agricultural Adjustment Act. The Soil Conservation Service (SCS) was established to run soil erosion control projects that were aimed at demonstrating the effectiveness of recommended soil conservation techniques (SCS 1937). The adjustments included converting cropland to grassland, planting alternate strips of cash crops and drought-resistant crops, and fallowing land with productive cover.[5] Soil conservation districts and increased farm sizes may have lowered coordination problems and helped prevent the Dust Bowl's reoccurrence (Hansen and Libecap 2004).[6]

Figure 1 presents aggregate changes in agriculture and population on the Plains over the twentieth century.[7] Average farmland per-acre became less valuable from 1910 to 1940 (Panels A and B), partly due to an increase in total farmland (Panel C). Total farmland stopped increasing in the 1940's, and average land values and revenues began to rise.[8] During the 1930's, cropland per-acre of farmland decreased and fallow land per-acre of cropland increased (Panels D and E). Farm sizes increased steadily after 1930 (Panel F). Total popula-

[4]Cunfer (2005) emphasizes the impact of severe weather and notes that broad land-use patterns have remained similar on the Plains, though the data may obscure important adjustments in fallowing and cropland management (Hansen 2005).

[5]Two additional techniques were retaining crop residues to provide ground cover and plowing along contour lines. The SCS also took responsibility over the administration of some Civilian Conservation Corps work camps, which employed workers on public projects to reduce unemployment. Some of the work focused on preventing erosion: terracing land, rehabilitating gullies, and planting trees as wind breaks.

[6]Historical accounts of government programs imply a substantial impact on land-use (e.g., Hurt 1985).

[7]Aggregate numbers are calculated by summing over the same 769 Plains counties in every reported period. The exception is Panel E: following Hansen and Libecap (2004), the sample is restricted to 587 counties for which comparable fallow data is available from 1925 to 1964.

[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.

tion grew at a roughly constant rate from 1910 to 2000, with slower growth from 1930 to 1950 (Panel G), and the fraction of people in rural areas declined (Panel H). From 1930 to 1940, total population declined between 3% and 7% in the five central Plains states (Oklahoma, Kansas, Nebraska, South Dakota, North Dakota).

The Dust Bowl was unexpected and likely increased farmers' expectations of future drought and erosion in all areas of the Plains, or at least created substantial uncertainty. All farmers may have had incentives to adjust to the Dust Bowl, regardless of whether their land was eroded. Conservation incentives may have contributed to aggregate decreases in cropland and increases in fallowing.

By contrast, it was observable which particular lands were eroded after the Dust Bowl. The subsequent analysis focuses on relative changes among differentially eroded counties, controlling for state-wide changes that capture changing expectations about future drought or erosion and other aggregate shocks (e.g., Great Depression, World War II, technology, prices).

Relative adjustments to the Dust Bowl should reflect the substantial decrease in productivity due to soil erosion. If crop production is sensitive to soil quality, then farmers may shift more-eroded land into animal pasture. Similarly, farmers may shift land from soil-sensitive crops (wheat) to erosion-resistant crops (hay). The Dust Bowl is also associated with substantial out-migration, famously described in Steinbeck's *The Grapes of Wrath*. There is little empirical evidence, however, that separates Dust Bowl migration and agricultural adjustment from aggregate changes in Plains' population and agricultural production.[9]

II Theoretical Framework

II.A Agricultural Production: Short-run vs. Long-run

Agricultural production may be slow to adjust following the Dust Bowl, delaying the partial recovery of profits. Decreased land values capitalize the true agricultural cost of the Dust Bowl, anticipating the partial recovery of profits. In such a model, land values initially decrease by less than profits only to the extent that agricultural adjustments will mitigate the initial cost (in present discounted value).[10]

In characterizing relative adjustment to the Dust Bowl, assume that a farmer chooses production decisions in every period to maximize the present discounted value of profits. The farmer produces one good in a competitive market and allocates a share θ of land between two production technologies, $\mathrm{F}_1(\theta, V_1)$ and $\mathrm{F}_2(1-\theta, V_2)$. Variable inputs V can be adjusted

[9]All migrants from the region may have been inappropriately (and derogatorily) lumped together as "Okies" fleeing the Dust Bowl. 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.

[10]Future periods are discounted, so long-run mitigation is more effective when it occurs sooner. The true agricultural cost includes both "short-run" and "long-run" costs, weighted appropriately.

quickly and are purchased in each period at a constant price (e.g., labor). The production technologies reflect methods or fixed inputs that can only be adjusted slowly (e.g., cropland vs. pasture or wheat vs. hay).

(i) Initial Equilibrium. For a given land allocation θ, the farmer chooses variable inputs to obtain the maximal profit in technology 1 ($\Pi_1(\theta)$) and technology 2 ($\Pi_2(1-\theta)$). The farmer chooses an optimal land allocation $\overline{\theta}$ such that $\Pi_1^{'}(\overline{\theta}) = \Pi_2^{'}(1-\overline{\theta})$.[11] The farmer obtains an initial profit $\pi^I = \Pi_1(\overline{\theta}) + \Pi_2(1-\overline{\theta})$. The value of land equals the present discounted value of profits, $\frac{\pi^I}{1-\beta}$, where β is a constant discount factor.[12]

(ii) Permanent Shock to Relative Profitability. At $t = 0$, the unexpected Dust Bowl permanently decreases the relative profitability of the first technology: $\Pi_1(\theta)$ decreases to $\delta\Pi_1(\theta)$, where $\delta \in (0,1)$. In the "short-run," when $t < T$, variable inputs can adjust but the land allocation is constrained at its previous level ($\theta = \overline{\theta}$). 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," when $t = T$, assume (for now) that the land allocation can adjust costlessly. 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 $\pi^{LR} = \delta\Pi_1(\widehat{\theta}) + \Pi_2(1-\widehat{\theta})$.

(iii) Long-run Changes in Profits. When the binding land allocation constraint is lifted in the long-run, land is shifted from the first technology ($\widehat{\theta} < \overline{\theta}$) and profits increase ($\pi^{SR} < \pi^{LR} < \pi^I$). In particular, profit increases 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 land unit adjusted. Taking a first-order Taylor expansion of each marginal profit function around $\overline{\theta}$, the 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.[13] Profits fall in the short-run and partially recover in the long-run as the land allocation adjusts.[14]

(iv) Changes in Land Values. Land values in each period are the net present value of profits, given a profit stream of π^{SR} until period T and π^{LR} thereafter. In each period

[11]The condition assumes that the profit functions are differentiable and concave, focusing on interior solutions and technological adjustment. If the initial equilibrium were a corner solution, later adoption of the other technology could be interpreted as technological change.

[12]The necessary assumptions are competition and free entry in land markets, with the marginal land buyer having access to credit at a fixed interest rate. If the latter 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.

[13]The approximation is exact if $\Pi_2^{'}(1-\overline{\theta})$ and $\Pi_1^{'}(\overline{\theta})$ are linear.

[14]Rearranging terms from the 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 land allocation changes more when there is a larger decrease in marginal return, and when marginal returns are less sensitive to changes in land allocation.

$0 \leq t \leq T-1$, the value of land is $\sum_{i=t}^{T-1} \pi^{SR}\beta^i + \sum_{i=T}^{\infty} \pi^{LR}\beta^i$; for $t \geq T$, land value is $\frac{\pi^{LR}}{1-\beta}$.

The equations generate three main implications that are explored in the data. First, land values initially fall by a smaller percentage than profits, due to the expected partial recovery in profits.[15] Second, land values increase if profits increase, though by a smaller percentage.[16] Third, the value of land at $t = 0$ capitalizes the true PDV agricultural cost of the Dust Bowl.[17]

(v) Adjustment Costs. The sharp distinction between "short-run" and "long-run" is of analytical convenience and can be interpreted as a simplified case of an unconstrained model with convex or declining adjustment costs. Adjustment costs may be convex if capital or other adjustment inputs have an upward sloping supply curve in each period. Adjustment costs may decline over time due to learning-by-doing or other positive spillovers in technological adoption (Griliches 1957, Foster and Rosenzweig 1995).[18]

The theoretical predictions are similar if land adjustment is costly: the land allocation is adjusted less, leading to less long-run recovery in profits.[19] Of particular empirical interest is whether the adjustment cost is recoverable; if not, then land values increase when the sunk cost is paid.[20] Thus, observed changes in land values indicate whether adjustment takes place on margins that require fixed or mobile investments.[21]

II.B General Equilibrium Effects of the Dust Bowl

The Dust Bowl was a major economic event and may have had general equilibrium effects on non-agricultural sectors and non-Dust Bowl areas. Applying a Roback (1982) model to a rural setting, this section outlines predicted long-run changes in population and production

[15] Rearranging terms, the value of land at $t = 0$ is $\frac{\pi^{SR}}{1-\beta} + (\pi^{LR} - \pi^{SR}) \sum_{i=T}^{\infty} \beta^i$. Land value is greater than the PDV of short-run profits (the first term) when the long-run increase in profits is larger and the long-run is achieved sooner.

[16] 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 as periods of short-run profits are past and periods of long-run profits become more immediate.

[17] Rearranging terms, the value of land at $t = 0$ is $\frac{\beta^T \pi^{LR} + (1-\beta^T)\pi^{SR}}{1-\beta}$. Intuitively, land value is a weighted average of long-run profits and short-run profits, where the weights are the relative value of each.

[18] Even with costless adjustment, the potential for learning to resolve uncertainty about optimal adjustments can delay investment (Dixit and Pindyck 1994; Bloom et al. 2007). Past crop-specific investments may also depreciate over time, discouraging early adjustment (Chari and Hopenhayn 1991).

[19] In a stark example, assume shifting land L from technology 1 to 2 requires a one-time non-recoverable cost $C_{12}(L)$ to be paid in period T. If some land adjustment remains optimal, it satisfies: $(1-\delta)\Pi_1'(\widehat{\theta}) = \Pi_2'(1-\widehat{\theta}) - (1-\beta)C_{12}'(\overline{\theta} - \widehat{\theta})$. Note that the first order condition assumes the farmer has perfect access to credit, so effectively $(1-\beta)$ of the adjustment cost is paid in each period. Capital constraints would make full initial adjustment more costly.

[20] When considering the evolution of land values over time, there is a less-interesting additional term that reflects the anticipated payment of the adjustment cost. For example, if a non-recoverable 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.

[21] Note, however, that the 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.

in the agricultural and industrial sectors.

In the model, there are two locations (Dust Bowl and non-Dust Bowl).[22] Two sectors (agriculture and industry) 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.

In the context of the model, assume that agricultural productivity declines in the Dust Bowl area. The demand for agricultural land decreases. If the supply of land for agriculture is inelastic, adjustment in the land market mainly occurs through decreased prices with little change in total farmland.[23]

Further, assume that the productivity of agricultural labor declines in the Dust Bowl area. Workers 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 (agricultural sector) to the extent that there are costs to moving (switching sectors). Note that workers consume land that is now cheaper, so paid wages fall by more than local price-adjusted wages.

In the Dust Bowl area, lower wages encourage labor-intensive production in the agricultural sector. Labor-capital ratios could increase and/or land allocations shift toward activities that use more labor (and happen also to be less erosion resistant, such as crops vs. animals or wheat vs. hay). Lower wages and land prices encourage the industrial sector to expand.[24]

Wages decrease in response to an in-migration of workers in the non-Dust Bowl area. Because the Dust Bowl area is less productive in agriculture, agricultural output prices increase and the agricultural sector expands in the non-Dust Bowl area. In general, disadvantaged production activities in the Dust Bowl area become advantaged in the non-Dust Bowl area, so relative comparisons in production decisions (and population) will overstate adjustments made in the Dust Bowl area. Land prices increase in the non-Dust Bowl area, so relative comparisons with the Dust Bowl area will overstate the total cost of the Dust Bowl. Note, however, if the Dust Bowl is small or the economy is open, spillovers to the non-Dust Bowl area become negligible.

[22] The locations could be a more-eroded and less-eroded county within Oklahoma, or an eroded county in Oklahoma and a non-eroded county in California.

[23] Supply is inelastic when workers and industrial firms (current or entering) have little use for additional marginal lands.

[24] If outputs were not traded freely, then the industrial sector could contract if it was supplied inputs by (or sold outputs to) the local agricultural sector.

III Data Construction and Baseline Characteristics by Erosion Level

County-level data on agriculture, population, and industry are drawn from the US census (Gutmann 2005; Haines 2005). Variables of interest include the value and quantity of agricultural land, agricultural revenue and capital, total cropland and pasture, revenue from crops or animals, production and acreage for specific crops, number of farms, population, rural population, farm population, retail sales, manufacturing workers and value added, and unemployment (see Data Appendix). Other data sources include banking data from the FDIC; New Deal expenditures from the Office of Government Reports (Fishback et al. 2005); and drought data from the National Climatic Data Center (Boustan et al. 2008).

Core results focus on a balanced panel of 769 Plains counties from 1910 to 1997, for which data on key variables are available in every period of analysis (see Data Appendix).[25] To account for county border changes, census data are adjusted in later periods to maintain the 1910 county definitions (Hornbeck 2009).

Figure 2 displays the 769 sample counties, overlaid with a map of cumulative erosion damage after the Dust Bowl. The white area is low erosion (less than 25% of topsoil lost), light gray is medium erosion (25% to 75% of topsoil lost), dark gray is high erosion (more than 75% of topsoil lost), and crossed out areas are not in the sample (mainly due to unavailable data in 1910 and 1925). The map, prepared by the Soil Conservation Service (SCS), was obtained from the National Archives and traced using GIS software.[26]

The main limitation of the erosion measure is that it does not just reflect erosion that occurred during the Dust Bowl.[27] Large-scale detailed erosion surveys only began in the 1930's, and were based on soil measurements by specialists sent to each county (SCS 1935).[28] Thus,

[25]Data from 1935 are omitted due to ongoing erosion and severe drought; production data corresponding to 1934 was often not collected.

[26]Documentation is sparse, but the map 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. There are no other erosion maps from December 1937 until the 1948 map.

[27]An additional type of published map indicates periods when wind erosion occurred on the Plains: showing broad areas of blowing from 1935 to 1936 and in 1938, which correspond closely to areas with the highest wind speeds (Chepil et al. 1962). The broad wind erosion region has less detailed variation, however, and it is not clear how the exact area was determined. There was substantial wind erosion in other places and at other times during the Dust Bowl, as well as water erosion, and the maps give little sense of the cumulative effect on the soil.

[28]The Soil Erosion Service (SES) was established in 1933 (replaced in 1935 by the SCS) and published the very detailed 1934 Reconnaissance Erosion Survey. 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. The erosion maps indicate whether areas experienced wind erosion or sheet (water) erosion, whether the erosion type was slight, moderate, or severe, and whether there were many gullies (water erosion). A limitation is that there is no natural way to compare erosion across types to generate a single index for how much an area was affected. Also, the maps do not directly measure erosion that occurred during the Dust Bowl, there is no baseline data, and the erosion categories vary over time. Hansen and Libecap (2004) assign

there is no baseline data on erosion and topsoil levels prior to the Dust Bowl. The empirical analysis does not require a literal interpretation of the erosion measure (percentage of original topsoil lost); rather, the categories are interpreted as proxies for differential erosion. To focus on the change in erosion over the 1930's, the empirical analysis controls for county characteristics in 1930, 1925, 1920, and 1910 that might predict baseline erosion levels.

The Dust Bowl occurred only on the Plains, so the main sample is restricted to the 12 Plains states in Figure 2: Colorado, Iowa, Kansas, Minnesota, Montana, Nebraska, New Mexico, North Dakota, Oklahoma, South Dakota, Texas, and Wyoming. The erosion map was prepared for the entire country and many areas in non-Plains states were also classified as moderately or severely eroded; presumably, based mainly on erosion in earlier periods. More-eroded counties experienced a substantial relative drop in land values in Plains states (and not in non-Plains states), which suggests that mapped erosion levels are an effective proxy for the Dust Bowl erosion on the Plains in the 1930's (see Results Appendix).

Table 1 presents baseline differences among sample counties in 1930, based on assigned post-Dust Bowl erosion levels.[29] Column 1 presents means for all counties in 1930. Columns 2 and 3 report coefficients from a single regression of each outcome variable on the fraction of a county in medium-erosion and high-erosion, controlling for state fixed effects.[30]

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 high-erosion county and a medium-erosion county. High-erosion and medium-erosion counties were more similar, though high-erosion counties had more cropland allocated to corn.

Measured erosion levels are correlated with county characteristics for two reasons. First, part of the 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 different characteristics may have changed differently after the 1930's, even if the Dust Bowl had not occurred. For example, an increase in the relative price of corn would differentially increase revenues in areas growing more corn.

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erosion categories based on the 1936 map, as they are focused specifically on causes of wind erosion.

[29] 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 the products are not produced).

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

The empirical analysis focuses on specifications that control for differential changes over time that are correlated with the reported county characteristics in 1930 and lagged values of the characteristics. The empirical analysis does not control for county characteristics after 1930, which are potential outcomes of the Dust Bowl. Measured erosion levels continue to predict large decreases in land values when instrumenting for erosion with drought intensity during the 1930's (see Results Appendix).

IV Empirical Framework

The empirical analysis is based on comparing changes in outcomes for counties that were differentially eroded after the Dust Bowl. Outcome Y_{ct} in county c and year t is differenced from its value in 1930, so each coefficient is interpreted as the relative change since 1930.[31] The difference is regressed on the fraction of the county in medium-erosion (M_c) and high-erosion (H_c) areas, a state-by-year fixed effect (α_{st}), pre-Dust Bowl county characteristics (X_c), and an error term (ϵ_{ct}):

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

Note that the effects of erosion and each county characteristic are allowed to vary in each year. The sample is balanced in each regression, i.e., every county included has data in every analyzed period.

Among the included county characteristics are the variables in panels B, C, D, and E of Table 1, and their values for all available pre-1930 periods (see Data Appendix). Each regression also includes as a county characteristic the outcome variable for 1930 and all available pre-Dust Bowl periods. Counties with different pre-1930's outcome levels are thereby allowed to experience systematically different changes after the 1930's.[32]

To interpret the estimated changes as the relative effect of the Dust Bowl, the identification assumption is that counties with different erosion levels would have changed the same if not for the Dust Bowl. In practice, the assumption must hold after controlling for differential changes over each period that are correlated with included pre-Dust Bowl county

[31] The specified regression is a special case, in which the sample is balanced and the regressors are fully interacted with each time period. Differencing the data does not change the difference between estimated β's across time periods; rather, it normalizes the β's relative to zero in 1930. Further, estimation of the regression is completely separable across year pairs, so differencing the data and including county fixed effects yield identical coefficients (as in the case of two time periods). Both methods improve the precision of the estimates by absorbing fixed county characteristics, and the two methods produce slightly different standard errors based on the degree of persistence in the error term. Differencing was done throughout the analysis for ease of interpretation and computational speed.

[32] Alternative models could assume that pre-1930 trends would have continued predictably. Such models appear theoretically inappropriate for asset prices, such as land values, and empirically questionable for other outcomes due to the Depression and subsequent economic changes.

characteristics.

Three other estimation details are worth noting. First, to condense the reported results, the specifications often pool the erosion variables for some combination of later time periods. Pooled estimates amount to averaging the estimated β's for the pooled years, as the control variable effects are allowed to vary in each year.

Second, regressions for agricultural outcomes are weighted by county farmland in 1930 (or an analogous land measure) to estimate the average effect for an acre of farmland. Regressions for labor outcomes are weighted by county population in 1930 to estimate the average effect for a person.

Third, 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 were also estimated for changes in land values from 1930 to 1940 (Conley 1999). The Conley standard errors are similar to standard errors clustered at the county level, indicating that the impact on lands' production potential was not highly spatially correlated.[33]

V Results

V.A Agricultural Land Value and Revenue

Agricultural Land Value. The primary effect of Dust Bowl erosion was to decrease lands' potential for agricultural production, so a natural starting point is an analysis of changes in the per-acre value of farmland. Figure 3 graphs estimated β's from versions of equation (1). Panel A graphs a simplified version of equation (1), including state-by-year fixed effects and no controls for county characteristics. State-by-year fixed effects control for regional differences in agricultural development (e.g., Oklahoma's late statehood) and public policy (e.g., state-wide relief efforts).

Prior to the Dust Bowl, high and medium-erosion counties had higher average per-acre land values than low-erosion counties in the same state. Land values were trending similarly for all county types, particularly from 1920 to 1930. After the Dust Bowl, land values decreased in high- and medium-erosion counties relative to low-erosion counties. Comparing the two lines, land values also decreased in high-erosion counties relative to medium-erosion counties.

Panel B graphs the estimated changes in land values, when also controlling for the effect of

[33] 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 county-clustered standard errors, the percent increase in Conley 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 difficult to weight by county farmland levels, so the comparison is relative to unweighted county-clustered standard errors.

counties' 1930 characteristics in each time period (variables in Panels B through E of Table 1). The control variables capture differences in the intensity of agricultural development (Panel B), population and density of settlement (Panel C), and original suitability of land for different crops (Panel D) or animals (Panel E). Counties that differ along each dimension might be affected differently by subsequent changes in relative prices and technology.

Panel C graphs the estimated changes when also controlling for the above county characteristics in 1925, 1920, and 1910 (when reported, see Data Appendix). The variables capture differential pre-trends in key variables; for example, lagged acres of land in farms (per county acre) reflect when counties were originally settled. Conditional on all covariates, differentially-eroded counties have similar land value levels and trends from 1920 to 1930.

The preferred specification is graphed in Panel D, which controls also for counties' land value in 1930, 1925, 1920, and 1910.[34] By construction, there are no residual pre-Dust Bowl differences by erosion level. 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.

Table 2 (column 1) reports numerical results from estimating equation (1), which correspond to the graphed estimates in Panel D of Figure 3. Panel A reports that, from 1930 to 1940, land values fell by 27.8% in high-erosion counties and 16.7% in medium-erosion counties, relative to low-erosion counties. If 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 land value. Estimates imply that the Dust Bowl erosion imposed an agricultural cost of \$153 million in 1930 dollars (\$1.9 billion in 2007 dollars).[35] If low-erosion counties were also damaged by the Dust Bowl, the estimate 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, the estimate would overstate the total cost.[36] The \$153 million cost represents 0.44% of the decline in GDP from 1930 to 1933 (Historical Statistics

[34]The land value regression also controls for agricultural revenues per-acre in 1930, 1925, 1920, and 1910, as the later analysis combines the land value and revenue specifications in a seemingly unrelated regression framework.

[35]Multiplying 1930 county farmland levels by the share of 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.

[36]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 World War II, while farm output prices increased during the severe droughts from 1934 to 1936.

2006); a relatively small number due to low 1930 land values, as \$153 million also represents the complete loss of an area of farmland the size of Oklahoma.

Panel B reports the estimated change in land values from 1930 to 1945. Column 2 expresses the change as a fraction of the change in land values from 1930 to 1940. The estimated ratios 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 clear *a priori* reason for one of the three relative comparisons to reflect a more or less persistent shock. Taking the efficient weighted average of the three parameters, the average persistence is 76.5%.[37]

Panels C, D, and E report later changes in land values, pooling the estimates over 2, 3, and 4 census periods to summarize the results. There is little indication of a systematic recovery in land values. Persistent land value declines suggest 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. It would be useful to compare changes in land values and agricultural profits, but data are only available for agricultural revenue and equipment capital inputs. 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).

As an alternative, the analysis focuses on agricultural revenue. For a Cobb-Douglas agricultural production function, a productivity decline leads to proportional decreases in profits, revenue, and all inputs. Percent changes in revenues then proxy for percent changes in profits. There are no general theoretical predictions about changes in revenue and inputs because such changes depend on the functional form of the production function, but analyzing changes in inputs will inform the relationship between revenue and profits and provide useful bounds.

Table 2 (column 3) reports changes after 1930 in the per-acre value of agricultural revenue from estimating equation (1). Panel A reports that revenue declined relatively from 1930 to 1940 by 31.6% in high-erosion counties and 20.2% in medium-erosion counties. Panels B to E report the changes in later periods, and column 4 expresses each change 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 lower than in 1930. Over later periods,

[37] The variance-covariance matrix for the three estimates is known, so the efficient average is estimated through GLS (regressing the three values on a constant, weighting by the square root of the inverse of the variance-covariance matrix). Intuitively, the procedure gives more weight to more-precisely estimated coefficients, and less weight to coefficients that are more correlated with another.

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.

Persistence of Short-run Costs. Assume, for now, that the percent changes in revenue reflect percent changes in profits. From the perspective of a farmer in 1940, it is possible to calculate the realized true economic loss as a fraction of the loss if there had been no recovery after 1940. For the realized true economic loss, take the present discounted value of all lost revenue after 1940.[38] For the no-recovery loss, take the PDV of all lost revenue assuming no recovery after 1940. The ratio of the two 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.[39] In theory, the numbers should be similar to the immediate decrease in land price (expected true economic loss) as a fraction of the immediate decrease in land rent or profit (initial per-period economic loss).

The ratio can also be estimated directly by taking the percent decrease in land value from 1930 to 1940 as a fraction of the percent decrease in land revenue from 1930 to 1940. In theory, the percent decrease in land value reflects the true economic loss from the Dust Bowl, anticipating and appropriately discounting the future recovery. Table 2 (column 5) reports the estimated ratio for each relative comparison between erosion levels.[40] Given the theoretical assumptions on land markets and revenue vs. profit, the ratios have a clear structural interpretation: for every 1% lost in the short-run (1940), the true economic loss is between 0.82% and 0.98%, with a weighted average of 0.86%. Theoretically, the ratio should be weakly less than one, though the estimated parameters need not be. Because none is statistically less than one, the estimates fail to reject the hypothesis that long-run adjustments did not mitigate the short-run cost. The coefficients are all statistically greater than zero, which rejects the hypothesis that the short-run cost was associated with no significant PDV cost. If the theoretical assumptions fail to hold, the numbers still have an appealing reduced-form interpretation: the true economic loss (land value) is scaled by the magnitude of the shock (revenue).

The main limitation in interpreting the estimated ratios (from both methods) is the strong assumption that percent changes in revenue approximate percent changes in profits. Percent changes in observed inputs are informative about the difference between revenues and profits, and are obtained by estimating equation (1) for the value of capital machinery and equipment. From 1930 to 1940, capital inputs fell substantially but somewhat less than revenue:

[38] The calculation assumes an interest rate of 5%, linearly interpolates annual values between each census period, and assumes that revenue is constant after 1992.

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

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

22.5% (5.5%) in high vs. low, 12.1% (3.7%) in medium vs. low, and 10.4% (4.8%) in high vs. medium. If all inputs fell by less than revenue from 1930 to 1940, then profits fell by more than revenue and the estimated ratios in column 5 (Table 2) *overstate* the persistence in costs. By contrast, capital inputs recovered after 1940, so profits recovered by less than revenue and the ratios of revenue PDVs *understate* the persistence in costs.[41]

Thus, the differences between percent changes in revenue and profit appear to bias the two estimated ratios in opposite directions. On average, the implied ratio of true economic loss to initial economic loss is between 72% and 86%.[42] Framed differently, the estimates imply that long-run adjustments recovered 14% to 28% of the initial cost (or the true cost if there had been no adjustment).

V.B Adjustment in Agricultural Production

Consistent with persistent agricultural costs, this section presents estimates that suggest adjustment of agricultural production was costly and slow. It appears that some productive adjustments were possible, but adjustments only occurred over long periods of time. Table 3 reports results from estimating equation (1) for several agricultural production decisions.

Total Farmland. Table 3 (column 1) reports estimated changes in the fraction of county land in farms. The extensive margin of farming was fairly stable: immediately after the Dust Bowl, there were no substantial or statistically significant relative changes in farmland. Thus, 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 experienced a gradual small decline in farming, which by the 1950's was lower by a statistically significant 3%. The declines in farming were then largely reversed, however, and medium-erosion counties were relatively unchanged.[43]

Little adjustment in total farmland is consistent with an inelastic supply of land, i.e., an inelastic demand for land in other sectors. The decline in demand for agricultural land would then be reflected mainly in lower land values, rather than decreased farmland.

Growing Crops vs. Raising Animals. Within the agricultural sector, farmers may have reallocated land toward production activities that were less sensitive to soil quality. Higher quality land generally has a comparative advantage in growing crops, as opposed

[41]For high-erosion vs. low-erosion counties, capital inputs decreased from 1930 by 11.8% (4.8%) in 1945, 16.0% (6.0%) in 1969, and 18.7% (6.8%) in 1992. For medium vs. low, capital inputs decreased by 4.1% (3.4%) in 1945, 2.7% (4.1%) in 1969, and 2.0% (4.8%) in 1992. For high vs. medium, capital inputs decreased by 7.6% (4.8%) in 1945, 13.3% (5.1%) in 1969, and 16.7% (5.7%) in 1992; somewhat larger declines in later periods.

[42]The range of estimates from the two approaches is: 76.2% to 88.1% for high-erosion vs. low-erosion, 68.7% to 82.4% for medium-erosion vs. low-erosion, and 89.6% to 98.1% for high-erosion vs. medium-erosion.

[43]The 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 the measure were never greater than 1% of the total land in farms, in either direction.

to raising animals. If erosion reduces the profitability of land for crops by more than for animals, farmland might be converted from cropland to pasture. Such land conversion was expected by contemporaries and was a major goal of government policy, advocated as both good for the farmer and good for society.[44]

The available data on changes in average productivity are consistent with the expectation that profitability of land for crops declined by more than for animals. Note, however, that changes in productivity need not imply changes in profitability.[45] Further, average productivity changes may differ from changes for the marginal unit of land that could be reallocated. Finally, if land allocations adjust, changes in land composition are 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. The measures would overstate the relative decline in crop productivity if farmers in more-eroded counties became more prone to use cropland to feed their own animals.

Table 3, columns 2 and 3, report changes in crop and animal productivity.[46] For high-erosion and medium-erosion counties, crop productivity declined more than animal productivity from 1930 to 1940. The relative decrease only persisted for medium-erosion counties.[47]

However, farmers did not begin systematically shifting cropland to pasture until the 1950's (Table 3, column 4). The estimates are consistent with adjustment costs declining in the long-run. Even when high- and medium-erosion counties shifted land allocations, the magnitudes are small and on the margin of statistical significance. Somewhat larger shifts occurred in high-erosion counties despite weaker evidence of relative productivity differences in later periods, which may reflect poor quality cropland being shifted to pasture.

Growing Wheat vs. Growing Hay. Within cropland allocations, a similar empirical exercise compares changes in the allocation of land to wheat and hay. Wheat and hay are the two widely grown crops for which comparable data are available over a long time period. In contemporaneous and later writings, it was generally recommended that farmers shift land from wheat to hay (or to native grasslands and pasture). Wheat production is more

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

[45]Indeed, later analysis of labor costs suggests that relative profitability did not initially change by as much as relative productivity.

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

[47]Note that there was no relative change in productivity for high-erosion counties relative to medium-erosion counties. The result is consistent with earlier results on land values and revenue in which the high vs. medium shock had more persistent costs, i.e., there may be fewer opportunities to adjust production.

sensitive to soil quality and more likely to cause erosion, while hay is cultivated grass (and an input in the production of animals).

Productivity for each crop is defined as the total quantity produced divided by the total acreage harvested. Data are unavailable in each period for acreage planted, so crop failure would cause the analysis to understate declines in productivity.[48] The same caveats apply as for the analysis of crops vs. animals.

Table 3, columns 5 and 6, report changes after 1930 in wheat and hay productivity.[49] From 1930 to 1940, wheat productivity decreased substantially. In 1950, when hay productivity data are again available, wheat productivity was lower than hay productivity.[50] Wheat productivity recovered substantially after 1964, but it remained relatively lower than hay productivity.

Table 3, column 7, reports that farmers did not begin systematically shifting land from wheat to hay until the 1960's. After 1964, there were substantial and statistically significant declines in the fraction of wheat and hay land allocated to wheat. Note that the reallocation occurs after data becomes unavailable for comparing cropland and pasture, so it is difficult to compare the degree of adjustment along each land-use margin.[51]

Average Farm Size and Land Fallowing. Land allocation adjustment may require the consolidation of farms, particularly if erosion-resistant activities (pasture, hay) are more land-intensive. In addition, larger farms may internalize land protection externalities and lead to increased land fallowing (Hansen and Libecap 2004).

Table 3, column 8, reports that average farm sizes increased by 6% to 10% after 1930. However, farm size increases did not translate into higher land fallowing among more-eroded counties (column 9).[52] There is some evidence that land fallowing declined in more-eroded counties from 1940 to 1945.[53]

[48] Crop failure was particularly extreme in 1934 and 1936, while acres harvested vs. planted are more similar and constant in other periods. For unknown reasons, many counties do not report wheat data for 1940. Restricting the analysis to a balanced panel reduces the sample size by roughly half.

[49] 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.

[50] As in the case for crop and animal productivity, there was less relative change between high- and medium-erosion counties.

[51] Fertilizer use is another potential margin of adjustment, but comparable data are unavailable before and after the Dust Bowl. The land value and revenue calculations should capture the partial recovery of short-run costs due to both observed and unobserved margins of adjustment.

[52] The result is not inconsistent with findings by Hansen and Libecap (2004), which relate more to aggregate increases in land fallowing (Figure 1).

[53] Similar to the previously estimated increases in capital inputs, the increase in cultivation intensity further suggests that the observed percent recovery in agricultural revenues may overstate the percent recovery in profits after 1940.

V.C Potential Explanations for Limited Agricultural Adjustment

This section explores three explanations for the observed slow and limited reallocation of land from crops (to animals) and from wheat (to hay): credit constraints, tenant incentives, and government payments. Among the remaining untested explanations are: prohibitive adjustment costs, convex or declining adjustment costs (e.g., technology spillovers or learning-by-doing), uncertainty about optimal adjustments, and depreciating vintage capital.

Credit Constraints. The Great Depression restricted access to credit. In particular, more-eroded counties lost substantial land value, so land-owning farmers lost potential collateral. Poorly performing local mortgages may have restricted banks' ability to lend. Estimating a modified version of equation (1), high-erosion counties experienced more bank failures during the 1930's than low- or medium-erosion counties (Results Appendix Figure 2A). 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).

Restricted access to credit may have constrained farmers' adjustments in agricultural production. Raising animals requires substantial upfront investment in livestock, and shifting crops may require different machinery. To explore the possibility, a regression is estimated that reports whether counties similarly affected by the Dust Bowl adjusted more if they had more banks prior to the 1930's.[54] The regression modifies equation (1) by adding interaction terms between the log number of banks (B) at the end of 1928 and the fraction of a county in high- and medium-erosion areas:

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

The coefficients of interest are β_{4t} and β_{5t}, which indicate whether counties with more banks adjusted differently than counties with fewer banks. For ease of interpretation, B is normalized to have a mean of zero and a standard deviation of one. The specification also controls for the main effect of banks, and an interaction between banks and each pre-Dust Bowl outcome level.

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, financial development), so it is a strong

[54]Subsequent banking appears to be affected by the Dust Bowl. The results are similar when using the amount of deposits prior to the Dust Bowl.

assumption that other omitted characteristics do not predict differential responses to erosion.

Table 4 (column 1) reports that more-eroded counties with more banks immediately shifted toward greater pasture. By contrast, there was no relative shift from wheat to hay (column 2). Livestock may require greater upfront capital expenditure than the difference between hay and wheat machinery. However, the results must be interpreted cautiously given the potential correlation between banking levels and other characteristics that predict adjustment to erosion.

Tenant Incentives. Land tenants may have inefficiently low incentives to make permanent investments in land, or otherwise adjust production to improve lands' future value. Contemporaries emphasized that tenants' focus was on their crop rather than the land (McDonald 1938). Thus, relatively high land tenancy rates may explain the lack of adjustment.[55]

To explore the possibility, equation (3) is estimated, 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 negative one, to be comparable to the banking results). Table 4, columns 3 and 4, report the results. There is little evidence of tenant farming predicting immediate land adjustment, though perhaps evidence for counties with less tenant farming shifting more land from wheat in later periods.

In 1930, 1940, and 1950, there is data on tenants' and non-tenants' land value, cropland, and equipment. Estimating equation (1) for tenants and non-tenants separately, there is little evidence of differential responses to erosion for the per-acre value of farmland, cropland share of farmland, and per-acre equipment. However, farmland became increasingly allocated away from tenants after the 1940's (Results Appendix Figure 2B). The shift away from tenancy, along with the move toward larger farm sizes, may indicate that long-run adjustment in land-use partly required the reorganization of land ownership. Overall, however, there is little evidence that tenant farming accounts for the limited amount of agricultural adjustment.

Government Payments. Government payment programs increased substantially during the 1930's, and many were targeted toward the agricultural sector. Payments encouraged the continuation of farming, but also some of the analyzed production adjustments.[56] Such policies may have had aggregate effects on the agricultural sector, but they seem unlikely to explain relative adjustments by erosion levels: payments from various observed programs were not targeted toward more-eroded counties, after controlling for state fixed effects and the usual county characteristics (Results Appendix Table 2).

[55] Tenant farmers may also be more credit constrained, but perhaps not if land owners lost substantial capital from lower land values and tenants' assets were more liquid.

[56] Traditional acreage restrictions were not imposed on pasture and hay, though some conservation payments restricted harvesting of hay. Wheat quotas may limit general equilibrium effects by restraining non-eroded counties from increasing wheat production.

Farmers may have expected future payments. Some New Deal programs were temporary, but others were extended or shifted into new forms of payments. Panel B of Appendix Table 2 reports that higher erosion counties did not receive more payments in 1969, but began to in 1974. Higher erosion counties received substantially less in 1987, while total payments were much higher. The estimates likely reflect the 1985 introduction of the Conservation Reserve Program (CRP), which paid farmers to take low-quality and erosion-prone land out of production (and precluded other farm payments). In 1992, more-eroded counties were receiving greater CRP payments, suggesting that counties eroded during the Dust Bowl were still farming worse lands (conditional on pre-1930's characteristics).

V.D Adjustment in Population, Income, and Industry

This section presents estimated changes in population, a proxy for income, and measures of local manufacturing activity. Immediate out-migration was the main margin of adjustment. Equilibrium was reestablished through further population declines, rather than increased industry. Temporarily lower wages and surplus labor may partly account for the observed slow agricultural adjustment.

Population. From 1930 to 1940, population declined relatively by 8.1% in high-erosion counties and 6.5% in medium-erosion counties (Table 5, column 1). Much of the relative decrease reflects aggregate out-migration; by comparison, state-wide populations decreased 3% to 4% in Oklahoma, Kansas, and Nebraska from 1930 to 1940. Estimated relative population declines continued through the 1950's.

Columns 2 and 3 report changes in the fraction of population in rural areas (fewer than 2,500 inhabitants) and living on farms. The overall decline in population did not occur disproportionally from rural or on-farm groups. The widespread population decrease is suggestive of overall economic decline, rather than within-county shifts to industry.[57]

Income Proxy. Direct data on income or wages is unavailable, but per-capita retail sales may serve as a proxy (Fishback et al. 2005). Changes in retail sales differ from changes in income if net savings change, and differ from wage changes if labor supply changes.

Per-capita retail sales declined from 1930 to 1940 by 9.8% and 6.3% in high- and medium-erosion counties (Table 5, column 4), and partly recovered from 1940 to 1958. Notably, the estimated magnitude of recovery in wages is roughly predicted by the population declines from 1940 to 1960. Estimated labor demand elasticities (Borjas 2003) imply that a 10% decrease in population would increase wages by 3% to 4%, or increase income by 6.4% once indi-

[57]In contrast to the standard Roback model outlined above, there may be important spillover effects between agricultural and industry through locally supplied inputs or services. Farmers may also be relatively resistant to migrate. Based on a survey of 1930's migrants to California, Janow and McEntire (1940) report that migrants from most regions were less likely to be from the agricultural sector than those originally in the sending region. Oklahoma migrants were slightly more likely to be from the agricultural sector.

viduals' labor supply adjusts. 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.[58] Thus, the observed recovery in per-capita retail sales could be explained by supply-side adjustment (out-migration), and need not reflect increased labor demand (increased local manufacturing).

Unemployment and Manufacturing. From 1930 to 1940, the unemployment rate increased by 0.71 percentage points in high-erosion counties (Table 5, column 5). The increase was gone by 1950, however, and medium-erosion counties had no increase in unemployment after 1940. Declining populations may have prevented further unemployment, because there is little evidence of an increase in manufacturing.

Table 6 reports estimated changes in the manufacturing sector, for smaller samples of counties with available data. Column 1 (column 2) reports small increases in the fraction of the labor force (population) employed in manufacturing in high-erosion counties.[59] Estimates represent large percent increases in manufacturing employment (11% and 15%), but account for little 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 perhaps later increases. Payroll per-worker declined (column 3), which could reflect declining wages and/or changes in the composition of the labor force.

Columns 4 and 5 report that total manufacturing establishments and value added did not increase following the Dust Bowl, though the coefficients are imprecisely estimated. Perhaps due to the Depression, manufacturing may have been too slow to expand and 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. The pattern of results is similar to estimates by Blanchard and Katz (1992) for state-level responses to labor demand shocks in the second half of the twentieth century.

Interactions with Agriculture. Previous estimates indicated that surplus agricultural labor had not entirely left more-eroded counties by 1940, or switched to other sectors. If overall wages were lower, then agricultural wages would be especially lower if switching sectors was costly. Temporary surplus labor and lower wages may have influenced agriculture.

Indeed, estimates indicate that the agricultural labor-capital ratio increased temporarily.

[58] Wages or incomes need not recover fully in equilibrium, as lower land prices partly compensate workers. The budget share for land is approximated by dividing 7% of the value of one agricultural acre by average per-capita retail sales. The estimated decreases in land values compensate workers for lower income of 2.78% and 1.67% in high- and medium-erosion counties.

[59] The labor force is defined as all workers employed, laidoff, or unemployed and searching.

The ratio is approximated by the number of people living on farms divided by the value of equipment and machinery on farms. Changes in the log of the ratio are estimated by equation (1). In high-erosion counties, the ratio increased after 1930: 14% (4.8%) by 1940, 2% (4.8%) by 1945, and 9% (5.5%) by 1969. In medium-erosion counties the ratio increased temporarily after 1930: 13% (4.1%) by 1940, 4.5% (4.1%) by 1945, and 2.4% (4.3%) by 1969. The estimates may reflect farmers delaying adoption of machinery improvements.

Further, surplus labor and lower wages in the agricultural sector may have delayed adjustment of land from cropland to pasture or from wheat to hay, which can use less labor. It was only in the 1950's, after surplus labor had left and population declines ceased, that agricultural adjustment began to appear along such margins.

VI Conclusion

The 1930's American Dust Bowl imposed substantial costs on Plains agriculture. Adjustment in agricultural land-use was slow and limited, despite evidence of potentially productive adjustments. Estimated changes in land values and revenues imply that the true agricultural cost was 72% to 86% of the initial cost; alternatively, that long-run adjustments recovered only 14% to 28% of the initial cost.

The Dust Bowl provides a detailed context in which to examine economic adjustment to a permanent change in environmental conditions. In this historical context, overlapping the Great Depression, adjustment may have been slowed by limited access to capital. Historical US labor markets are also known for high geographic labor mobility, relative to internal mobility in other countries and cross-country mobility. The experience of the American Dust Bowl highlights that agricultural costs from environmental destruction need not be mostly mitigated by agricultural adjustments, and that mass migration may result. Further research on historical shocks may help understand what conditions facilitate long-run adjustment.

References

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

Ashcraft, A. 2005. "Are Banks Really Special? New Evidence from FDIC-induced Failures of Healthy Banks." *AER*, 95(5)1712-1730.

Bernanke, B. 1983. "Nonmonetary Effects of the Financial Crisis in the Propagation of the Great Depression." *AER*, 73(3)257-276.

Blanchard, O., and L. Katz. 1992. "Regional Evolutions." *BPs on Econ Activity*, 1992(1)1-61.

Bloom, N., S. Bond, and J. Van Reenen. 2007. "Uncertainty and Investment Dynamics." *Review of Economic Studies*, (74)391-415.

Borjas, G.. 2003. "The Labor Demand Curve *is* Downward Sloping: Reexamining the Impact of Immigration on the Labor Market." *QJE*, 118(4)1335-74

Boustan, L., P. Fishback, and S. Kantor. 2008. "The Effect of Internal Migration on Local Labor Markets: American Cities During the Great Depression." Mimeo.

Bresnahan, T. and V. Ramey. 1993. "Segment Shifts and Capacity Utilization in the U.S. Automobile Industry." *AER*, 83(2)213-218.

Calomiris, C., and J. Mason. 2003. "Consequences of Bank Distress during the Great Depression." *AER*, 93(3)937-947.

Carrington, W. 1996. "The Alaskan Labor Market during the Pipeline Era." *JPE*, 104(1)186-218.

Chari, V. and H. Hopenhayn. 1991. "Vintage Human Capital, Growth, and the Diffusion of New Technology." *JPE*, 99(6)1142-1165.

Chepil, W., F. Siddoway, and D. Armbrust. 1962. "Climatic Factor for Estimating Wind Erodibility of Farm Fields." *Journal of Soil and Water Conservation*, (17)162-165.

Chetty, R., J. Friedman, T. Olsen, and L. Pistaferri. 2009. "The Effect of Adjustment Costs and Institutional Constraints on Labor Supply Elasticities: Evidence from Denmark." Mimeo.

Conley, T. 1999."GMM estimation with cross sectional dependence."*J of Econometrics*,(92)1-45

Cunfer, G. 2005. <u>On the Great Plains: Agriculture and Environment</u>. Texas A&M Press.

Cutler, D., G. Miller, and D. Norton. 2007. "Evidence on early-life income and late-life health from America's Dust Bowl era." *PNAS*, 104(33)13244-13249.

Davis, D., and D. Weinstein. 2002. "Bones, Bombs, and Break Points: The Geography of Economic Activity." *AER*, 92(5)1269-1289.

Dell, M., B. Jones, and B. Olken. 2009. "Climate Shocks and Economic Growth: Evidence from the Last Half Century." April, Mimeo.

Deschenes, O. and M. Greenstone. 2007. "The Economic Impacts of Climate Change: Evidence from Agricultural Output and Random Fluctuations in Weather." *AER*, 97(1)354-385.

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

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

Duflo, E. 2004. "The medium run effects of educational expansion: evidence from a large school construction program in Indonesia." *JDE*, (74)163-197.

Fisher, A., M. Hanemann, M. Roberts, and W. Schlenker. 2009. "Climate change and agriculture reconsidered." Mimeo.

Fishback, P., W. Horrace, and S. Kantor. 2005. "Did New Deal Grant Programs Stimulate Local Economies? A Study of Federal Grants and Retail Sales During the Great Depression." *JEH*, 65(1)36-71.

Foster, A., and M. Rosenzweig. 1995. "Learning by Doing and Learning from Others: Human Capital and Technical Change in Agriculture." *JPE*, 103(6)1176-1209.

Griliches, Z. 1957. "Hybrid Corn: An Exploration in the Economics of Technical Change." *Econometrica*, 25(4)501-522.

Guiteras, R. 2009. "The Impact of Climate Change on Indian Agriculture." Mimeo.

Gutmann, M. 2005. *Great Plains Population and Environment Data: Agricultural Data*, ICPSR.

Haines, M. 2005. *Historical, Demographic, Economic, and Social Data: US, 1790-2000*, ICPSR.

Hansen, Z. 2005. "Book Review of On the Great Plains," *JEH*, 65(4)1162-1163.

Hansen, Z. and G. Libecap. 2004. "Small Farms, Externalities, and the Dust Bowl of the 1930s." *JPE*, 112(3)665-694.

Historical Statistics of the United States, 2006. http://hsus.cambridge.org

Hornbeck, R. 2009. "Barbed Wire: Property Rights and Agricultural Development." Forth. *QJE*.

Hoyt, J. 1936. "Droughts of 1930-1934." Water-Supply Paper 680, U.S. GPO.

Hurt, D. 1981. The Dust Bowl: An Agricultural and Social History. Nelson Hall, Chicago.

--. 1985. "The National Grasslands: Origin and Development in the Dust Bowl," in The History of Soil and Water Conservation, eds. D. Helms and S. Flader, pp.144-157.

Janow, S., and D. McEntire. 1940. "The Migrants: Migration to California." *Land Policy Review*, July-August, pp. 24-36.

Leuchtenburg, W. 1963. Franklin D. Roosevelt and the New Deal, 1932-1940. H&R, NY.

Margo, R. 1997. “Wages in California during the Gold Rush.” NBER Historical WP 101.

McDonald, A. 1938. “Erosion and its Control in Oklahoma Territory.” SCS Misc Pub 301, GPO.

Mendelsohn, R., W. Nordhaus, and D. Shaw. 1994. "The impact of global warming on agriculture: A Ricardian analysis." *AER*, 84(4)753-771.

Miguel, E., and G. Roland. 2006. “The Long Run Impact of Bombing Vietnam.” Mimeo

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, S. 2007. This Land, This Nation. Cambridge University Press.

Rasmussen, W. and G. Baker. “Price-Support and Adjustment Programs From 1933 Through 1978: A Short History.” Agricultural Info Bulletin No. 424, Dept. of Ag., GPO.

Redding, S., and D. Sturm. 2008. “The Costs of Remoteness: Evidence from German Division and Reunification.” *AER*, 98(5)1766-1797.

Roback, J. 1982. “Wages, Rents, and the Quality of Life.” *JPE*, 90(6)1257-1278.

Rosenzweig, M., and K. Wolpin. 2000. “Natural ‘Natural Experiments’ in Economics.” *JEL*, 38(4)827-874.

Saloutos, Theodore. 1982. The American Farmer and the New Deal. Iowa State Press.

Schlenker, W. and M. Roberts. 2009. "Nonlinear temperature effects indicate severe damages to U.S. crop yields under climate change." Proceedings of NAS, 106(37)15594-98.

Scheffer, M., S. Carpenter, J. Foley, C. Folke, and B. Walker. 2001. "Catastrophic shifts in ecosystems," *Nature*, (413)591-596.

Science. 1934. “The Recent Destructive Dust Cloud.” New Series, 79(25)473.

SCS. 1935. “Soil Erosion: A Critical Problem in American Agriculture.” GPO.

--. 1937. “Soil Conservation Districts for Erosion Control.” Misc. Pub 293, GPO.

--. 1955. “Facts About Wind Erosion and Dust Storms on the Great Plains.” Leaflet 394, USDA.

Sutch, R. 2008. "Henry Agard Wallace, the Iowa Corn Yield Tests, and the Adoption of Hybrid Corn," NBER WP 14141.

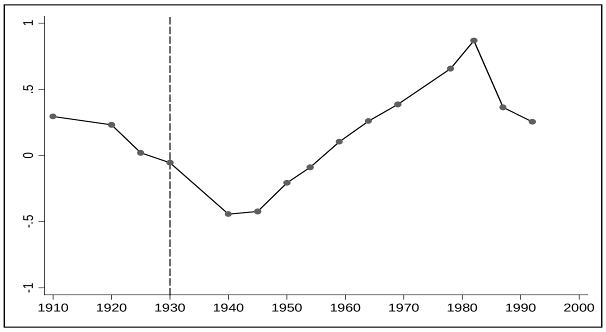
USDA. 1940. “The Dust Bowl: Agricultural Problems and Solutions,” Ed. Ref. No. 7 July 15.

Wallace, H. 1938. “Forward” in Soils and Men: Yearbook of Agriculture. USDA.

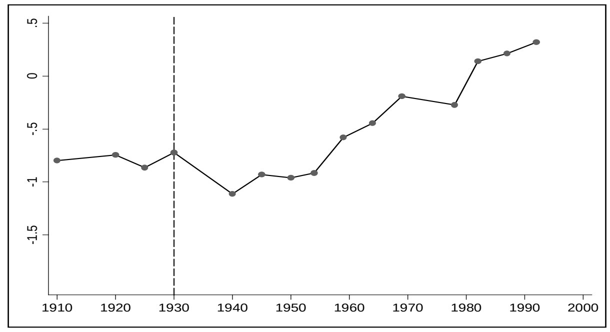
Worster, D. 1979. Dust Bowl: The Southern Plains in the 1930s. Oxford University Press.

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

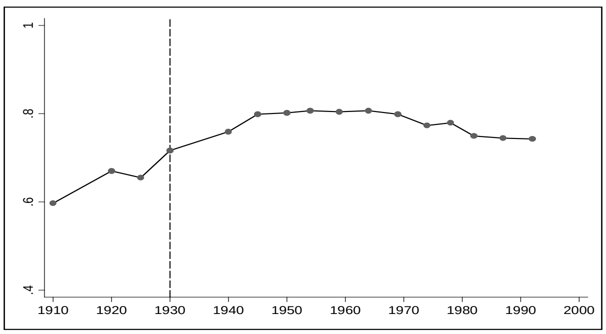
A. Farmland Value, per farm acre (Log/CPI)



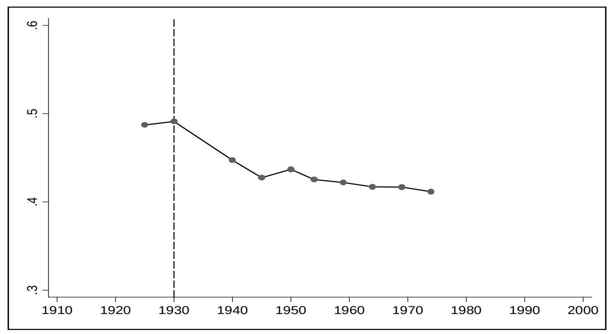
B. Ag Revenue, per farm acre (Log/PPI)



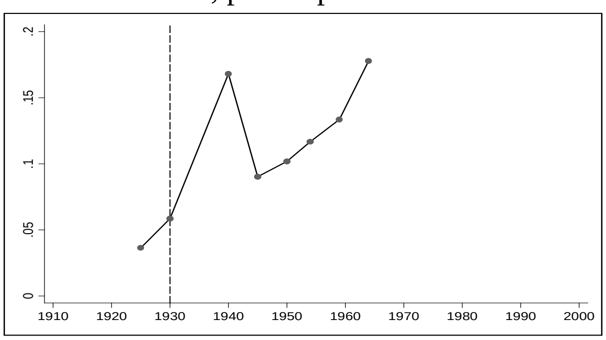
C. Farmland Acres, per county acre



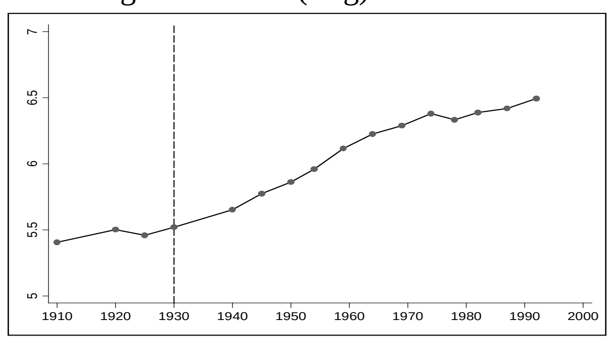
D. Cropland Acres, per farm acre



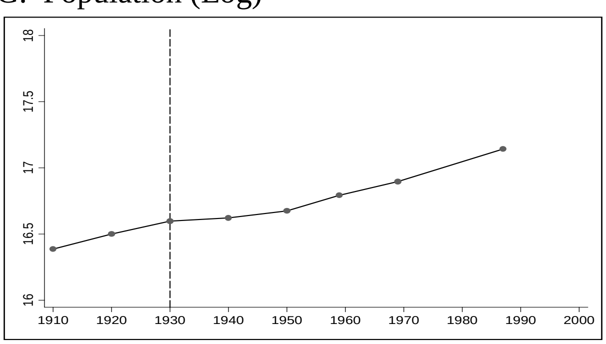
E. Fallow Acres, per cropland acre



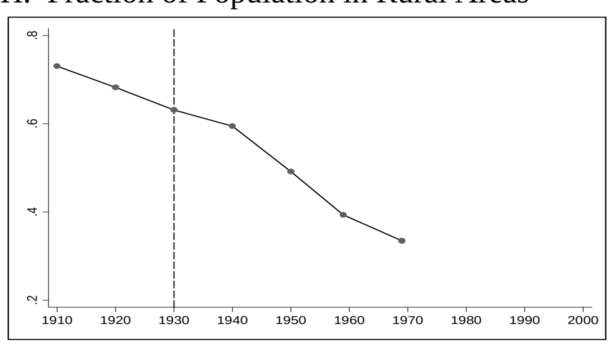
F. Average Farm Size (Log)



G. Population (Log)

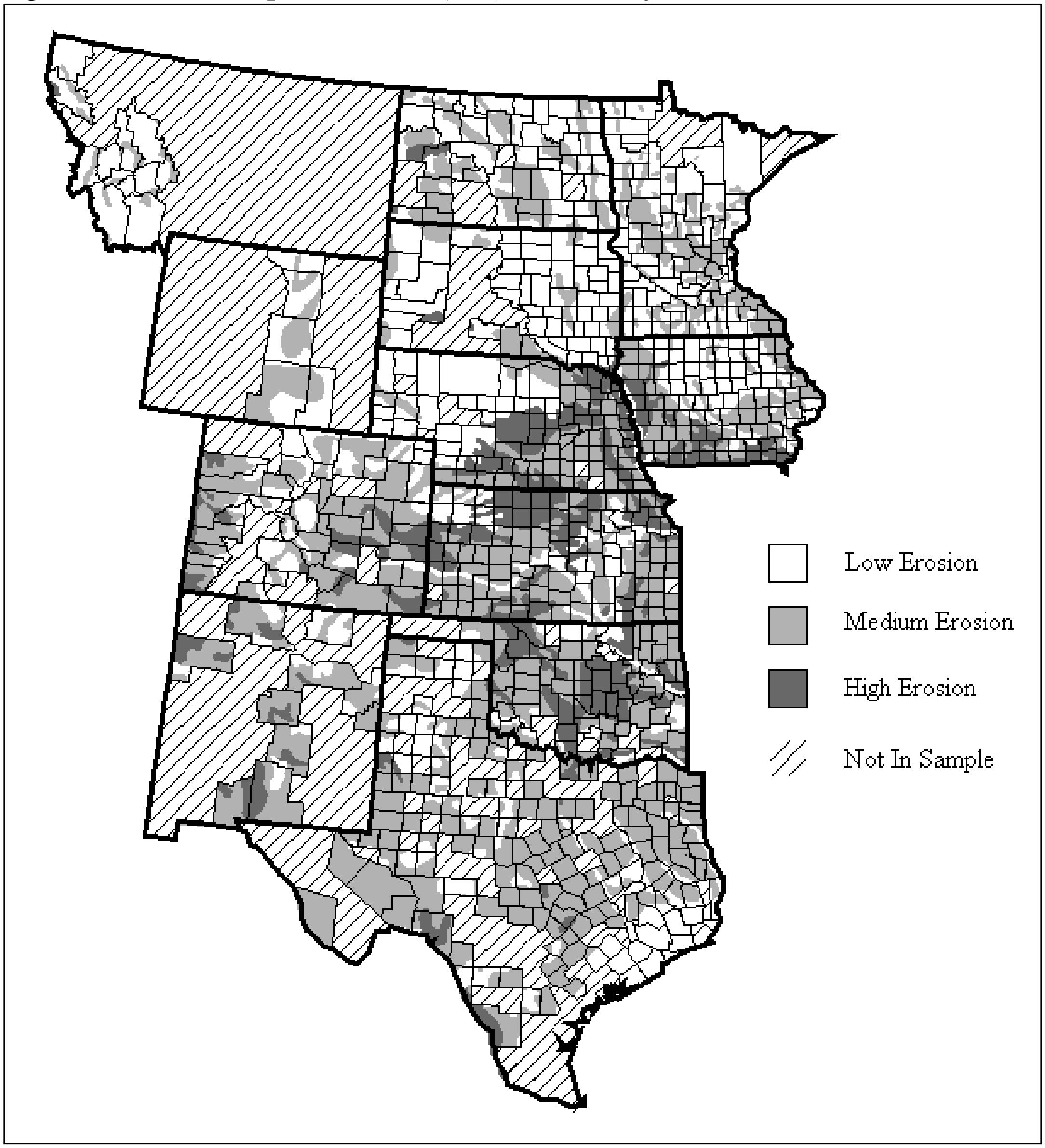


H. Fraction of Population in Rural Areas



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.

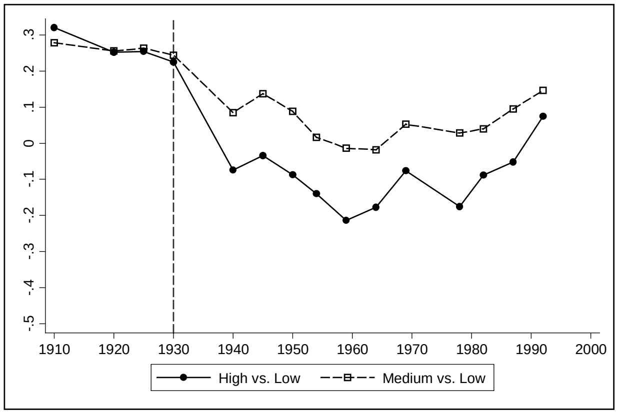
Figure 2. Main Sample Counties (769), Shaded by Erosion Level



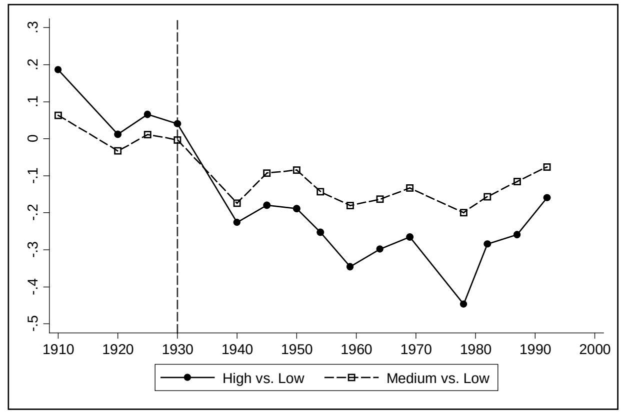
Notes: Mapped erosion levels are indicated as low (less than 25% of topsoil lost), medium (25%-75% of topsoil lost and may have some gullies), or high (more than 75% of topsoil lost and may have numerous or deep gullies). Thin lines denote 1910 county borders, corresponding to the main sample of 769 counties described in Table 1. Thick lines denote state boundaries. Crossed out areas are not in the sample. Source: National Archives (College Park, MD), RG 114, Cartographic Records of the Soil Conservation Service, #149.

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

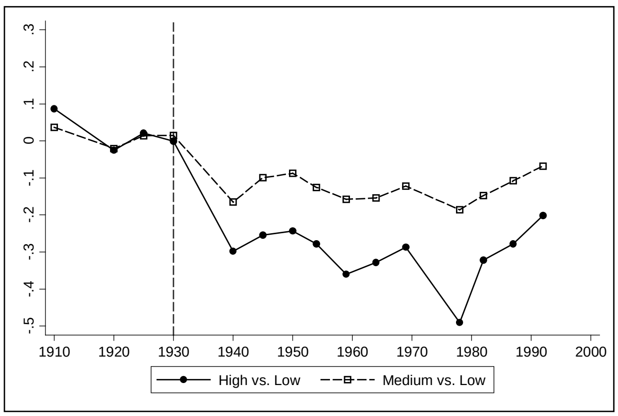
A. State-by-Year Fixed Effects



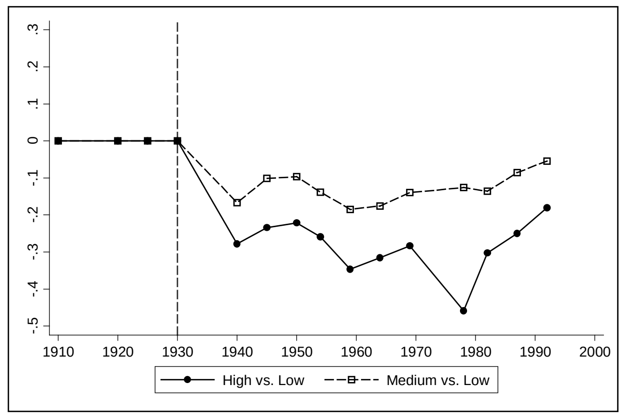
B. 1930 County Characteristics + (A)



C. Lagged County Characteristics + (B)



D. Lagged Outcome Variable + (C)



Notes: Each panel graphs the estimated coefficients (β) from versions of 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. In Panel A, these coefficients are estimated by regressing the per-acre value of farmland on the fraction of a county in a high erosion area (solid circle) and the fraction of a county in a medium erosion area (hollow square), controlling for state-by-year fixed effects. Panel B also includes as controls the interaction between each year and each county characteristic in panels B – E of Table 1. Panel C also includes as controls the interaction between each year and the available lagged values of each county characteristic in panels B – E of Table 1 (see Data Appendix). Panel D also includes as controls the interaction between each year and the outcome variable for each lagged year.

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

		Relative to Low Erosion:		
	All Counties	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				
Cattle, per county acre	0.056	0.011**	0.013**	0.003
	[0.033]	(0.003)	(0.004)	(0.003)
Swine, 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 reports average values for the 769 main 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 regression that regresses the indicated county characteristic in 1930 on the fraction 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. Estimated 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: (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 estimates from equation (1) in the text; Column 1 corresponds to panel D of Figure 3, where the coefficients are pooled across the indicated years. Columns 2 and 4 report the estimated change, as a fraction of the change from 1930 to 1940. Reported in parentheses are robust standard errors clustered by county.

Table 3. Estimated Changes After 1930 in Agricultural Production, by Erosion Level

Erosion Level:	Farmland Share (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
Counties	769	769	769	769	388	388	388	769	587
Weight by 1930	Farmland	Cropland	Pasture	(2) + (3)	Wheat	Hay	(5) + (6)	Farmland	Farmland

Notes: For each outcome variable, the column reports estimates from equation (1) in the text and panel D of Figure 3. Each regression is weighted by the 1930 value for the indicated land unit. Reported in parentheses are robust standard errors clustered by county. ** statistical significance at the 1% level, * at 5%.

Table 4. Estimated Changes in Land-use after 1930, Interacted with County Pre-Characteristics

	Relative Adjustment in Areas with:			
	More Banks		Less Tenant Farming	
	Land Share in Crops	Land Share in Wheat	Land Share in Crops	Land Share in Wheat
Erosion Level:	(1)	(2)	(3)	(4)
High - Low				
1940	-0.041**	0.014	0.013	0.020
	(0.015)	(0.019)	(0.010)	(0.018)
1945	-0.049**		0.002	
	(0.017)		(0.012)	
1950 – 1954	-0.069**	-0.016	0.013	-0.048*
	(0.019)	(0.021)	(0.015)	(0.020)
1959 – 1964	-0.073**	0.000	0.013	-0.026
	(0.020)	(0.021)	(0.017)	(0.021)
Medium - Low				
1940	-0.017**	-0.012	0.005	0.009
	(0.006)	(0.013)	(0.006)	(0.014)
1945	-0.024**		-0.007	
	(0.007)		(0.008)	
1950 – 1954	-0.013	-0.010	-0.016	-0.056**
	(0.008)	(0.018)	(0.010)	(0.018)
1959 – 1964	-0.021*	-0.007	-0.015	-0.057**
	(0.011)	(0.017)	(0.013)	(0.019)
R-squared	0.7456	0.4808	0.7280	0.4962
Sample Counties	698	698	698	698
Weighted by 1930 Value of:	Cropland plus Pasture	Wheat plus Hay	Cropland plus Pasture	Wheat plus Hay

Notes: For the indicated outcome variable, each column reports estimates from equation (2) in the text. For columns 1 and 2, the reported coefficients are from the interaction term: adjustment to erosion in areas with more banks in 1928, relative to the adjustment in areas with fewer banks. Columns 3 and 4 report the analogous coefficients, but for the tenant share of farmland in 1930 (instead of banks). The log number of banks is normalized to have mean zero and standard deviation one, the tenant share of farmland is normalized to have mean zero and standard deviation (negative) one. Reported in parentheses are robust standard errors clustered by county. ** statistical significance at the 1% level, * at 5%.

Table 5. Estimated Changes After 1930 in Population Outcomes, by Erosion Level

Erosion Level:	Log Population (1)	Fraction Rural (2)	Fraction on Farm (3)	Log Retail Sales per-capita (4)	Unemployment Rate (5)
High - Low					
1940	-0.081**	-0.0118	0.0159	-0.098**	0.0071*
	(0.021)	(0.0090)	(0.0095)	(0.029)	(0.0034)
1950	-0.108**	-0.0115	0.0204*		-0.0031
	(0.041)	(0.0157)	(0.0095)		(0.0020)
1960	-0.148*	-0.0165		-0.058	
	(0.064)	(0.0199)		(0.031)	
1970	-0.157	0.0084	0.0334**	-0.034	
	(0.080)	(0.0225)	(0.0121)	(0.039)	
1990	-0.127		0.0120	-0.059	
	(0.109)		(0.0081)	(0.053)	
Medium - Low					
1940	-0.065**	-0.0102	0.0000	-0.063**	-0.0016
	(0.020)	(0.0075)	(0.0049)	(0.022)	(0.0025)
1950	-0.108**	-0.0065	0.0077		-0.0007
	(0.035)	(0.0126)	(0.0070)		(0.0017)
1960	-0.170**	-0.0144		0.005	
	(0.055)	(0.0157)		(0.021)	
1970	-0.180*	-0.0094	-0.0027	0.033	
	(0.072)	(0.0181)	(0.0096)	(0.028)	
1990	-0.160		0.0004	0.011	
	(0.103)		(0.0065)	(0.042)	
R-squared	0.5954	0.4558	0.9451	0.9749	0.8550
Counties	769	769	769	758	769

Notes: For the indicated outcome variable, each column reports estimates from equation (1) in the text and described in the notes to Panel D of Figure 3. All regressions are weighted by county population in 1930. Reported in parentheses are robust standard errors clustered by county. ** statistical significance at the 1% level, * at 5%. Retail sales data is available in 1958, 1967, 1987 (and is divided by population in 1960, 1970, 1990)

Table 6. Estimated Changes After 1930 in Manufacturing Outcomes, by Erosion Level

	Workers per-labor force (1)	Workers per-capita (2)	Log Payroll per-worker (3)	Log Establishments (4)	Log Value Added (5)
1930 Mean:	0.0628	0.0262			
	[0.0629]	[0.0276]			
Erosion Level:					
High - Low					
1940	0.0072	0.0040	-0.050	0.022	0.108
	(0.0041)	(0.0021)	(0.067)	(0.069)	(0.145)
1945			-0.049	-0.078	0.003
			(0.062)	(0.066)	(0.183)
1950					
1954			-0.095	-0.137	-0.138
			(0.069)	(0.078)	(0.247)
1958 (-1964)		0.0036	-0.130*	-0.126	-0.058
		(0.0061)	(0.060)	(0.080)	(0.261)
1967 (-1974)		0.0024	-0.209*	-0.014	-0.226
		(0.0093)	(0.104)	(0.099)	(0.259)
1978 (-1982)			-0.043	-0.036	-0.443
			(0.110)	(0.110)	(0.494)
1987 (-1992)		0.0050	-0.077	-0.044	0.157
		(0.0109)	(0.065)	(0.129)	(0.362)
Medium - Low					
1940	0.0000	0.0005	-0.131**	-0.080	-0.127
	(0.0035)	(0.0020)	(0.049)	(0.049)	(0.111)
1945			-0.116**	-0.011	0.003
			(0.040)	(0.047)	(0.128)
1950					
1954			-0.092*	-0.037	-0.041
			(0.045)	(0.058)	(0.182)
1958 (-1964)		0.0063	-0.106*	-0.100	-0.111
		(0.0047)	(0.044)	(0.062)	(0.178)
1967 (-1974)		0.0131	-0.073	-0.060	-0.153
		(0.0076)	(0.046)	(0.079)	(0.187)
1978 (-1982)			-0.080	-0.061	0.022
			(0.072)	(0.093)	(0.338)
1987 (-1992)		0.0250**	-0.065	-0.045	-0.087
		(0.0075)	(0.045)	(0.109)	(0.263)
R-squared	0.5803	0.9203	0.9906	0.5754	0.9456
Sample Counties	550	336	257	551	275

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

Data Appendix

The sample is restricted to Plains counties that have data on: land values, revenue, and farmland from 1910 to 1992; cropland from 1925 to 1974; population and rural population from 1910 to 1969. A small number of counties are excluded that have less than 1000 acres of farmland and extreme infeasible outcome values that reflect measurement error. The main reasons counties are dropped from the sample are: insufficiently settled by 1910 for reported data; unavailable Gutmann data for 1925; agricultural revenue unavailable from 1920-1930; and border adjustments left data unavailable for any piece of a county that covered more than 1% of the county's original area. Variable Definitions and Available Years of Data:

County Acres. Acres in each county, held fixed at 1910 borders.

Farmland. Acres of land in farms, including: cropland, pasture, woodland not used for pasture, and "other." 1910, 1920, 1925, 1930, 1940, 1945, 1950, 1954, 1959, 1964, 1969, 1974, 1978, 1982, 1987, 1992.

Cropland. Acres of cropland: cropland harvested, failed cropland, fallow land (does not include pasture that could be used for crops without improvement). 1925-1974.

Fallow Land. Land in cultivated fallow, not harvested (Hansen & Libecap 2004). 1925-1964.

Pasture. Acres of pasture, including land used for pasture that could be used for crops without further improvement. 1925-1964.

Wheat Land. Harvested acres of wheat, prior year. 1910-1997 (restricted sample).

Hay Land. Harvested acres of hay, prior year. 1910-1997, except 1945 (restricted sample).

Other Crops. Harvested acres of other types of crops, included separately as controls for 1925 and 1930 (Missing values are treated as zeros; total cropland only available back to 1925). Land harvested twice is counted twice, and reflects the prior year.

Cattle, Swine, Chickens. Numbers of each in 1910-1930, or 1920-1930 (Chickens).

Land Value. The value of farmland, including buildings and improvements attached to the land (excluding implements and machinery). 1910-1992, except 1974. Data include the average value of a farm and the average value of a farm acre (the two begin to differ slightly after 1950, when the census began to sample farms). Total values are calculated from each measure, and the average of the two is used (oversampling large farms will tend to bias the averages in opposite directions). Results are not sensitive to using either measure. The value of land only (not buildings) is available in 1910, 1920, 1930, 1940.

Revenue. Crop revenue and animal revenue (double-counts intermediate products, i.e., it is not value added). 1910-1992, except 1974.

Crop Revenue. Value of all crops sold, prior year. 1910-1964.

Animal Revenue. Value of all animal products and animals sold, prior year. 1910-1964. From 1920 to 1930, revenue is not directly reported; only the total value of animals is reported.

The ratio of animal revenue to total value of animals (stock) is calculated for each county in 1910 and 1940 and used to impute animal revenue from 1920 to 1930. Results are not sensitive to using the revenue/stock ratio in 1910 or 1940. Reported estimates use a weighted average (1910 ratio weighted two-thirds in 1920, one-half in 1925, one-third in 1930).

Wheat Output. Bushels of wheat harvested, prior year. 1910-1997.

Hay Output. Tons of hay harvested, prior year. 1910-1997, except 1940-1945.

Capital. Market value of machinery and equipment used on the farm, regardless of owner. 1910-1945, 1969, 1992.

Population. Total population. 1910, 1920, 1930, 1940, 1950, 1960, 1970, 1990, 2000.

Rural Population. Population living in areas with fewer than 2500 inhabitants. 1910-1970.

Farm Population. Population living on farms. 1930, 1940, 1945, 1950, 1970, 1990.

Number of Farms. Number of farms, 1910-1992.

Retail Sales per-capita. Sales in the retail sector. 1930, 1940, 1958, 1967, 1987.

Labor Force. Workers employed, laid-off without pay (excluding sick or idle), or unemployed and searching for a job. 1930, 1940, 1950.

Unemployed. Workers unemployed or laid-off. 1930, 1940, 1950.

Manufacturing Workers, per capita. 1920, 1930, 1940, 1958, 1967, 1987.

Mfg Outcomes. Payroll per-worker, establishments, value added. 1920-1992, except 1950.

Number of Banks. Number of active banks at year end. 1920-1936, annually.

Tenant Farmland. Farmland share operated by tenants. 1910-1992, except 1954 and 1960.

Results Appendix

Estimated changes in land values provide opportunities to explore the validity of the erosion measure. Some of the measured erosion damage occurred prior to the 1930's; if counties with different baseline erosion levels would have changed differently, the differential changes would be confounded with the estimated impact of the Dust Bowl. Appendix Figure 1 compares estimated relative changes in land values for more more-eroded counties in Plains and non-Plains states.[60] Panel A (panel B) graphs the estimated difference in land values between high- (medium-) and low-erosion counties, controlling for state-by-time fixed effects.[61]

Before 1930, more-eroded Plains counties had relatively higher land values than in non-Plains states; as expected because Plains counties had yet to experience much of their measured erosion. After the Dust Bowl, more-eroded counties' land values fall sharply only in the Plains. The estimates imply that measured erosion captures Dust Bowl erosion on the

[60]The nationwide map of cumulative erosion indicates many severely eroded areas outside the Plains, where the Dust Bowl did not cause additional erosion.

[61]Control variables are unavailable for all non-Plains counties. The sample includes Plains and non-Plains counties with available land value data in each period: 867 Plains and 1840 non-Plains counties.

Plains, while counties with baseline erosion differences changed similarly in other regions.

A related concern is that observed erosion levels partly reflect counties' land-use, both prior to 1930 and during the Dust Bowl. Estimated declines in land values would be negatively biased if farmers in counties otherwise becoming less valuable did not protect land from Dust Bowl erosion. Estimates would be positively biased if counties otherwise becoming more valuable were farmed more intensely, causing 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 during the 1930's (the worst recorded Plains drought). Appendix Table 1 presents estimates when instrumenting for erosion levels using the number of months during the 1930's that a county was in extreme drought, severe drought, moderate drought, average drought levels and annual temperature in the 1930's, and the standard deviation of temperatures in the 1930's.[62] The specifications control for the drought and temperature variables from 1895 to 1929.

The identifying assumption is that 1930's weather was not correlated with changes in land values, aside from its impact through erosion. The instruments are sometimes correlated with pre-1930's county characteristics, so specifications continue to control for the characteristics and state-by-year fixed effects. Temporary weather shocks should have limited effects on land values, though the exclusion restriction would likely fail for other county outcomes.

Appendix Table 1, columns 1 and 2, report first-stage results. Column 1 reports estimates from regressing the fraction of a county in high-erosion on the instruments and controls: erosion is greater in counties with more months of extreme drought, and a weaker effect in counties with more severe drought. Medium-erosion is predicted more by moderate drought (column 2). The instruments are jointly significant, but the explanatory power is not high.[63]

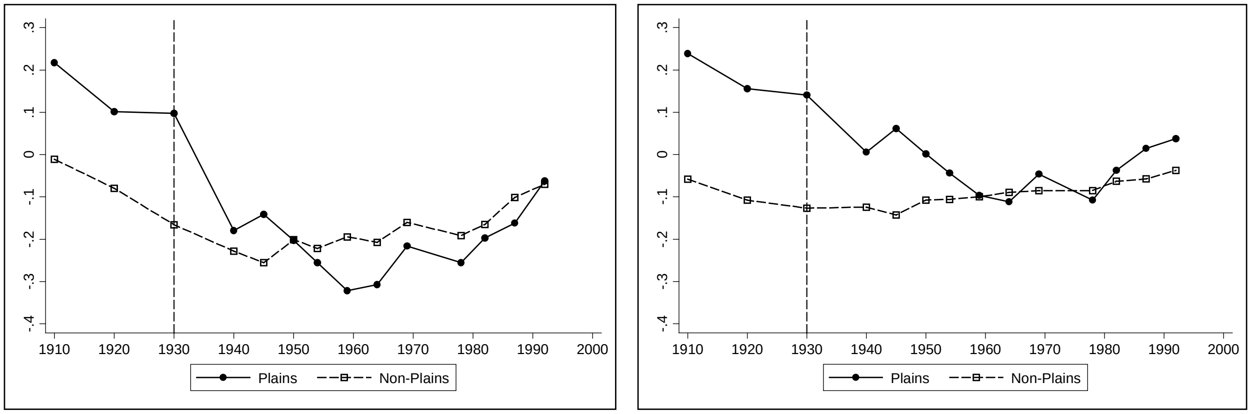
Column 3 reports estimated relative changes in land values from 1930 to 1940, instrumenting for erosion levels with the 1930's weather variables. Column 4 presents OLS results for the same sample and controls. When instrumenting, higher erosion counties experienced a larger relative decline in land values (70% instead of 27%) and medium-erosion counties experienced a similar relative decline (19% vs. 17%). Any 2SLS bias may be blown up by weak instruments, but the first-stage and implied reduced-form results are clearer: 1930's weather predicts both erosion and declining land values from 1930 to 1940. The results are consistent with measured erosion levels proxying for Dust Bowl erosion.

[62]Drought is measured by the Palmer Drought Index, which varies with the arrival of rainfall and loss of moisture. Extreme, severe, and moderate reflect conventional Index cutoffs. High and extreme temperatures contribute to drought and crop failure. Data were collected at weather stations, and the PDI is reported by district (10 districts to a state), see ftp://ftp.ncdc.noaa.gov/pub/data/cirs/

[63]Direct measures of soil characteristics and susceptibility to erosion are only available in the modern era, and may be an outcome of Dust Bowl erosion.

Appendix Figure 1. Changes in Land Value, Plains Counties vs. Non-Plains Counties

A. High - Low Erosion B. Medium - Low Erosion



Notes: estimates in both panels are from the specification in Panel A of Figure 3, estimated separately for Plains (Figure 2) and non-Plains states. Panel A reports the difference between high and low erosion counties; Panel B the difference between medium and low erosion counties. (867 Plains counties, 1840 non-Plains counties)

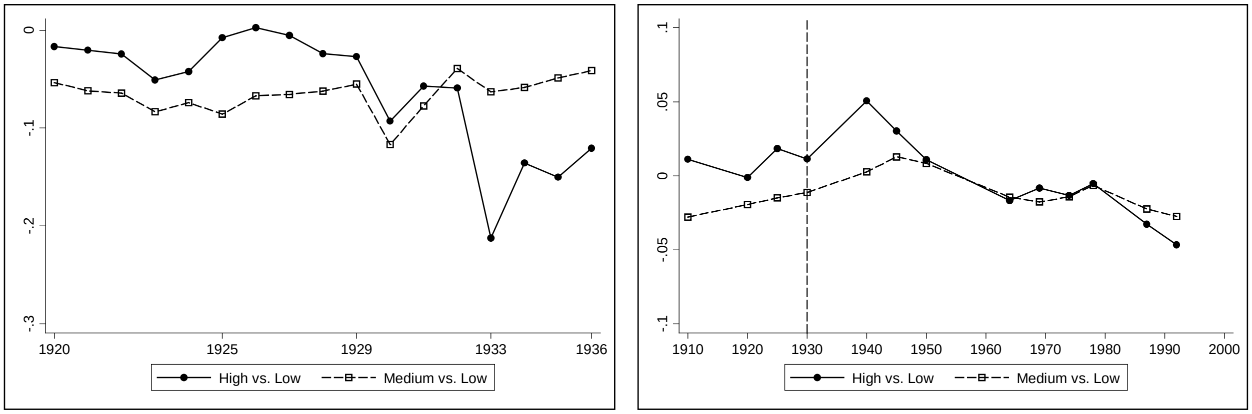
Appendix Table 1. Instrumental Variables Estimate for Change in Land Value, 1930-1940

	First-Stage:		2SLS:	OLS:
	Fraction of County in High Erosion (1)	Fraction of County in Medium Erosion (2)	Change in Land Value, 1930-1940 (3)	Change in Land Value, 1930-1940 (4)
Erosion Level:				
High - Low			-0.698**	-0.269**
			(0.180)	(0.041)
Medium - Low			-0.193	-0.165**
			(0.114)	(0.031)
Instruments:				
Months in Extreme Drought, 1930s	0.0075**	0.0053		
	(0.0021)	(0.0032)		
Months in Severe Drought, 1930s	0.0033*	0.0071**		
	(0.0016)	(0.0022)		
Months in Moderate Drought, 1930s	-0.0009	0.0077**		
	(0.0016)	(0.0025)		
Average Palmer Drought Severity Index, 1930s	0.1017**	0.2028**		
	(0.0332)	(0.0616)		
Average Annual Temperature, 1930s	-0.0176	0.0939*		
	(0.0286)	(0.0419)		
Standard Deviation of Temperature, 1930s	0.1328**	0.1891**		
	(0.0441)	(0.0787)		
F-stat: Instruments	6.04	4.98		
P-value: Instruments = 0	0.0000	0.0001		
Sample Counties	766	766	766	766

Notes: Column 1 reports first-stage estimates from regressing the fraction of a county in high erosion areas on the instruments, controlling for the same variables from 1895-1929 and the controls in Table 2. Column 2 reports analogous estimates for the fraction 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 variables in columns 1 and 2 and instrumenting for erosion levels with the reported instruments. Column 4 reports OLS estimates (as in Table 2), with the same controls and sample. Robust standard errors are reported in parentheses. ** statistical significance at the 1% level, * at 5%.

Appendix Figure 2. Estimated Changes after 1930 in:

A. Number of Active Banks (Log) B. Tenant Share of Farmland



Notes: These figures graph the estimated coefficients (β) from a modified version of equation (1), described in Panel C of Figure 3. Banking data is available annually, so the regression in Panel A controls for state-by-year fixed effects and county characteristics interacted with every year.

Appendix Table 2. Government Program Payments per farm acre, by Erosion Level

		Relative to Low Erosion:		
	All Counties	Med. Erosion	High Erosion	(3) – (2)
	(1)	(2)	(3)	(4)
Panel A. New Deal payments (1933-39)				
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)
CRP payments, 1992	1.571	0.750**	1.776**	1.026**
	[1.490]	(0.162)	(0.263)	(0.245)
Fraction of money from CRP, 1992	0.217	0.089**	0.185**	0.096**
	[0.149]	(0.018)	(0.027)	(0.023)

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