American Economic Review 2012, 102(4): 1477–1507
http://dx.doi=10.1257/aer.102.4.1477

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

By Richard Hornbeck*

The 1930s American Dust Bowl was an environmental catastrophe that greatly eroded sections of the Plains. The Dust Bowl is estimated to have immediately, substantially, and persistently reduced agricultural land values and revenues in more-eroded counties relative to less-eroded counties. During the Depression and through at least the 1950s, there was limited relative adjustment of farmland away from activities that became relatively less productive in more-eroded areas. Agricultural adjustments recovered less than 25 percent of the initial difference in agricultural costs for more-eroded counties. The economy adjusted predominantly through large relative population declines in more-eroded counties, both during the 1930s and through the 1950s. (*JEL* N32, N52, Q15, Q18, Q54)

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, Nordhaus, and Shaw 1994; Schlenker, Hanemann, and Fisher 2006; Deschenes and Greenstone 2007; Dell, Jones, and Olken forthcoming; Guiteras 2009; Schlenker and Roberts 2009; Olmstead and Rhode 2011). 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. 2011). 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; Collins and Margo 2007; Redding and Sturm 2008; Miguel and Roland 2011).

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† To view additional materials, visit the article page at http://dx.doi.org/articles.php?doi=10.1257/aer.102.4.1477.

This paper analyzes the aftermath of large and permanent soil erosion during the 1930s that became widely known as the "American Dust Bowl." Large dust storms swept topsoil from the land such that, by the 1940s, many Plains areas had cumulatively lost more than 75 percent of their original topsoil. Detailed data allow for an examination of relative adjustment from 1940 to the present, and the empirical analysis compares changes between more-eroded counties and less-eroded counties within the same state and with similar pre-1930s characteristics.

The relative impacts of erosion are interpreted using a model of agricultural production in which land allocations are fixed in the short run. Declines in agricultural production possibilities are immediately capitalized into lower land values. Land allocations can adjust in the long run, which leads to a partial recovery in land rents. Land values decrease by less than rents in the short run, only to the extent that land rents are expected to recover. Outside the agricultural sector, more-eroded counties may also adjust through relative population declines and increased nonagricultural land use. The Dust Bowl may have general equilibrium effects on noneroded counties, so it is difficult to quantify the total impact of the Dust Bowl on eroded counties. Instead, the empirical analysis focuses on the speed and magnitude of relative agricultural adjustments in more-eroded counties, the resulting relative difference in short-run and long-run agricultural costs, and the geographic reallocation of labor and capital.

The Dust Bowl is estimated to have imposed substantial relative long-run agricultural costs in more-eroded counties. From 1930 to 1940, more-eroded counties experienced large and permanent relative declines in agricultural land values: the per acre value of farmland declined by 30 percent in high-erosion counties and declined by 17 percent in medium-erosion counties, relative to changes in low-erosion counties. Agricultural revenues declined substantially and immediately in more-eroded counties relative to less-eroded counties, and these revenue declines mostly persisted over time. Two calculations, based on the persistence of lower revenues and a comparison between immediate declines in revenues and land values, imply that long-run relative agricultural adjustments recovered less than 25 percent of the initial difference in agricultural costs for more-eroded counties.

Observed relative adjustments in agricultural land use were limited and slow, consistent with the estimated persistent short-run costs. While full recovery may not be expected in more-eroded areas, there were some potentially productive land-use adjustments. Consistent with contemporaries' recommendations for land-use adjustment, erosion decreased the relative productivity of land for crops (compared to animals) and for wheat (compared to hay). Through the Great Depression and into the 1950s, however, there was not substantial relative adjustment of farmland in more-eroded counties from crops to pasture or from wheat to hay. Total farmland declined slowly and moderately in more-eroded counties, reflecting an inelastic demand for land in nonagricultural sectors.

The main margin of economic adjustment was large relative population declines in more-eroded counties, reflecting both out-migration and diverted in-migration. Population declined substantially from 1930 to 1940 in more-eroded counties relative to less-eroded counties, coinciding with out-migration from the entire region. Labor market equilibrium was reestablished through further relative declines in population rather than through capital inflows and an increase in local industry.

The Great Depression may have partly accounted for limited agricultural adjustment and persistence in costs. Contemporaries discussed four main potential barriers to land-use adjustment, including: limited access to capital; small farm sizes; land tenancy; and surplus labor. Some estimates suggest that access to capital enabled faster land-use adjustment, and there is limited support for the other explanations.

Overall, the Dust Bowl is estimated to have imposed substantial and persistent relative agricultural costs in more-eroded Plains counties. Adjustment took place mainly through relative declines in land values and population, while relative changes in agricultural land use were limited and slow. Historical experiences from the American Dust Bowl highlight that agricultural costs from environmental destruction may not be mostly mitigated by agricultural adjustments, and that population declines may be the primary margin of economic adjustment.

I. Historical Background

In the late nineteenth century, agricultural production began to expand substantially on the American Plains, and native grasslands were increasingly plowed up for crops. The Plains experienced severe drought during the 1930s, particularly in 1934 and 1936, which led to widespread crop failure. This 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 in the 1930s blew enormous quantities of topsoil off Plains farmland; on "Black Sunday" in 1935, one such storm blanketed East Coast cities in a haze.[1] The dust storms were unexpected and some feared that the region would become the once-imagined "American Desert" (*Science* 1934; *Newsweek* 1936).[2,3] The Dust Bowl period continued through 1938 and ended with the return of wetter weather and increased ground cover.[4]

In the aftermath of the Dust Bowl, much farmland was left severely eroded. A Kansas agricultural experiment station released a 1941 bulletin on "reestablishing native grasses by the hay method" (Wenger 1941). While regrassing was expected to occur naturally over 25 to 40 years on Kansas lands eroded during the Dust Bowl, the "hay method" was developed in 1937 to speed this process and increase returns from pasture. In Colorado, where cropland and pasture had been damaged by prolonged drought and overgrazing, reseeding and conversion of cropland to pasture were recommended to assist the slow natural revegetation process (Nelson and

[1] The Dust Bowl was caused by a combination of prolonged severe drought and intensive land use (Soil Conservation Service (SCS) 1935, Hoyt 1936, Wallace 1938, SCS 1939, SCS 1955, Worster 1979, Hurt 1981, Cunfer 2005, and Hansen 2005). 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.

[2] Due to periodic blowing soil, some Plains residents were afflicted with dust pneumonia. Cutler, Miller, and Norton (2007) do not detect later health effects among cohorts from regions more exposed in utero to crop yield shocks during the Dust Bowl.

[3] *Science*. 1934. "The Recent Destructive Dust Cloud." 79 (2056): 473. and *Newsweek*. 1936. "Drought: A Merciless Sun and a Scourge of Insects Destroy Crops, Cattle and Men–Two-thirds of the Country Afflicted." July 18.

[4] Worster (1979, p. 30) reports a substantial wind erosion area in 1940, which Cunfer (since publishing) discovered to be erroneous: it is based on a 1940 United States Department of Agriculture (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.

Shepherd 1940). An agricultural experiment station and extension service in Iowa reported estimated impacts of seeding, fertilizer, and lime on the pasture productivity of eroded former cropland (Hughes and Thorp 1940).

The newly formed Soil Conservation Service (SCS) encouraged farmers to shift land from wheat and other row crops into hay and pasture, where productivity was less affected by erosion and production was less likely to cause additional erosion (SCS 1936, SCS 1939, SCS 1941).[5] A Kansas experiment station and extension service suggested that greater agricultural success could be obtained by increased emphasis on livestock and shifting cropland from relatively less productive areas to more productive areas (Pine 1942).

For such land-use adjustment to be economically viable, the SCS anticipated that farm size increases and population declines would be necessary. Land tenancy was cited as a major obstacle to land-use adjustment, as tenants' short-term incentives were thought to encourage the overuse of land (McDonald 1938). Experimental SCS land-use adjustment programs were associated with long-term income gains, but farmers' participation was thought to be limited partly by access to credit; reasons cited by the SCS include high interest rates, short-term income needs for consumption and mortgage payments, lack of equipment, and a general lack of finances.[6]

National agricultural policies attempted to reduce production of certain crops and animal products, though the initial motivation was to raise prices, increase farm income, and stimulate the Depression economy. The 1933 Agricultural Adjustment Act paid farmers to reduce planted crop acreages, and the government purchased and destroyed livestock (Leuchtenburg 1963; Saloutos 1982; Volanto 2005). After the Supreme Court declared aspects of these programs unconstitutional, efforts to increase prices were combined with erosion control and conservation in the 1935 and 1936 Soil Conservation and Domestic Allotment Acts and the 1938 Agricultural Adjustment Act (Rasmussen 1979; Phillips 2007). Subsequent federal agricultural policy continued in attempts to support crop prices while limiting expansion of crop acreages.

Figure 1 presents aggregate changes in agriculture and population on the Plains over the twentieth century.[7] Total farmland increased from 1910 through the 1940s, remained constant, and declined slightly during the 1970s. Total population increased steadily over this time period, though somewhat below trend from 1930 to 1960. Of particular interest, the total value of agricultural land and agricultural revenue changed similarly over the sample period: booming during World War I, falling during the 1930s, and generally increasing since 1940.

[5] The SCS was established in 1935 to research and demonstrate the effectiveness of soil conservation techniques: converting cropland to grassland; planting alternate strips of cash crops and drought-resistant crops; fallowing land with protective cover; retaining crop residues on harvested land; and plowing along contour lines. The SCS began to oversee some Civilian Conservation Corps work camps and directed efforts to terrace land, rehabilitate gullies, and plant trees as wind breaks.

[6] These arguments were echoed by those at Agricultural Experiment Stations and Extension Services in Montana (Renne 1936) and Iowa (Schickele, Himmel, and Iowa Agricultural Experiment Station 1936). Rural rehabilitation programs partly encouraged land-use adjustment and "balanced farming" by providing finance through the Farm Credit Administration, Farm Security Administration, and the Resettlement Administration (Grant 2002).

[7] These aggregate measures are calculated in each reported period by summing over the same 779 Plains counties (mapped in Figure 2).

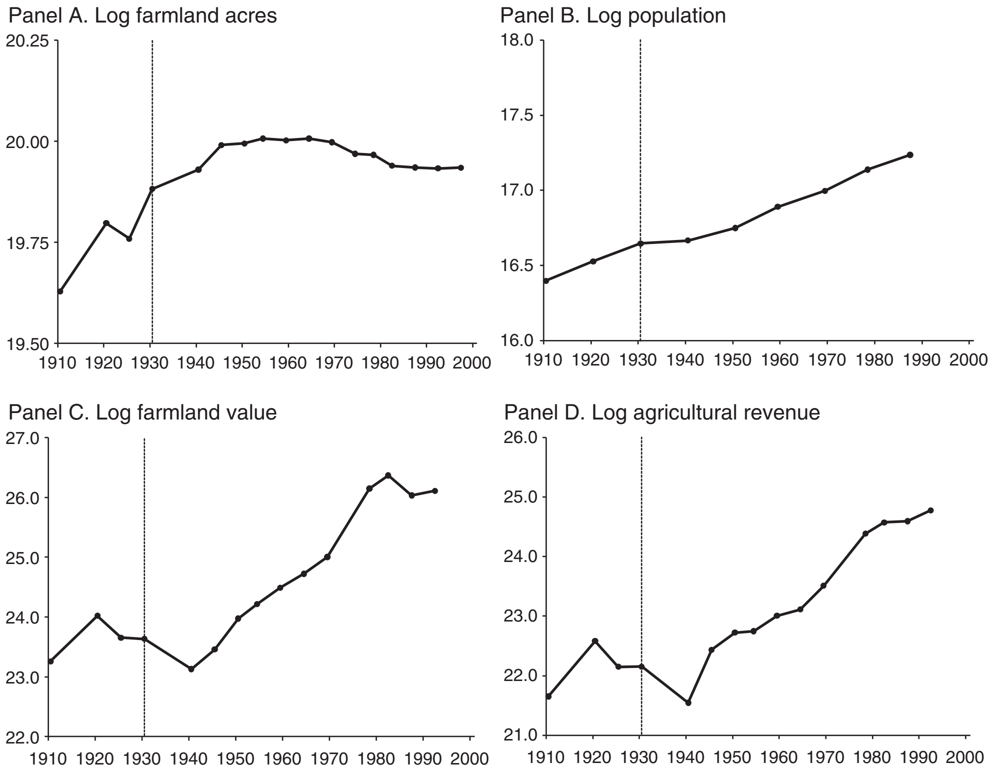

Figure 1. Aggregate Changes on the Plains in Agriculture and Population

Notes: Data are from the US Census of Population and the US Census of Agriculture (Haines 2005; Gutmann 2005). Each panel reports values aggregated in each period over the same 779 sample counties mapped in Figure 2. Panel A reports the log total acres of land in farms. Panel B reports the log total population. Panel C reports the log total value of land in farms. Panel D reports the log total value of agricultural revenue.

II. Theoretical Framework

A. *Agricultural Production: Short-Run versus Long-Run*

Dust Bowl erosion was a major shock that reduced agricultural rents in the short run and long run. In this simple model, farmland values decrease immediately to reflect the present discounted value of lost agricultural rents. Land values decrease by a smaller percentage than agricultural rents in the short run, only to the extent that subsequent land-use adjustments mitigate the long-run costs from erosion.

Assume that a farmer produces one composite agricultural good and allocates a share θ of land between two production technologies, $F_1(\theta, V_1)$ and $F_2(1 - \theta, V_2)$. Variable inputs V, e.g., labor, are chosen in each period to obtain the maximum rent from technology 1 $(\Pi_1(\theta))$ and technology 2 $(\Pi_2(1 - \theta))$. The two production technologies reflect methods or inputs that may be costly to adjust quickly (e.g., cropland versus pasture, or wheat versus hay). All prices are set in competitive markets.

In an unconstrained initial equilibrium, the farmer chooses an optimal land allocation $\bar{\theta}$ such that $\Pi_1'(\bar{\theta}) = \Pi_2'(1 - \bar{\theta})$.[8] The farmer obtains an initial rent π^I, equal to $\Pi_1(\bar{\theta}) + \Pi_2(1 - \bar{\theta})$. The value of land equals the present discounted value of rents, $\pi^I/(1 - \beta)$, where β is a constant discount factor.

At some time period $t = 0$, the Dust Bowl unexpectedly and permanently decreases the relative profitability of the first technology; i.e., $\Pi_1(\theta)$ decreases to $\delta\Pi_1(\theta)$ and $\delta \in (0,1)$. In the "short run," when $t < T$, the land allocation is constrained at its previous level $(\theta = \bar{\theta})$. This short-run land allocation constraint binds because $\delta\Pi_1'(\bar{\theta}) < \Pi_2'(1 - \bar{\theta})$. The farmer earns a short-run rent π^{SR} equal to $\delta\Pi_1(\bar{\theta}) + \Pi_2(1 - \bar{\theta})$.

In the "long run," when $t = T$, a new optimal land allocation is chosen such that $\delta\Pi_1'(\hat{\theta}) = \Pi_2'(1 - \hat{\theta})$. Land is shifted from the first technology $(\hat{\theta} < \bar{\theta})$, and land rents partly recover $(\pi^{SR} < \pi^{LR} < \pi^I)$.[9] In particular, land rents increase from the short run to the long run by $\int_{\hat{\theta}}^{\bar{\theta}} \Pi_2'(1 - x) - \delta\Pi_1'(x)\,dx$; intuitively, the difference in marginal rents is regained for each land unit adjusted. Taking a first-order Taylor expansion of each marginal rent function around $\bar{\theta}$, the term simplifies to $(1/2)(\bar{\theta} - \hat{\theta})(1 - \delta)\Pi_1'(\bar{\theta})$.[10] Thus, the recovery in land rents is proportional to the adjustment in land allocation.[11]

Land values are particularly informative about the effectiveness of long-run adjustment. In each period $0 \leq t \leq T - 1$, the value of land is $\sum_{i=t}^{T-1} \pi^{SR}\beta^i + \sum_{i=T}^{\infty} \pi^{LR}\beta^i$; for $t \geq T$, the value of land is $\pi^{LR}/(1 - \beta)$.[12] Initially, land values fall by a smaller percentage than rents to the extent that rents will recover.[13] Over time, land values increase as land rents increase, though by a smaller percentage than land rents.[14] Additionally, the initial decrease in land values at $t = 0$ capitalizes the full present discounted value of lost rents from erosion.[15]

The binding short-run constraint on land allocation is of analytical convenience, but it can be interpreted as a simplified case of unconstrained adjustment with adjustment costs that are convex or decline over time. 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

[8] 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.

[9] The farmer earns a long-run rent π^{LR} equal to $\delta\Pi_1(\hat{\theta}) + \Pi_2(1 - \hat{\theta})$.

[10] The value of this "adjustment triangle" corresponds to one-half the change in land allocation multiplied by the initial decrease in marginal return. The approximation is exact if $\Pi_2'(1 - \bar{\theta})$ and $\Pi_1'(\bar{\theta})$ are linear.

[11] Note that 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. Rearranging terms from the Taylor expansion, the change in land allocation $(\hat{\theta} - \bar{\theta})$ equals the initial decrease in marginal return $((1 - \delta)\Pi_1'(\bar{\theta}))$, divided by the summed slopes of the two technologies' marginal returns at the initial equilibrium $(\Pi_2''(1 - \bar{\theta}) + \Pi_1''(\bar{\theta}))$.

[12] Land values in each period are set equal to the net present value of agricultural rents, given a rent stream of π^{SR} until period T and π^{LR} thereafter.

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

[14] Rearranging terms, the value of land in each period $0 \leq t \leq T - 1$ is $\pi^{LR}/(1 - \beta) - (\pi^{LR} - \pi^{SR})\sum_{i=t}^{T}\beta^i$. Land values increase as periods of short-run rents are past and periods of long-run rents become more immediate.

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

Rosenzweig 1995; Sutch 2010).[16] Land values increase whenever adjustment costs are paid and fixed to the land; otherwise, the empirical predictions are similar when allowing for adjustment costs.[17]

B. *General Equilibrium Effects of the Dust Bowl*

If Dust Bowl erosion directly affects agricultural production, then there may be indirect effects on population and industrial outcomes. In addition, noneroded areas may be affected indirectly by changes in prices and mobile factors. This section applies a Roback (1982) model to a rural setting and outlines how erosion might affect agriculture, population, and industry in eroded areas relative to noneroded areas.

In this model, there are two locations (eroded and noneroded). 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 consume land, 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.

Assume that Dust Bowl erosion decreases agricultural productivity in the eroded location. Farmland demand declines in the eroded location; if supply is inelastic then the value of land decreases with little decrease in total farmland. Agricultural output decreases in the eroded location, so the price of agricultural output increases in both locations. Higher output prices increase farmland demand in the noneroded location and the value of land increases. Thus, the decline in land values in the eroded location relative to the noneroded location overstates the absolute decline in land values in the eroded location.

Assume further that Dust Bowl erosion decreases agricultural labor productivity in the eroded location. Workers move to the noneroded location and/or switch to the industrial sector. Wages remain lower in the eroded location (and agricultural sector) to the extent that there are costs to moving (and switching sectors).[18] Lower wages encourage labor-intensive production in the agricultural sector, and the expansion of industrial production.[19] Population increases in the noneroded location and wages decrease, so relative geographic comparisons overstate out-migration and understate wage declines in the eroded location.

In general, Dust Bowl erosion can affect the noneroded location through changes in shared prices. Erosion discourages certain types of production in the eroded location, increases output prices, and encourages those types of production in the

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

[17] Intuitively, the land allocation adjusts less and there is less recovery in rents. In a stark example, assume shifting land L from technology 1 to 2 requires a one-time nonrecoverable cost $C_{12}(L)$ to be paid in period T. If some land adjustment remains optimal, it satisfies $(1-\delta)\Pi_1'(\hat{\theta}) = \Pi_2'(1-\hat{\theta}) - (1-\beta)C_{12}'(\overline{\theta}-\hat{\theta})$. Effectively $(1-\beta)$ of the adjustment cost is paid in each period, but any capital constraints would make full initial adjustment more costly.

[18] Workers consume land, which is cheaper in the eroded location, so paid wages decrease by more than local price-adjusted wages.

[19] Lower land prices also encourage the expansion of industrial production.

noneroded location. Thus, relative changes in production will overstate the absolute degree of adjustment in the eroded location.

III. Data Construction and Baseline Characteristics by Erosion Level

County-level data on agriculture, population, and industry are drawn from the US census of agriculture, census of population, and census of manufacturing (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 establishments, and unemployment (see Data Appendix). Other data sources include banking data from the Federal Deposit Insurance Corporation (Haines 2005); New Deal expenditures from the Office of Government Reports (Fishback, Horrace, and Kantor 2005); and drought data from the National Climatic Data Center (Boustan, Fishback, and Kantor 2010).

The main sample is a balanced panel of 779 Plains counties from 1910 to 1997. The 1924 USDA *Atlas of Agriculture* is used to define a contiguous set of ecologically similar Plains counties within the sample states (USDA 1924).[20] To account for county border changes, census data are adjusted in later periods to maintain the 1910 county definitions (Hornbeck 2010).

Figure 2 displays the sample counties, overlaid with a map of cumulative erosion damage after the Dust Bowl. The white area is low erosion (less than 25 percent of topsoil lost), light gray is medium erosion (25 percent to 75 percent of topsoil lost), and dark gray is high erosion (more than 75 percent of topsoil lost).[21] There is no direct measure of topsoil lost during the 1930s because detailed erosion surveys only began in the 1930s, and were based on soil measurements by specialists sent to each county (SCS 1935).[22] Thus, the empirical analysis uses cumulative erosion damage as a proxy for differential erosion during the 1930s, and the methodology is designed to address omitted variable bias arising from the absence of pre-1930s erosion data.[23]

[20] Excluded non-Plains counties have less than 50 percent of their area in the typical central United States grassland and forest vegetation regions (Tall Grass, Short Grass, Mesquite Grass, Mesquite and Desert Grass Savanna, and Oak-Hickory Forest). In practice, this excludes a ring of ecologically dissimilar counties in western Montana, central and western Wyoming/Colorado/New Mexico, southwestern Texas, eastern Texas, southeastern Oklahoma, and northeastern Minnesota. The empirical results are robust to excluding Iowa and Minnesota.

[21] The cumulative erosion map was prepared by the SCS "based on the 1934 Reconnaissance Erosion Survey and other surveys." The map was obtained from the National Archives and traced erosion regions were merged with county borders using Geographic Information Systems software. The National Archives maintains records of the SCS and its predecessor, the Soil Erosion Service (SES), which contain three identical versions of the map with publishing dates of 1948, 1951, and 1954. There are no other erosion maps from December 1937 until the next period of substantial erosion in the mid-1950s.

[22] The 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. All erosion maps indicate the cumulative severity (slight, moderate, severe) of wind erosion or water erosion, though the level of detail and definition of categories changes over time.

[23] Intuitively, the desired independent variable is $(erosion_{post} - erosion_{pre})$ and the included variable is only $erosion_{post}$. Thus, the variable $erosion_{pre}$ appears negatively in the error term, and will bias the estimated coefficient on $erosion_{post}$ depending on its correlation with the dependent variable after conditioning on any control variables. The estimating equation includes a number of control variables that may proxy for pre-1930s erosion. The Results Appendix reports estimates from two specification checks. One specification check instruments for $erosion_{post}$ using 1930s

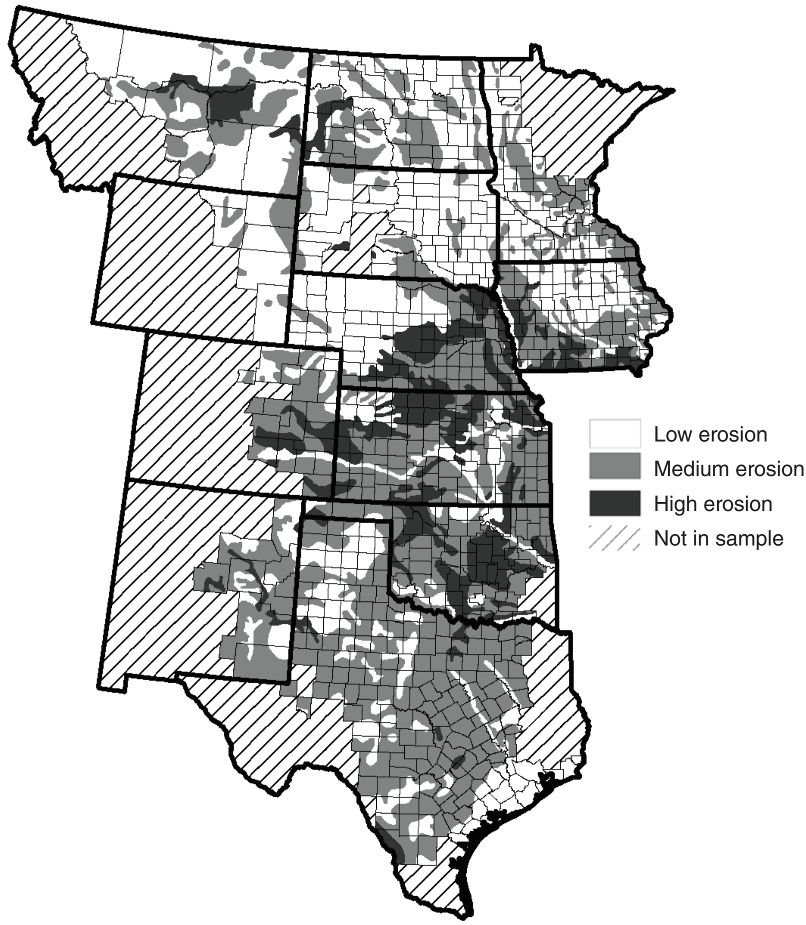

FIGURE 2. THE 779 MAIN SAMPLE COUNTIES, SHADED BY EROSION LEVEL

Notes: Mapped erosion levels are indicated as low (less than 25 percent of topsoil lost), medium (25 percent to 75 percent of topsoil lost and may have some gullies), or high (more than 75 percent of topsoil lost and may have numerous or deep gullies). Thin lines denote 1910 county borders, corresponding to the main sample of 779 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.

Measured erosion levels may be correlated with pre-1930s county characteristics for two reasons. First, some erosion differences may have occurred prior to the Dust Bowl and have been caused by, reflected in, or otherwise jointly determined with pre-1930s county characteristics.[24] Second, the intensity of Dust Bowl erosion may have been partly determined by county land use. The main empirical challenge is that counties with different pre-1930s characteristics may have changed differently after the

weather. Another specification check, similar to a difference-in-difference-in-difference estimate, contrasts the main estimated effects with the estimated effect of $erosion_{post}$ in non-Plains areas that did not experience Dust Bowl erosion.

[24] For example, intensive land use over many decades may have caused higher 1920s erosion levels in Iowa, as compared to the Texas panhandle. Alternatively, high erosion levels in the 1920s may reduce land values in the 1920s or discourage the production of soil-sensitive crops. Finally, climate or topology may affect county outcomes and 1920s erosion levels.

1930s, 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.

Table 1 reports mean county characteristics in 1930 (column 1) and estimated within-state differences based on measured post-1930s erosion levels (columns 2 and 3). Among the reported characteristics, there is a statistically significant correlation between higher erosion and higher land values, higher agricultural density, more cropland in corn, less cropland in wheat and hay, and more animals. High-erosion and medium-erosion counties were more similar (column 4). Because pre-1930s differences may predict differential changes after 1930, the empirical analysis focuses on specifications that control for differential changes over time that are correlated with the reported 1930 county characteristics and available lagged values of those characteristics in 1925, 1920, and 1910 (see Data Appendix).[25] These control variables also proxy for the omitted pre-1930s erosion variable, to the extent that pre-1930s erosion is correlated with these outcome variables of interest.

IV. Empirical Framework

The empirical analysis is based on estimating average changes for more-eroded counties, relative to changes for less-eroded counties in the same state and with similar pre-1930s characteristics. Formally, outcome Y_{ct} in county c and year t is differenced from its value in 1930. This difference is regressed on the fraction of the county in medium-erosion (M_c) and high-erosion (H_c) regions, a state-by-year fixed effect (α_{st}), pre-1930s county characteristics (X_c), and an error term (ϵ_{ct}):

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

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.[26]

The included controls for 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 controls for the outcome variable in 1930 and all available pre-1930 periods. Along these observable dimensions, differentially eroded counties are thereby allowed to experience systematically different changes after 1930. For example, counties with lower land values in 1925 and higher land values in 1930 are allowed to experience different land value changes from 1930 to 1940.[27]

The identification assumption is that counties with different measured erosion levels would have changed the same after the 1930s if not for the Dust Bowl. In

[25] Specifications do not control for county characteristics after 1930, which are potential outcomes of the Dust Bowl.

[26] For this class of regression, in which the sample is balanced and the regressors are fully interacted with each time period, differencing the data and including county fixed effects yield numerically identical coefficients (as in the case of two time periods). Both methods improve the estimates' precision by absorbing fixed county characteristics. Differencing is more efficient when the untransformed error term is closer to a random walk, the differenced coefficients are easier to interpret, and differencing is computationally faster.

[27] This econometric model is preferable to controlling directly for trends in land values, which would contradict economic theory on the nonpredictability of past asset price trends.

Table 1—County Characteristics in 1930, by Post–Dust Bowl Erosion Level

		Relative to low erosion:		
	All counties (1)	Medium erosion (2)	High erosion (3)	Difference: (3) − (2) (4)
Panel A. Value				
Log value of farmland and buildings, per acre in farms	3.377	0.297**	0.241	−0.056
	[0.889]	(0.094)	(0.140)	(0.102)
Log value of farmland, per acre in farms	3.178	0.264**	0.211	−0.052
	[0.851]	(0.092)	(0.136)	(0.099)
Log value of all farm products, per acre in farms	1.959	0.268**	0.193	−0.074
	[0.802]	(0.083)	(0.122)	(0.094)
Panel B. Land use				
Acres of land in farms, per county acre	0.834	0.012	−0.038	−0.050**
	[0.153]	(0.018)	(0.021)	(0.019)
Acres of cropland, per acre in farms	0.457	0.048	−0.003	−0.050
	[0.236]	(0.027)	(0.036)	(0.028)
Panel C. Population and farms				
Population, per 100 county acres	3.242	1.109	1.223	0.114
	[6.871]	(0.694)	(0.761)	(0.711)
Fraction of population, rural areas	0.825	−0.014	0.038	0.051
	[0.215]	(0.030)	(0.042)	(0.041)
Fraction of population, on farms	0.549	0.035	0.056	0.021
	[0.164]	(0.022)	(0.031)	(0.031)
Farms, per 100 county acres	0.292	0.151**	0.154**	0.003
	[0.239]	(0.023)	(0.030)	(0.031)
Average farm size (acres)	685	−341**	−425**	−84
	[1,022]	(128)	(144)	(99)
Panel D. Cropland allocation				
Fraction corn	0.167	0.066**	0.193**	0.128**
	[0.163]	(0.016)	(0.025)	(0.023)
Fraction wheat	0.208	−0.054*	−0.117**	−0.063
	[0.217]	(0.027)	(0.035)	(0.036)
Fraction hay	0.130	−0.034	−0.088*	−0.054**
	[0.132]	(0.025)	(0.038)	(0.020)
Fraction cotton	0.108	0.053**	0.017	−0.036
	[0.211]	(0.019)	(0.019)	(0.021)
Fraction oats, barley, and rye	0.125	0.003	−0.030*	−0.033**
	[0.113]	(0.009)	(0.012)	(0.010)
Panel E. Animal production				
Cattle, per county acre	0.053	0.006	0.010**	0.005
	[0.033]	(0.003)	(0.004)	(0.004)
Swine, per county acre	0.056	0.035**	0.055**	0.020
	[0.091]	(0.007)	(0.012)	(0.010)
Chickens, per county acre	0.261	0.112**	0.121**	0.009
	[0.272]	(0.022)	(0.032)	(0.031)

Notes: Column 1 reports average values for the 779 sample counties (Figure 2). Counties are weighted by acres of farmland in 1930, and the standard deviation is reported in brackets. Columns 2 and 3 report coefficients from a single regression of the indicated county characteristic in 1930 on the fraction of the county in medium erosion and in high erosion (low erosion is omitted), 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.

**Significant at the 1 percent level.

*Significant at the 5 percent level.

practice, this assumption must hold after controlling for differential changes over each period that are correlated with state and the included pre-1930s county 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 βs 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.[28]

V. Results

A. *Agricultural Land Value and Revenue*

To illustrate the empirical methodology and analyze relative changes in the log value of agricultural land and buildings per acre of farmland, Figure 3 graphs estimated βs from versions of equation (1). Panel A includes only state-by-year fixed effects as controls for regional differences in agricultural development and public policy (e.g., Oklahoma's late statehood and differences in statewide relief efforts and agricultural extension services). Panel B also includes 1930 county characteristics, interacted with year, as controls for differential effects of changes in agricultural prices and technology (e.g., controlling for baseline corn allocations to adjust for differential effects from changes in the relative return to corn). Panel C includes county characteristics available from 1910 to 1925, interacted with year, as additional measures of county differences in agricultural suitability.[29] After World War I, from 1920 to 1930, land values in high-erosion and medium-erosion counties were similar to land values in low-erosion counties in both levels and trends. Panel D includes controls for pre-1930s differences in land values, implementing the full version of equation (1).[30]

After the 1930s Dust Bowl, agricultural land values declined in high-erosion and medium-erosion counties relative to changes in low-erosion counties. Land values also declined in high-erosion counties relative to medium-erosion counties, comparing the two lines graphed in Figure 3. The relative declines in land values were substantial and persistent.

[28] Conley standard errors were also estimated for changes in land values from 1930 to 1940 (Conley 1999), and were similar to standard errors clustered at the county level. 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 versus low-erosion counties is: 7 (50-mile cutoff), 18 (100 mile), 18 (300 mile), 14 (500 mile), and 5 (700 mile). For changes in medium-erosion versus low-erosion counties, the percent increase in Conley standard errors is: 5 (50-mile cutoff), 8 (100 mile), 9 (300 mile), 7 (500 mile), and −3 (700 mile). The Conley specifications are difficult to weight by county farmland levels, so the comparison is relative to unweighted county-clustered standard errors.

[29] The included 1930 county characteristics are listed in Table 1, panels B to E. The Data Appendix describes the availability of these variables from 1910 to 1925.

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

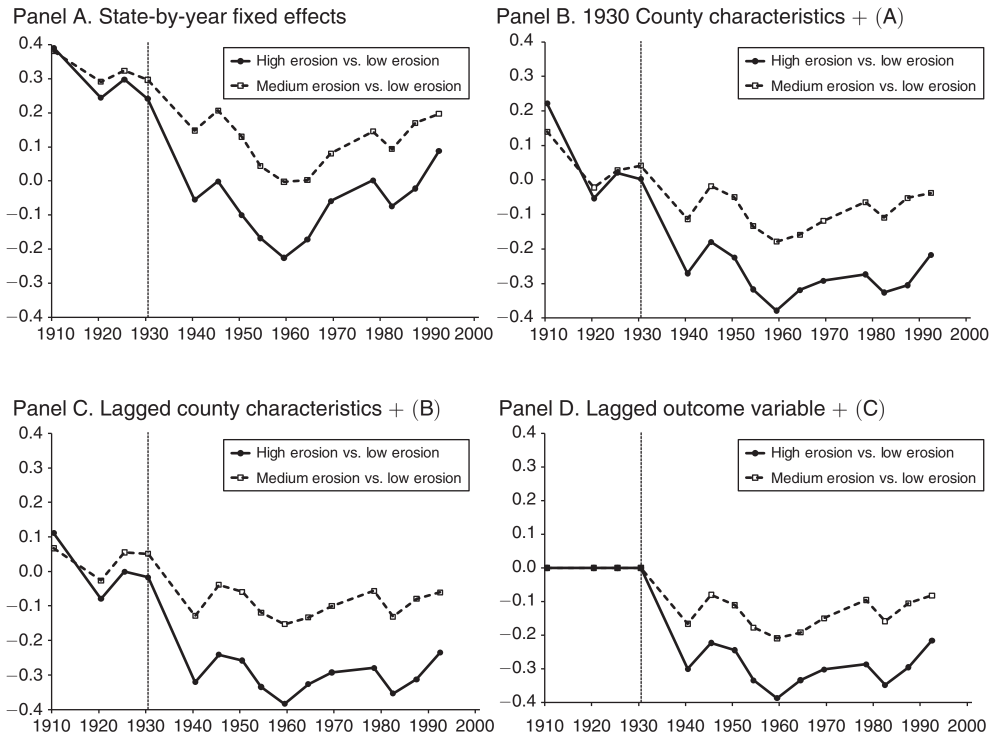

Figure 3. Estimated Differences in Log Value of Farmland per Acre, by Erosion Level

Notes: Each panel graphs the estimated coefficients (β) from versions of equation (1) in the text. For each year, the solid circles and solid line report differences in the log per acre value of farmland and buildings for high-erosion counties, relative to low-erosion counties. The hollow squares and dashed line report differences for medium-erosion counties, relative to low-erosion counties. In panel A, these coefficients are estimated by regressing the log per acre value of farmland and buildings 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 in 1930 and in each lagged year.

Table 2, column 1, reports numerical results from estimating equation (1), as graphed in panel D of Figure 3. From 1930 to 1940, land values fell by 30 percent in high-erosion counties and 17 percent in medium-erosion counties, relative to changes in low-erosion counties (panel A). Multiplying by agricultural land values in 1930, these estimates indicate a relative economic loss of $2.4 billion ($30 billion in 2007 dollars).[31] This relative cost overstates the aggregate cost of the Dust Bowl to the extent that the Dust Bowl increased agricultural prices and raised land prices in low-erosion counties.[32] This relative cost understates the aggregate cost

[31] Multiplying 1930 county farmland levels by the share of area in each erosion category, there were approximately 55 million farm acres in high-erosion areas and 197 million farm acres in medium-erosion areas. The per acre value of farmland was $58 in high-erosion counties and $44 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: $1 billion from high-erosion and $1.4 billion from medium-erosion counties.

[32] The Dust Bowl substantially decreased production and may have increased agricultural prices, though it is difficult to know what agricultural prices would have been in the absence of the Dust Bowl. Prices for agricultural products increased during the 1934 and 1936 droughts, but declined over the entire 1930s in absolute levels and

Table 2—Estimated Changes in Agricultural Land Value and Revenue, by Erosion Level

	Change after 1930		
	Log land value (1)	Log revenue (2)	Ratio: (1)/(2) (3)
Panel A. 1940			
High erosion versus low erosion	−0.300**	−0.267**	1.123**
	(0.038)	(0.055)	(0.184)
Medium erosion versus low erosion	−0.166**	−0.155**	1.069**
	(0.030)	(0.040)	(0.226)
High erosion versus medium erosion (calculated)	−0.134**	−0.112*	1.197**
	(0.032)	(0.051)	(0.418)
Averaged value (GLS)			1.109**
			(0.174)
Panel B. 1945			
High erosion versus low erosion	−0.223**	−0.107**	
	(0.036)	(0.038)	
Medium erosion versus low erosion	−0.080**	−0.100**	
	(0.027)	(0.030)	
Panel C. 1950–1954 (pooled)			
High erosion versus low erosion	−0.289**	−0.240**	
	(0.041)	(0.049)	
Medium erosion versus low erosion	−0.144**	−0.187**	
	(0.032)	(0.037)	
Panel D. 1959–1969 (pooled)			
High erosion versus low erosion	−0.340**	−0.257**	
	(0.044)	(0.058)	
Medium erosion versus low erosion	−0.183**	−0.118**	
	(0.036)	(0.042)	
Panel E. 1978–1992 (pooled)			
High erosion versus low erosion	−0.286**	−0.297**	
	(0.049)	(0.080)	
Medium erosion versus low erosion	−0.110**	−0.034	
	(0.041)	(0.060)	
R^2	0.972	0.921	
Sample counties	779	779	

Notes: Columns 1 and 2 report estimates from equation (1) in the text, for the log value of agricultural land and buildings per acre of farmland (column 1) and the log value of agricultural revenue per acre of farmland (column 2). Column 1 corresponds to panel D of Figure 3, where the estimated coefficients are pooled across the indicated years in each panel. Column 3 reports the ratio of the estimated coefficients in panel A of columns 1 and 2. Reported in parentheses are robust standard errors clustered by county.

**Significant at the 1 percent level.

*Significant at the 5 percent level.

to the extent that the Dust Bowl also damaged low-erosion counties. As a further basis of comparison, the $2.4 billion cost represents seven percent of the decline in

relative to the urban consumer price index. For a rough calculation, assume that the demand for agricultural land has an elasticity of −1. A $2.4 billion decline in farmland value reflects five percent of the total value of farmland in the United States in 1930, so low-erosion county land values may have increased by five percent (the spillover would be smaller if world agricultural markets are integrated and farmland demand is less inelastic, while the spillover would be larger if US markets are imperfectly integrated and a dollar of Plains farmland is an imperfect substitute for a dollar of non-Plains farmland). This calculation implies that, in absolute terms, land values in high-erosion and medium-erosion counties declined by 25 percent and 12 percent, respectively, implying a cost of $1.8 billion in eroded areas. For the overall economic cost, price increases benefit land owners in noneroded areas at the expense of consumers.

GDP from 1930 to 1933 (Carter et al. 2006) or the total 1930 value of high-erosion farmland over an area the size of Oklahoma.

Panel B reports that land values in 1945 remained lower in high-erosion and medium-erosion counties, relative to land values in low-erosion counties. For conciseness, panels C to E pool the estimated coefficients in subsequent periods. Through the end of the sample period in 1992, land values continued to remain substantially lower in more-eroded counties. Overall, there is little indication of a systematic relative recovery in land values following the Dust Bowl. These estimates suggest that long-run economic adjustments did not lead to a substantial recovery in land rents and were not associated with substantial fixed investments, which would become capitalized in higher land values.

Changes in agricultural revenue measure the losses to agriculture in each time period. While the ideal variable would be agricultural rents, unobserved inputs can bias estimates of the impact of environmental shocks on imputed rents (Rosenzweig and Wolpin 2000). For a Cobb-Douglas production function, a productivity decline leads to the same percent declines in rents, revenue, and all inputs. Thus, the empirical analysis focuses on percent changes in agricultural revenue as a proxy for percent changes in agricultural rents. Estimated percent changes in observed inputs provide some guidance on when percent changes in revenue may overstate or understate the percent changes in rents.

Table 2, column 2, reports estimates from equation (1) for changes in the log value of agricultural revenue per acre of farmland. From 1930 to 1940, agricultural revenue declined by 27 percent in high-erosion counties and by 16 percent in medium-erosion counties, relative to changes in low-erosion counties (panel A). In later periods, revenues only partially recovered in more-eroded counties relative to less-eroded counties. Two parameters of interest from the perspective of a farmer in 1940 are (a) the net present value of future revenue losses, and (b) the net present value of future revenue losses if there had been no recovery after 1940.[33] The ratio of (a) to (b) reflects the economic loss (allowing for adjustment) as a fraction of the short-run economic loss (not allowing for adjustment). The estimated ratios (and standard errors) are 0.866 (0.171) for high-erosion counties relative to low-erosion counties, 0.764 (0.203) for medium-erosion counties relative to low-erosion counties, and 1.007 (0.436) for high-erosion counties relative to medium-erosion counties. Ratio values between 0.75 and 1 indicate that relative agricultural adjustments recovered between 25 percent and 0 percent of the initial relative agricultural cost.

Table 2, column 3, reports the ratio of percent declines in land values and agricultural revenues from 1930 to 1940.[34] In a similar exercise as above, the immediate decline in land values may reflect the economic loss (anticipating adjustment) and the immediate decline in revenues may reflect the short-run economic loss (not allowing for adjustment). The estimated ratios (and standard errors) are 1.123 (0.184), 1.069 (0.226), and 1.197 (0.418). The efficient weighted average of these

[33] This calculation assumes an interest rate of five percent, linearly interpolates annual values between each census period, and assumes that revenue losses remain constant after 1992.

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

three ratios is 1.109 (0.174).[35] The estimated average ratio is statistically greater than 0.761 and is statistically indistinguishable from 1, which implies that long-run relative adjustments mitigated less than 25 percent of the initial relative cost.

A strict interpretation of the estimated ratios requires that percent changes in revenue are equal to percent changes in economic rents. Percent changes in observed input costs are informative about the difference between revenue and rents: if inputs initially decline by less than revenue, then rents initially decline by more than revenue; if inputs recover more than revenue, then rents recover less than revenue. This pattern of results is found for agricultural capital (machinery and equipment), suggesting that the land value ratio may overstate the degree of cost persistence and the revenue ratio may understate the degree of cost persistence.[36] Overall, the estimated changes in land values and revenues are consistent with substantial short-run costs, persistent long-run costs, and adjustments that mitigated between 0 percent and 25 percent of the initial relative cost in more-eroded counties.

B. *Adjustment in Agricultural Production*

Table 3 reports relative changes in agricultural production following the Dust Bowl, from estimating equation (1) for each agricultural outcome. On the extensive margin, more-eroded counties did not experience a substantial relative decline in total farmland through the 1930s and 1940s (column 1). By the 1950s, the fraction of county land in farms had declined by two to four percentage points. Small declines in farmland and large declines in agricultural land values are consistent with an inelastic demand for land in other sectors of the economy. Further, these estimates suggest that estimated relative impacts of the Dust Bowl do not reflect large changes in the relative composition of farmland.

Within the agricultural sector, farmers had an incentive to reallocate land toward production activities that were less sensitive to soil quality. As discussed in Section I, contemporaries recommended that farmers convert eroded cropland to pasture.[37] Consistent with these recommendations, more-eroded counties experienced large relative declines in the productivity of cropland (column 2) and smaller relative declines in the productivity of pasture (column 3).[38] On this intensive margin,

[35] The variance-covariance matrix for the three estimates is known, so the efficient average is estimated through generalized least squares (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.

[36] Equation (1) is estimated for the value of capital machinery and equipment. From 1930 to 1940, capital inputs fell substantially but by less than revenue: 21.2 percent (5.9) in high-erosion counties relative to low-erosion counties, and 9.2 percent (4.2) in medium-erosion counties relative to low-erosion counties. In subsequent time periods, for high-erosion relative to low-erosion counties, capital inputs decreased from 1930 by 7.3 percent (5.1) in 1945, 16.2 percent (6.8) in 1969, and 15.0 percent (6.9) in 1992. For medium-erosion counties relative to low-erosion counties, capital inputs decreased by 0.7 percent (3.6) in 1945, 2.9 percent (4.6) in 1969, and −0.5 percent (5.0) in 1992. From another estimation of equation (1), fallowed cropland is found to have declined in more-eroded counties after 1940, consistent with increased use of inputs leading to a recovery in revenue greater than the recovery in rents.

[37] The SCS in 1955 continued to recommend converting land from cropland to grassland (Allred and Nixon 1955).

[38] Cropland productivity is defined as the total value of crops sold divided by acres of cropland. Pasture productivity is defined as the total value of animals sold and animal products sold, divided by acres of pasture. These measures are imperfect proxies for productivity because some portion of a farm's crops may be fed directly to that farm's animals. The productivity regressions are weighted by 1930 levels of county cropland and pasture, so the

Table 3—Estimated Changes in Agricultural Production after 1930, by Erosion Level

	Farmland share (1)	Log cropland productivity (2)	Log pasture productivity (3)	Land share in cropland (4)	Log wheat productivity (5)	Log hay productivity (6)	Land share in wheat (7)
Panel A. High erosion versus low erosion							
1940	−0.025	−0.390**	−0.224**	−0.000	−0.156		0.035
	(0.017)	(0.120)	(0.044)	(0.009)	(0.115)		(0.022)
1945	−0.017	−0.141	−0.116*	−0.012	−0.194**		
	(0.016)	(0.074)	(0.053)	(0.011)	(0.070)		
1950–1954	−0.037*	−0.382**	−0.116*	−0.030*	−0.230**	0.019	0.017
	(0.016)	(0.068)	(0.053)	(0.014)	(0.068)	(0.047)	(0.021)
1959–1964	−0.043**	−0.333**	−0.244**	−0.060**	−0.214**	0.089*	−0.001
	(0.016)	(0.077)	(0.074)	(0.017)	(0.075)	(0.045)	(0.022)
1969–1974	−0.013				0.021	0.143**	−0.039
	(0.015)				(0.058)	(0.044)	(0.025)
1978–1992	−0.050**				−0.011	0.210**	−0.066*
	(0.016)				(0.045)	(0.046)	(0.028)
1997					0.008	0.139*	−0.102**
					(0.056)	(0.064)	(0.032)
Panel B. Medium erosion versus low erosion							
1940	−0.019	−0.381**	−0.060	−0.003	−0.086		−0.008
	(0.013)	(0.089)	(0.038)	(0.006)	(0.085)		(0.017)
1945	0.004	−0.289**	−0.052	−0.008	−0.064		
	(0.012)	(0.062)	(0.040)	(0.007)	(0.049)		
1950–1954	−0.008	−0.313**	−0.014	−0.018	−0.181**	0.017	−0.002
	(0.013)	(0.056)	(0.041)	(0.010)	(0.065)	(0.045)	(0.020)
1959–1964	−0.025	−0.275**	0.006	−0.028*	−0.257**	0.041	−0.026
	(0.014)	(0.068)	(0.054)	(0.012)	(0.062)	(0.046)	(0.021)
1969–1974	−0.011				−0.039	−0.028	−0.070**
	(0.012)				(0.044)	(0.036)	(0.023)
1978–1992	−0.026*				−0.064*	−0.004	−0.110**
	(0.013)				(0.033)	(0.039)	(0.023)
1997					−0.066	−0.016	−0.138**
					(0.050)	(0.050)	(0.025)
R^2	0.656	0.791	0.850	0.679	0.890	0.823	0.435
Sample counties	779	779	779	779	421	421	421
Weighted by 1930 value of:	Farmland	Cropland	Pasture	(2) + (3)	Wheat	Hay	(5) + (6)

Notes: Each column reports estimates from equation (1) in the text: farmland per county acre (column 1), log crop revenue per cropland acre (column 2), log animal revenue per pasture acre (column 3), cropland per acre of cropland and pasture (column 4), log wheat output per wheat acre (column 5), log hay output per hay acre (column 6), wheat per acre of wheat and hay (column 7). Reported in parentheses are robust standard errors clustered by county.

**Significant at the 1 percent level.

*Significant at the 5 percent level.

more-eroded counties did not experience a substantial relative decline in the allocation of farmland to crops through the 1930s and 1940s (column 4). By the 1950s and 1960s, there were moderate relative declines in the allocation of farmland to crops in more-eroded counties.

estimates can be interpreted as the percent change for an average unit of that land type. Three additional caveats in interpreting the productivity regressions are: (1) changes in productivity need not imply changes in profitability; (2) average productivity changes may differ from changes for the marginal unit of land that could be reallocated; and (3) later changes in land allocations could confound productivity effects with composition effects.

Within the allocation of land to crops, contemporaries also recommended that farmers convert eroded cropland from wheat to hay.[39] Wheat production is more sensitive to soil quality, while hay is cultivated grass and relatively robust. Consistent with contemporaries' recommendations, more-eroded counties experienced a relative decline in wheat productivity after the Dust Bowl (column 5), while hay productivity was relatively unaffected in later measured periods (column 6).[40] The allocation of land between wheat and hay, however, was mostly constant through the 1960s in more-eroded and less-eroded counties, and then wheat cultivation declined substantially relative to hay cultivation (column 7).[41] Overall, the estimates suggest that there were some potential margins of adjustment within the agricultural sector, and that adjustments along the extensive and intensive margins were mostly delayed for 15 to 30 years.

C. *Adjustment in Population, Industry, and the Labor Market*

Immediately after the Dust Bowl, population declined substantially in high-erosion and medium-erosion counties relative to changes in low-erosion counties (Table 4, column 1). By 1940, high-erosion and medium-erosion counties had experienced 12 percent and 9 percent relative declines in total population. Immediate large-scale "Dust Bowl migration" was discussed by contemporaries and famously portrayed in literature, film, art, and music. The estimated relative population declines also reflect diverted in-migration, however. Further, if all affected migrants moved to low-erosion Plains counties, then the estimated relative population declines are twice the implied direct effect on migrants. Consistent with large out-migration from 1930 to 1940, total population declined between three percent and eight percent in the five central Plains states (Oklahoma, Kansas, Nebraska, South Dakota, and North Dakota).

Relative declines in population continued through the 1950s in high-erosion and medium-erosion counties (column 1). The decline in population did not occur disproportionally from rural or on-farm populations, suggesting an overall economic decline rather than increases in nonagricultural employment.[42] There was no substantial short-run or long-run relative increase in manufacturing establishments (column 2) or manufacturing workers per capita (column 3).[43] There was relatively little initial manufacturing activity or related infrastructure on the Plains, so there may have been little basis for subsequent growth and development of manufacturing clusters.

[39] Contemporaries also recommended converting other soil-sensitive crops to soil-resistant crops, but wheat and hay are the two widely grown crops for which comparable data are available over a long time period.

[40] 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 (and no harvesting) would cause the analysis to understate declines in productivity. The regressions are weighted by 1930 acres of land allocated to that crop. Data are only available for a subset of counties in all reported time periods. The other crop and animal variables are omitted as controls, as they directly change along with wheat and hay.

[41] Estimated post-1960s changes in productivity may be affected partly by these changes in the composition of lands used for production.

[42] From estimating equation (1), there is little relative change in the fraction of county population in rural areas or the fraction of county population living on farms. There may be important linkages between local agriculture and nonagricultural production and services, and the local nonfarm or urban population may participate directly in agriculture (e.g., seasonally).

[43] Manufacturing data are unavailable for some of the sample counties. In addition, there is no estimated increase in log manufacturing value added or the fraction of manufacturing workers per capita in the labor force.

TABLE 4—ESTIMATED CHANGES IN POPULATION AND MANUFACTURING AFTER 1930, BY EROSION LEVEL

	Log population (1)	Log mfg. establishments (2)	Mfg. workers per capita (3)	Unemployment rate (4)	Log retail sales per capita (5)
Panel A. High erosion versus low erosion					
1940	−0.116**	−0.015	0.003	0.010**	−0.122**
	(0.021)	(0.069)	(0.002)	(0.003)	(0.029)
1950	−0.180**	−0.183**		−0.004	
	(0.047)	(0.067)		(0.002)	
1960	−0.267**	−0.188*	0.005		−0.066*
	(0.072)	(0.082)	(0.007)		(0.029)
1970	−0.268**	−0.104	0.006		−0.044
	(0.088)	(0.100)	(0.010)		(0.037)
1980	−0.250*	−0.041	0.013		−0.093*
	(0.101)	(0.117)	(0.013)		(0.043)
1990	−0.227*	−0.087	0.010		−0.090
	(0.114)	(0.136)	(0.012)		(0.051)
Panel B. Medium erosion versus low erosion					
1940	−0.088**	−0.100*	−0.001	0.003	−0.066**
	(0.017)	(0.047)	(0.002)	(0.002)	(0.021)
1950	−0.145**	−0.084		−0.002	
	(0.033)	(0.046)		(0.002)	
1960	−0.236**	−0.139*	0.005		0.023
	(0.054)	(0.062)	(0.005)		(0.021)
1970	−0.246**	−0.116	0.012		0.041
	(0.070)	(0.075)	(0.008)		(0.026)
1980	−0.251**	−0.036	0.018*		−0.021
	(0.082)	(0.092)	(0.009)		(0.032)
1990	−0.223*	−0.026	0.024**		−0.013
	(0.094)	(0.107)	(0.008)		(0.039)
R^2	0.654	0.637	0.612	0.866	0.998
Sample counties	779	516	287	779	758

Notes: Each column reports estimates from equation (1) in the text for the indicated outcome variable. In columns 2, 3, and 5, manufacturing and retail data are combined with population data from the nearest decade and the estimated coefficients are pooled over the following years: 1945 and 1954 for 1950; 1959 and 1964 for 1960; 1969 and 1974 for 1970; 1978 and 1982 for 1980; 1987 and 1992 for 1990. All regressions are weighted by county population in 1930. Reported in parentheses are robust standard errors clustered by county.
**Significant at the 1 percent level.
*Significant at the 5 percent level.

Relative population declines appear to have been the main mechanism through which equilibrium in the labor market was reestablished. By 1940, the unemployment rate was only one percentage point higher in high-erosion counties and a statistically insignificant 0.3 percentage points higher in medium-erosion counties (column 4). By 1950, unemployment was no longer relatively higher in more-eroded counties. Direct data on income or wages is unavailable, but changes in per capita retail sales may serve as a proxy for changes in local consumption and earnings (Fishback, Horrace, and Kantor 2005).[44] From 1930 to 1940,

[44] Changes in retail sales will differ from changes in wages to the extent that there are changes in net savings or labor supply.

per capita retail sales declined by 12.2 percent and 6.6 percent in high-erosion and medium-erosion counties (column 5). Assuming a value of −0.3 to −0.6 for the elasticity of labor demand (Borjas 2003), the estimated relative population declines in a high-erosion county from 1940 to 1960 predict a 4.5 percent to six percent increase in wages and a 9.7 percent increase in income, compared to the estimated 5.6 percent recovery in per capita retail sales from 1940 to 1958.[45] In a medium-erosion county, the relative population declines predict a 4.4 percent to 5.9 percent increase in wages and a 9.5 percent increase in income, compared to the estimated 8.9 percent recovery in per capita retail sales. The population declines are of approximately the correct magnitude to explain observed labor market recovery through supply-side declines and no increase in labor demand. This pattern of results is similar to estimates by Blanchard and Katz (1992) for the United States in the second half of the twentieth century; in response to a negative shock, adjustment took place through relative population declines rather than increased industry.

D. *Potential Factors Contributing to Slow Agricultural Adjustment*

After the Dust Bowl, there was limited and slow adjustment within the agricultural sector; instead, relative population declines were the main margin of adjustment. Contemporaries discussed four main factors that may have discouraged agricultural adjustment, described in Section I: access to capital, small farm sizes, farm tenancy, and surplus labor. This section explores the potential role of these four factors, in addition to government agricultural policies.

Restricted access to capital may have constrained farmers' ability to adjust agricultural production. Indeed, high-erosion counties lost access to more banks during the 1930s than low-erosion or medium-erosion counties (Appendix Figure 2).[46] Even when banks remained open, decreased deposits and local economic weakness may have restricted banks' ability to lend. Bank weakness and bank failures can lead to persistent decreases in the local supply of credit (Bernanke 1983; Calomiris and Mason 2003; Ashcraft 2005), particularly in this era when banks were small and lent locally. Land-owning farmers also lost potential collateral when land values decreased substantially in more-eroded counties. Access to capital may have been restricted during the Great Depression, despite substantial compensatory efforts by the Farm Credit Administration and Farm Security Administration (Fishback, Kantor, and Wallis 2003).

To estimate the impact of factors that may affect agricultural adjustment, equation (1) is modified to examine heterogeneity in the response of different counties to erosion. Differences during the 1930s, such as bank failures or government credit programs, are potentially affected by the Dust Bowl; instead, the analysis focuses on variation in baseline county characteristics. Equation (2) includes interaction terms

[45] Estimates from Borjas (2003) imply that a ten percent decrease in population would increase wages by three percent to four percent, or increase income by 6.4 percent once individuals' labor supply adjusts.

[46] These estimates are from an annual version of equation (1), reporting annual residual differences by erosion level for the log number of banks open at the end of each year. Bank deposits experienced a similar decline in high-erosion counties.

between the log number of banks in 1928 (B) and the fraction of a county in high-erosion and medium-erosion areas:

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

The coefficient β_{5t} reports whether high-erosion counties changed differently than low-erosion counties when there were more banks, compared to the difference in changes between high-erosion counties and low-erosion counties when there were fewer banks (and β_{4t} for medium-erosion counties). Equation (2) controls for the main effect of banks and interactions between banks and lags of the county outcome. For ease of interpretation across different baseline characteristics, B is normalized to have a standard deviation of one.

The identification assumption is that counties with more banks in 1928 maintained better access to capital through the Dust Bowl, but otherwise would have made similar adjustments in agricultural land use. Estimates of β_{4t} and β_{5t} should be interpreted cautiously because it is a strong assumption that other county characteristics are not correlated with both the number of banks and counties' differential responses to erosion.

Table 5, column 1, reports that more-eroded counties with more banks immediately shifted land from cropland to pasture. In contrast, there was no difference in shifting land from wheat to hay (column 2). Livestock may require greater upfront capital expenditure than shifting between wheat and hay machinery, but the estimates may also reflect mixed support for the capital constraints hypothesis.[47]

Changing agricultural land use in a county may have required the reorganization of land ownership. Erosion-resistant activities, such as pasture and hay, are associated with a larger scale of production. After 1940, farm sizes generally increased on the Plains and there is some evidence of relative increases in more-eroded counties.[48] Tenants' incentives for short-term production may have discouraged land-use adjustment, though land owners often coordinate with tenants on inputs and crop choices (see, e.g., Alston and Higgs 1982, and Reid 1977).[49] After 1940, the fraction of farmland operated by tenants declined in aggregate and in more-eroded counties.[50] Farm size increases and declines in tenancy may have encouraged later land-use adjustments, though there is little evidence that areas with larger farm sizes or fewer tenants were able to adjust land use more immediately. Columns 3 to 6 (Table 5) report estimates from a version of equation (2) that replaces the number of banks with the

[47] Greater bank deposits also predict more adjustment from cropland to pasture, though these effects are marginally statistically insignificant until 1950.

[48] From estimating equation (1), farm sizes increased five percent to nine percent in high-erosion counties and were relatively unchanged in medium-erosion counties, relative to changes in low-erosion counties.

[49] Using data from 1930, 1940, and 1950, equation (1) can be estimated separately for tenants and nontenants and there is little evidence for slower land-use adjustment among tenants. There is some evidence for faster land-use adjustment among tenants, though changes in land tenancy make these estimates difficult to interpret.

[50] From estimating equation (1), land tenancy shares declined from 1940 to 1960 by seven percentage points in high-erosion counties and three percentage points in medium-erosion counties, relative to changes in low-erosion counties. From 1930 to 1940, land tenancy had increased relatively by five percentage points in high-erosion counties and two percentage points in low-erosion counties.

Table 5—Estimated Changes in Agricultural Land Use after 1930, Interacted with County Precharacteristics

	Relative adjustment in areas with one standard deviation:							
	More banks		Larger farms		Less tenant farming		Less dense farm population	
	Land share in cropland (1)	Land share in wheat (2)	Land share in cropland (3)	Land share in wheat (4)	Land share in cropland (5)	Land share in wheat (6)	Land share in cropland (7)	Land share in wheat (8)
Panel A. High erosion versus low erosion								
1940	−0.043**	0.026	0.025*	−0.010	0.018	0.008	0.030**	−0.005
	(0.015)	(0.019)	(0.011)	(0.017)	(0.009)	(0.017)	(0.011)	(0.018)
1945	−0.038*		0.014		0.006		0.021	
	(0.017)		(0.014)		(0.011)		(0.014)	
1950–1954	−0.056**	0.007	0.034*	−0.034	0.019	−0.057**	0.040*	−0.034
	(0.019)	(0.021)	(0.017)	(0.020)	(0.015)	(0.019)	(0.016)	(0.020)
1959–1964	−0.058**	0.016	0.027	−0.008	0.018	−0.033	0.037	−0.006
	(0.021)	(0.022)	(0.020)	(0.023)	(0.017)	(0.023)	(0.019)	(0.022)
Panel B. Medium erosion versus low erosion								
1940	−0.019**	−0.010	0.010	0.020	0.009	0.012	0.013	0.024
	(0.006)	(0.012)	(0.007)	(0.014)	(0.007)	(0.013)	(0.007)	(0.014)
1945	−0.019**		0.004		−0.005		0.005	
	(0.007)		(0.008)		(0.008)		(0.008)	
1950–1954	−0.011	−0.002	0.000	−0.027	−0.015	−0.052**	0.002	−0.021
	(0.009)	(0.017)	(0.012)	(0.018)	(0.012)	(0.016)	(0.012)	(0.017)
1959–1964	−0.015	0.002	0.006	−0.021	−0.020	−0.055**	0.007	−0.009
	(0.011)	(0.017)	(0.015)	(0.019)	(0.016)	(0.017)	(0.015)	(0.019)
R^2	0.695	0.468	0.688	0.472	0.689	0.491	0.689	0.480
Sample counties	705	705	705	705	705	705	705	705
Weighted by 1930:	Cropland + Pasture	Wheat + Hay	Cropland + Pasture	Wheat + Hay	Cropland + Pasture	Wheat + Hay	Cropland + Pasture	Wheat + Hay

Notes: Each column reports estimates from equation (2) in the text for the indicated outcome variable. For columns 1 and 2, the interaction term is the log number of banks at the end of 1928. For columns 3 and 4, the interaction term is the log average farm size in 1930. For columns 5 and 6, the interaction term is the tenant share of farmland in 1930. For columns 7 and 8 the interaction term is the log farm population per acre of farmland in 1930. All interaction terms are normalized to have mean zero and standard deviation of one (negative one for columns 5–8). Reported in parentheses are robust standard errors clustered by county.

** Significant at the 1 percent level.

* Significant at the 5 percent level.

average size of farms (columns 3 and 4) or the tenant share of farmland (columns 5 and 6).

Surplus agricultural labor and temporarily lower wages may have discouraged faster land-use adjustment in more-eroded counties, as cropland and wheat are more labor-intensive than pasture and hay. Agricultural land use shifted toward less labor-intensive activities after relative population declines had ceased. Consistent with lower agricultural wages (or capital constraints), more-eroded counties experienced an immediate relative increase in the agricultural labor-to-capital ratio.[51] There is no evidence, however, of more immediate land-use adjustment among more-eroded counties with initially fewer people living on farms per acre of farmland (Table 5, columns 7 and 8).

[51] Equation (1) is estimated for log number of people living on farms per dollar invested in equipment and machinery on farms. In high-erosion counties, the ratio increased temporarily after 1930: 15.3 percent (4.8) by 1940, 1.2 percent (4.4) by 1945, and 7.8 percent (4.7) by 1969. In medium-erosion counties the ratio increased temporarily after 1930: 11.1 percent (3.9) by 1940, 2.0 percent (3.6) by 1945, and 4.9 percent (3.9) by 1969.

Table 6—Estimated Differences in Government Payments per Farm Acre, by Erosion Level

		Relative to low erosion:		
	All Counties (1)	Medium Erosion (2)	High Erosion (3)	Difference: (3) − (2) (4)
Panel A. New Deal payments (1933–39)				
AAA payments	0.459	0.012	−0.030	−0.042*
	[0.325]	(0.016)	(0.022)	(0.021)
Public works spending	0.229	0.019	−0.055	−0.074
	[0.568]	(0.049)	(0.060)	(0.061)
Relief spending	0.426	0.099	0.167	0.068
	[2.167]	(0.075)	(0.107)	(0.091)
New Deal loans	0.446	−0.058	−0.037	0.021
	[1.094]	(0.080)	(0.095)	(0.080)
Mortgage loans guaranteed	0.112	0.018	−0.067	−0.085*
	[0.801]	(0.033)	(0.050)	(0.039)
Panel B. Government payments in 1992				
Conservation Reserve Program	1.430	0.713**	1.333**	0.619**
	[1.298]	(0.140)	(0.226)	(0.211)
All government payments	6.659	−0.666	−1.655**	−0.989*
	[5.206]	(0.408)	(0.507)	(0.464)
Fraction of payments through CRP	0.248	0.065**	0.162**	0.096**
	[0.158]	(0.020)	(0.027)	(0.024)

Notes: Panel A reports differences in 1930's New Deal spending across 776 counties. Panel B reports differences in conservation reserve program (CRP) payments in 1992, all government payments in 1992, and the fraction of payments through the CRP in 1992. Column 1 reports the mean and standard deviation in brackets. Column 2 (column 3) reports the average difference for medium-erosion counties (high-erosion counties) relative to low-erosion counties, controlling for state fixed effects and county characteristics in panels B–E of Table 1, and lagged values of the characteristics. Column 4 reports the difference in coefficients between columns 2 and 3. The means and regressions are weighted by county farmland in 1930. Robust standard errors are reported in parentheses.
** Significant at the 1 percent level.
* Significant at the 5 percent level.

The government intervened substantially in agricultural markets during the 1930s and after, and some of these policies may have discouraged agricultural adjustment. Crop payments and price supports encouraged continued farming, though some conservation payments and crop acreage restrictions discouraged wheat and cropland in favor of pasture and hay. Government programs provided direct relief, payments for crop reductions, farm and housing credit, and public works employment, but there is no evidence of differential 1930s New Deal payments to more-eroded counties (Table 6). In the 1990s, more-eroded counties received greater payments from the Conservation Reserve Program (CRP) to take damaged lands out of production (precluding other agricultural payments). Estimated higher take-up of the CRP is consistent with more-eroded counties persisting in the agricultural use of lower-quality damaged farmland.

Dust Bowl erosion affected agriculture across a wide range of Plains counties, which included a variety of agricultural enterprises. When splitting the main analysis into more homogeneous subsamples of counties, more-eroded areas generally experience large land value declines, persistent agricultural costs, limited adjustment in agricultural production, and population declines.[52] This subsample analysis

[52] The regressions were estimated separately on 12 subsamples of counties that were above or below the median of six different county characteristics in 1930: acres of cropland per acre of farmland; acres of corn per acre of

is consistent with estimates from equation (2), as there do not appear to be clear agricultural characteristics that enabled more-eroded counties to mitigate quickly the impacts of Dust Bowl erosion.

VI. Conclusion

The 1930s American Dust Bowl imposed substantial agricultural costs in more-eroded Plains counties, relative to less-eroded Plains counties. From 1930 to 1940, more-eroded counties experienced large and permanent relative declines in agricultural land values: the per acre value of farmland declined by 30 percent in high-erosion counties and declined by 17 percent in medium-erosion counties, relative to changes in low-erosion counties. It is difficult to quantify the aggregate cost of the Dust Bowl, however, as declines in productive farmland may have increased land values in low-erosion counties.

Relative adjustments in agricultural land use were slow and limited, despite the availability of productive land-use adjustments recommended by contemporary state agricultural experiment stations and extension services. Consistent with these contemporaries' hypotheses, credit constraints may have limited agricultural adjustment. More-eroded counties had greater declines in access to credit during the 1930s and there was greater land-use adjustment in more-eroded counties that had more banks prior to the 1930s. There is more limited evidence that land-use adjustment was slowed by contemporaries' other hypothesized explanations (small farm sizes, land tenancy, or farm labor surpluses). Estimated relative changes in land values and revenues imply that agricultural adjustments recovered less than 25 percent of the initial relative cost in more-eroded counties.

The main margin of economic adjustment was large relative population declines in more-eroded counties. From 1930 to 1940, populations declined by 12 percent in high-erosion counties and declined by 9 percent in medium-erosion counties, relative to changes in low-erosion counties. These estimates are consistent with historical accounts of substantial out-migration, though the estimated relative population declines overstate out-migration to the extent that migrants moved to low-erosion counties. The Great Depression may have limited outside employment opportunities and, by 1940, population adjustment remained incomplete: unemployment was higher, a proxy for wages was lower, and the labor-capital ratio in agriculture was higher. These indicators recovered as large relative population declines continued through the 1950s.

The Dust Bowl provides a detailed context in which to examine economic adjustment to a permanent change in environmental conditions. The Great Depression may have slowed adjustment by limiting access to capital or outside employment opportunities. Agricultural adjustment continued to be slow, however, through the 1940s and 1950s. Further research on historical shocks may help understand what conditions facilitate long-run economic adjustment. The experience of the American Dust Bowl highlights that agricultural costs from environmental destruction need not be mitigated mostly by agricultural adjustments, and that economic adjustment may require a substantial relative decline in population.

cropland; acres of wheat per acre of cropland; number of cows per county acre; acres of farmland per farm; and number of people on farms per acre of farmland.

Data Appendix

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 a small category of "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. 1925–1974.

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 cotton and oats/barley/rye, included as controls for 1925 and 1930 (missing values are treated as zeros).

Cattle, *Swine*, *Chickens.* Number of cattle and swine in 1910–1930, number of chickens in 1920–1930.

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 including buildings) is available in 1910, 1920, 1930, and 1940.

Revenue. Crop revenue and animal revenue. 1910–1992, except 1974.

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

Animal Revenue. Value of all animal products sold and animals sold, prior year. 1910–1964. From 1920 to 1930, animal revenue is not directly reported but the total value of animals is reported. The ratio of animal revenue to total value of animals 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). When the revenue/stock ratio is unavailable in 1910, the ratio is used from 1940.

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

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

Agricultural 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 2,500 inhabitants. 1910–1970.

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

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. 1920, 1930, 1940, 1958, 1967, 1987.
Manufacturing Establishments. 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

There is no direct measure of erosion levels prior to the 1930s, as detailed erosion surveys were funded in response to the Dust Bowl. The main empirical analysis uses cumulative post-1930s erosion damage as a proxy for differential erosion during the 1930s, and the control variables in equation (1) are intended to proxy for any correlation between pre-1930s erosion and later changes in the outcome variable.

In the absence of sufficient control variables, an empirical concern is that areas with high-erosion and medium-erosion by the 1920s may have experienced a substantial land value decline in the 1930s even if the Dust Bowl had not occurred. The cumulative erosion map in Figure 2 was prepared by the Soil Conservation Service for the entire country, and many areas outside these Dust Bowl states were classified as being high-erosion or medium-erosion. Counties in other states were not directly eroded by the Dust Bowl and so much of this high erosion and medium erosion is more likely to reflect higher erosion levels by the 1920s. Restricting the analysis to these non-Dust Bowl states, a falsification exercise compares changes in the log value of agricultural land per acre of farmland in high-erosion and medium-erosion counties, relative to changes in low-erosion counties in the same state.

The dashed line in Figure A1, panel A, graphs the estimated relative differences in land values between high-erosion and low-erosion counties in non-Dust Bowl states. By comparison, the solid line graphs the estimated relative differences in land values between high-erosion and low-erosion counties in the Dust Bowl sample states (from Figure 3, panel A). Panel B graphs the relative differences between medium-erosion and low-erosion counties. From 1930 to 1940, relative land values declined more sharply in Dust Bowl states than in non-Dust Bowl states, as counties with baseline erosion differences changed similarly in non-Dust Bowl states. Prior to 1930, more-eroded counties had relatively higher land values in Dust Bowl states compared to the relative differences in non-Dust Bowl states, consistent with more of the measured post-1930s erosion having not yet occurred in Dust Bowl states.

In another specification check, instrumenting for post-1930s erosion levels may focus the empirical analysis on variation in erosion that occurred during the 1930s. Dust Bowl erosion was partly caused by severe drought during the 1930s, which is the worst recorded drought on the Plains. Appendix Table 1 reports estimates from regressing the fraction of a county in high erosion (column 1) and medium erosion (column 2) on: the number of months during the 1930s that a county was in extreme drought, severe drought, and moderate drought; the average 1930s drought level; the average annual 1930s temperature; and the standard deviation of

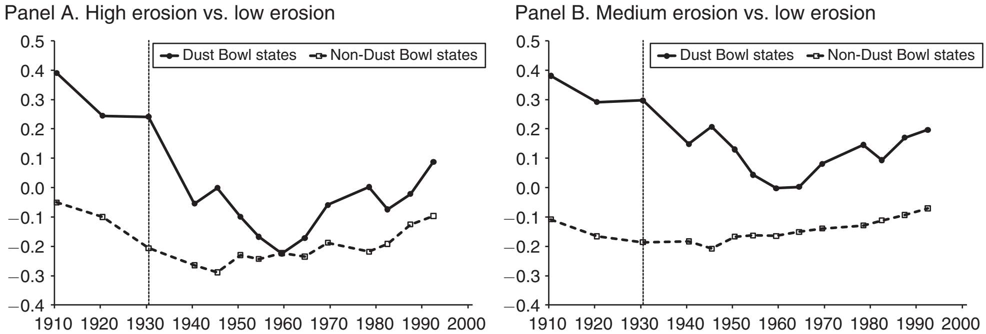

Figure A1. Estimated Differences by Erosion Level in Log Value of Farmland: Dust Bowl vs. Non-Dust Bowl States

Notes: The solid line in both panels corresponds to estimated within-state differences by erosion level in the log value of agricultural land and buildings per acre of farmland (from panel A of Figure 3), for the 779 sample counties in Figure 2. The dashed line in both panels corresponds to estimated within-state differences by erosion level for 1,848 counties in other US states (not those depicted in Figure 2). Panel A reports the difference between high-erosion and medium-erosion counties; panel B reports the difference between medium-erosion and low-erosion counties.

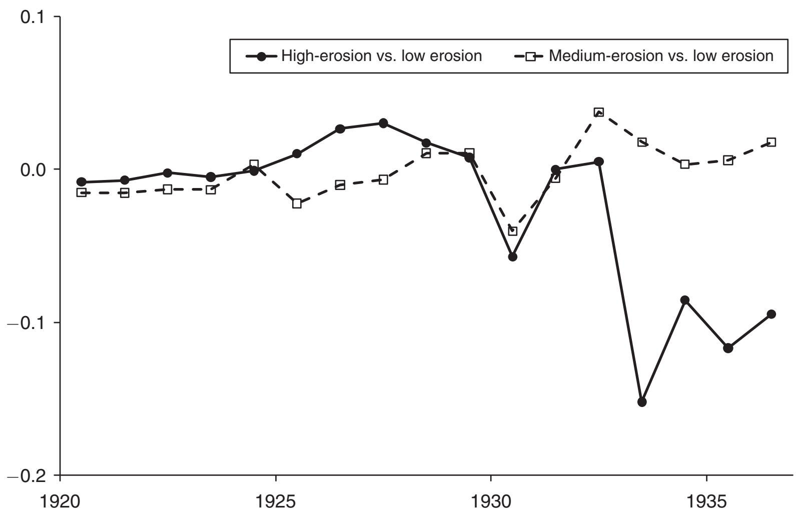

Figure A2. Estimated Differences in Log Number of Local Banks at Year End, by Erosion Level

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

temperatures in the 1930s.[53] The specifications control for the same drought and temperature variables from 1895 to 1929, to adjust for average climate differences among counties.

[53] The specifications control for the same variables as in equation (1). Drought is measured by the Palmer Drought Severity Index (PDSI), and extreme/severe/moderate drought reflects conventional cutoffs in the PDSI. High and extreme temperatures contribute to drought, crop failure, and erosion on bare farmland. Data were collected at weather stations and the PDSI is reported by district (ten districts to a state). See ftp://ftp.ncdc.noaa.gov/pub/data/cirs/.

Table A1—Estimated Effects of 1930s Weather on Erosion, and Instrumental Variables Estimates for Changes in Land Values from 1930 to 1940

	First stage: Fraction high-erosion (1)	First stage: Fraction medium-erosion (2)	Change in land value, 1930–1940: 2SLS (3)	Change in land value, 1930–1940: OLS (4)
Panel A. Erosion level				
High-erosion versus low-erosion			−0.996**	−0.312**
			(0.229)	(0.037)
Medium-erosion versus low-erosion			−0.137	−0.175**
			(0.175)	(0.031)
Panel B. Weather instruments				
Months in extreme drought, 1930s	0.0070**	0.0056*		
	(0.0018)	(0.0028)		
Months in severe drought, 1930s	0.0020	0.0085**		
	(0.0015)	(0.0023)		
Months in moderate drought, 1930s	0.0001	0.0038		
	(0.0016)	(0.0024)		
Average Palmer Drought Severity, 1930s	0.0897**	0.1640**		
	(0.0313)	(0.0578)		
Average annual temperature, 1930s	−0.0277	0.0957*		
	(0.0254)	(0.0413)		
Temperature standard deviation, 1930s	0.1209*	0.1424		
	(0.0518)	(0.0863)		
F-stat: Instruments	8.376	52.77		
p-value: Instruments = 0	0.0002	0.0000		
Sample counties	776	776	776	776

Notes: Column 1 reports first-stage estimates from regressing the fraction of a county in high-erosion areas on the 1930s weather instruments, controlling for the same weather variables from 1895–1929 and the county controls included 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 1930s weather instruments. Column 4 reports OLS estimates (as in Table 2), with the same controls and sample as column 3. Robust standard errors are reported in parentheses.

** Significant at the 1 percent level.

* Significant at the 5 percent level.

Months of extreme drought, average drought, and temperature extremes during the 1930s are predictive of high erosion, while months of less extreme drought are also predictive of medium erosion. These estimates suggest that a meaningful portion of measured post-1930s erosion levels reflect erosion that took place during the 1930s.

Interpreting these first-stage estimates requires weather shocks to be random, but interpreting 2SLS estimates requires a stronger assumption that 1930s weather only affects changes in the outcome variable through its impacts on erosion. Temporary weather shocks may have some direct effects on changes in land values from 1930 to 1940, but this exclusion restriction is especially likely to fail for other county outcomes (e.g., population, capital investments, or even revenue). Column 3 reports the 2SLS estimates and column 4 reports OLS estimates for the same sample and control variables. When instrumenting for erosion levels, high-erosion counties experienced a much larger relative decline in land values and medium-erosion counties experienced an imprecise similar relative decline, compared to changes in low-erosion counties.[54] The implied reduced-form results have a more cautious interpretation: 1930s weather appears to predict higher erosion and declining land values. These estimates are consistent with higher measured erosion levels partly reflecting the 1930s Dust Bowl and causing persistent agricultural costs.

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[54] The OLS estimates may be positively biased if lands becoming more valuable were farmed intensely during the 1930s and this caused greater erosion; the OLS estimates may be negatively biased if lands becoming less valuable were not protected from erosion. The OLS estimates may also be attenuated by measurement error in erosion.

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1. SOLOMON M. HSIANG, DAIJU NARITA. 2012. ADAPTATION TO CYCLONE RISK: EVIDENCE FROM THE GLOBAL CROSS-SECTION. *Climate Change Economics* **03**:02, 1250011. [CrossRef]