Nature versus Nurture: The Environment's Persistent Influence through the Modernization of American Agriculture

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Enrivonmental challenges are projected to increase through the 21st century, and it is natural to consider how new technologies change agricultural dependence on the environment. Technological innovation in agriculture was substantial during the 20th century. Is there a progression toward "modern" technological control of the environment that replaces a "primitive" dependency on natural advantages and disadvantages? Alternatively, even as new technologies are introduced, is there a persistent dependence of agricultural production on the environment? There often appears to be a wide dispersion of views implicit among economists, environmental historians, scientists, and others on how much technology mitigates the importance of environmental differences and, in turn, how future environment differences will affect the economy.

The development of the United States' Great Plains offers historical perspective on this fundamental relationship between technology and the environment. During the 20th century, increased availability of commercial fertilizers compensated for soil nutrient deficiencies. Center pivot irrigation machinery and improved pumps made groundwater from the Ogallala aquifer available in otherwise arid Plains regions (Hornbeck and Keskin, 2011). There was substantial mechanical innovation in tractors and harvesters; as well as biological innovation in crop varieties (Olmstead and Rhode, 2008), such as hybrid corn (Griliches, 1957; Sutch, 2010). Some agricultural technologies compensate for environmental disadvantages and other technologies exploit environmental advantages; on average, technological innovation may decrease or increase agricultural dependence on the environment.

This paper estimates how the 20th century modernization of Plains agriculture changed the impact of environmental characteristics on agricultural land values. There is substantial variation among Plains counties in soil type, average precipitation, and average temperature.[1] The relative importance of these environmental characteristics for agricultural production are capitalized by differences in agricultural land values, available every five years. From a regression of county land values in each time period on 21 soil type shares, 20 average precipitation bins, or 20 average temperature bins, the dispersion of the estimated coefficients indicates the relative influence of each environmental characteristic.

Despite substantial technological innovation and rising agricultural land values from 1945 to 2002, counties' environmental characteristics largely maintained influence on land values. Initially more-valuable environmental characteristics remained more-valuable; indeed, there was little convergence in the estimated group coefficients for each of the three environmental characteristics.[2] Most convergence in relative land values occured before 1945, consistent

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[1] By limiting the sample to the United States and the Great Plains region, the analysis focuses on areas with similar agricultural technologies, labor and capital markets, goods markets, and institutions. Plains agricultural land values are also relatively unaffected by the small urban land sector.

[2] These results are consistent with the enduring impact of Dust Bowl erosion on Plains counties' land values (Hornbeck, 2011). Agricultural adaptation mitigated only a small share of the initial losses from erosion, and technological improvements were not biased toward more-eroded areas. Similarly, despite large increases in US crop yields during the 20th century, crop yields remain persistently sensitive to extreme heat (Schlenker and Roberts, 2009, 2010).

with delayed settlement of environmentally-disadvantaged areas.[3]

I. Theory

The empirical analysis draws on a Ricardian-style model, in which agricultural land values reflect the production possibility frontier (see, e.g., Mendelsohn, Nordhaus and Shaw, 1994). The value of land in county c and time t is a function of the broadly-defined technological frontier A_t and a county's environment E_c: $V_{ct}(A_t, E_c)$. In this stylized model, changes in the technological frontier are unexpected.[4] County environmental characteristics are distributed among G discrete values.

First, it is useful to consider whether a change in technology preserves environmental advantages or disadvantages.

Definition 1. *A change in technology from* A_1 *to* A_2 **preserves environmental rank** *of* $(i,j) \in G$ *if* $V_{i1}(A_1, E_i) \geq V_{j1}(A_1, E_j)$ *implies that* $V_{i2}(A_2, E_i) \geq V_{j2}(A_2, E_j)$.

Second, it is useful to consider how technological change affects the dispersion of environmental advantages or disadvantages.

Definition 2. *A change in technology from* A_1 *to* A_2 *is* **environment-neutral** *if the standard deviation of land values over environmental characteristics is constant:*

$$(1) \qquad \sqrt{\frac{\sum_{i=1}^{G}\left(V_{i2}-\overline{V_2}\right)^2}{G-1}} - \sqrt{\frac{\sum_{i=1}^{G}\left(V_{i1}-\overline{V_1}\right)^2}{G-1}} = 0.$$

By contrast, a change in technology from A_1 *to* A_2 *leads to* **environmental convergence** *if equation (1)* < 0 *and* **environmental divergence** *if equation (1)* > 0.

II. Data Construction

County-level data are drawn from the US Census of Agriculture (Gutmann, 2005; Haines, 2005). From 1920 to 2002, every five years, the main variable of interest is the value of agricultural land and buildings per county acre.[5] The sample is a balanced panel of 967 Plains counties, from 1920 to 2002, with county borders held constant at 1920 definitions (Hornbeck, 2010).[6]

In the sample region, in aggregate, the fraction of county land settled in farms increased from 0.6 in 1920 to 0.75 in the 1940's, and remained similar through 2002. The nominal value of all agricultural farmland declined moderately from 1920 through 1945, reflecting declining agricultural prices and the Dust Bowl, and increased more than three-fold from 1945 through 2002. The real value of agricultural farmland, deflated by a national farm producer price index (NBER), was more constant and increased mainly from 1945 through the 1960's.

County-level environmental characteristics are measured using major soil type, average precipitation, and average temperature. There are 21 major soil groups in the sample region, as defined by the Soil Conservation Service in 1951 (Soil Conservation Service, 1951), though some soil groups cover substantially more area than other groups.[7] County-level average precipitation and average temperature reflect average weather from 1940 to 2000 (PRISM Climate Group, 2004). Counties are separated into 20 groups by average precipitation and 20 groups by average temperature.

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[3] American agriculture has expanded substantially into new climates (Olmstead and Rhode, 2011).

[4] In practice, some portion of technological change is unexpected and the discount rate is sufficiently high, such that land values largely reflect contemporaneous technology.

[5] In periods when data on land values and building values are separately available, the value of land is the largest component of this combined measure. Data are self-reported by farmers, and unsettled land is assumed to have zero agricultural value.

[6] The sample includes counties in Colorado, Iowa, Kansas, Minnesota, Nebraska, New Mexico, North Dakota, Oklahoma, South Dakota, Texas, and Wyoming.

[7] A 1951 SCS map was scanned, traced in GIS software, and merged to 1920 county borders to assign each county the fraction of its area in each soil group (Hornbeck and Keskin, 2011).

III. Empirical Framework

In the first empirical step, average values by soil group and year are estimated by regressing the log real value of agricultural land and buildings per county acre on the share of county land in each soil group:

$$(2) \quad LogV_{ct} = \sum_{i=1}^{G} \theta_{it} Share_c^i + \epsilon_{ct}.$$

For the 20 average precipitation groups and 20 average temperature groups, land values are simply regressed on group-by-year fixed effects. The regressions are weighted by county area, as larger counties represent a larger sample of land values.

In the second empirical step, for each of the three environmental characteristics, the cross-group standard deviation is estimated in each time period:

$$(3) \qquad \sigma_t = \sqrt{\frac{\sum_{i=1}^{G} (\theta_{it} - \overline{\theta}_t)^2}{G-1}}.$$

The standard deviation formula is weighted by group area, as mean land values (θ_{it}) are estimated more precisely for larger groups.

IV. Results

Figure 1 graphs the estimated coefficients from equation (2) for soil groups (Panel A), average temperature groups (Panel B), and average precipitation groups (Panel C). In each panel, changes over time generally **preserve environmental rank**; that is, for each pairwise comparison, the more-valuable environmental feature generally remains more-valuable over time.

Consistent with broad improvements in technology, low-value environmental features in 2002 are of similar real value to average-value or high-value environmental features in 1920. There remains substantial dispersion among the estimated coefficients, however, with little change in dispersion after 1945 as real values increased.[8]

Figure 2 graphs the area-weighted standard deviation over soil groups (Panel A), average temperature groups (Panel B), and average precipitation groups (Panel C). There has been some **environmental convergence**, but mostly before the 1945 as the region was becoming increasingly settled. From 1945 through 2002, during most of the increase in real land values, technological change has been mainly **environment-neutral**.[9]

V. Conclusion

Projected changes in the environment will impose greater economic costs if there is less adaptation (Mendelsohn, Nordhaus and Shaw, 1994; Schlenker, Hanemann and Fisher, 2006; Deschenes and Greenstone, 2007; Guiteras, 2009; Dell, Jones and Olken, 2011). While new agricultural technologies may be developed in response to environmental changes, all new technologies generate rents and innovation need not be directed toward overcoming environmental disadvantages.

On average, during the later half of the 20th century, substantial advances in agricultural technology on the United States' Plains have not reduced the importance of natural advantages or disadvantages; instead, environmental characteristics have largely maintained relative influence on agricultural land values. Further research may extend this analysis to other time periods and regions, broadening our understanding of this fundamental relationship between technology and the environment.

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[8] It is difficult to display group precision in Figure 1; in Panel A, two rare soil groups that cover less than 0.5% of the sample region are omitted for clarity. The two omitted soil groups have low and highly variable estimated land values, with little convergence over time. The estimated standard deviations in Figure 2a include all groups, weighted by group land area.

[9] Changes in the standard deviation are similar when equations (2) and/or (3) are not weighted by land area.

REFERENCES

Dell, Melissa, Benjamin F. Jones, and Benjamin A. Olken. 2011. "Temperature Shocks and Economic Growth: Evidence from the Last Half Century." August, Mimeo.

Deschenes, Olivier, and Michael Greenstone. 2007. "The Economic Impacts of Climate Change: Evidence from Agricultural Output and Random Fluctuations in Weather." *American Economic Review*, 97(1): 354–385.

Griliches, Zvi. 1957. "Hybrid Corn: An Exploration in the Economics of Technological Change." *Econometrica*, 25(4): 501–522.

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

Gutmann, Myron P. 2005. "Great Plains Population and Environment Data: Agricultural Data."

Haines, Michael R. 2005. "Historical, Demographic, Economic, and Social Data: The United States, 1790-2000."

Hornbeck, Richard. 2010. "Barbed Wire: Property Rights and Agricultural Development." *Quarterly Journal of Economics*, 125: 767–810.

Hornbeck, Richard. 2011. "The Enduring Impact of the American Dust Bowl: Short and Long-run Adjustments to Environmental Catastrophe." *American Economic Review*. Forthcoming.

Hornbeck, Richard, and Pinar Keskin. 2011. "The Evolving Impact of the Ogallala Aquifer: Agricultural Adaptation to Groundwater and Climate." Mimeo.

Mendelsohn, Robert, William D. Nordhaus, and Daigee Shaw. 1994. "The impact of global warming on agriculture: A Ricardian analysis." *American Economic Review*, 84(4): 753–771.

Olmstead, Alan, and Paul Rhode. 2008. *Creating Abundance: Biological Innovation and American Agricultural Development.* Cambridge University Press.

Olmstead, Alan, and Paul Rhode. 2011. "Adapting North American wheat production to climatic challenges, 1839 - 2009." *PNAS*, 108(2): 480–485.

PRISM Climate Group. 2004. "http://prism.oregonstate.edu."

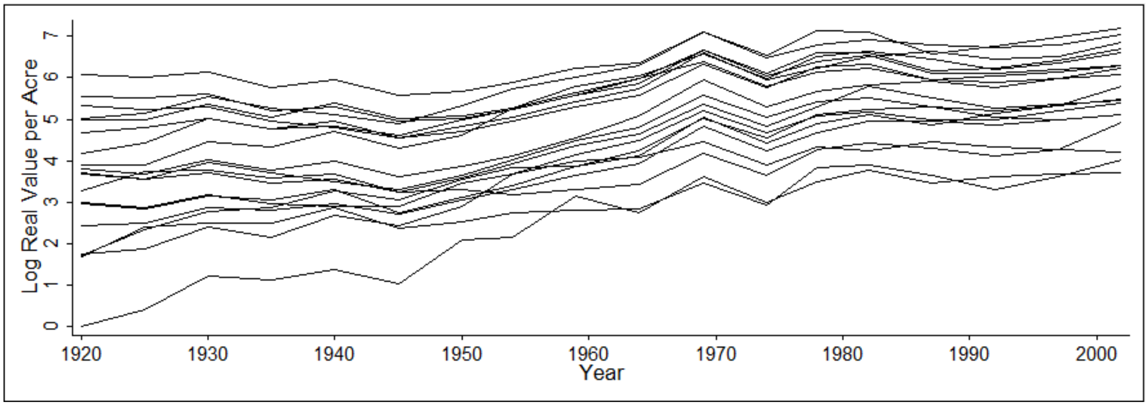
Schlenker, Wolfram, and Michael J. Roberts. 2009. "Nonlinear temperature effects indicate severe damages to U.S. crop yields under climate change." *PNAS*, 106(37): 15594–98.

Schlenker, Wolfram, and Michael J. Roberts. 2010. "The Evolution of Heat Tolerance of Corn: Implications for Climate Change." In *The Economics of Climate Change: Adaptations Past and Present.* , ed. G. Libecap and R.H. Steckel, 225–251. Chicago:University of Chicago Press.

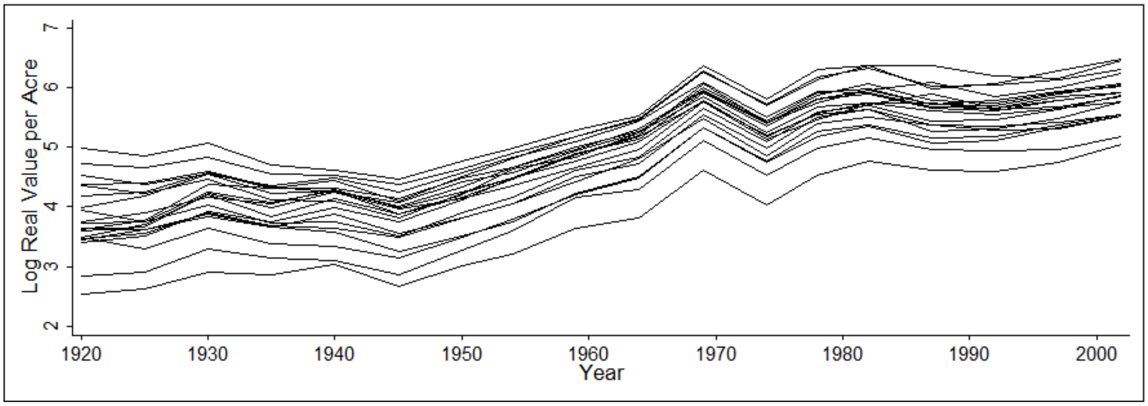
Schlenker, Wolfram, W. Michael Hanemann, and Anthony C. Fisher. 2006. "The Impact of Global Warming on U.S. Agriculture: An Econometric Analysis of Optimal Growing Conditions." *Review of Economics and Statistics*, 88(1): 113–125.

Soil Conservation Service. 1951. "Map of Major Soil Groups." National Archives Record Group 114, item 148.

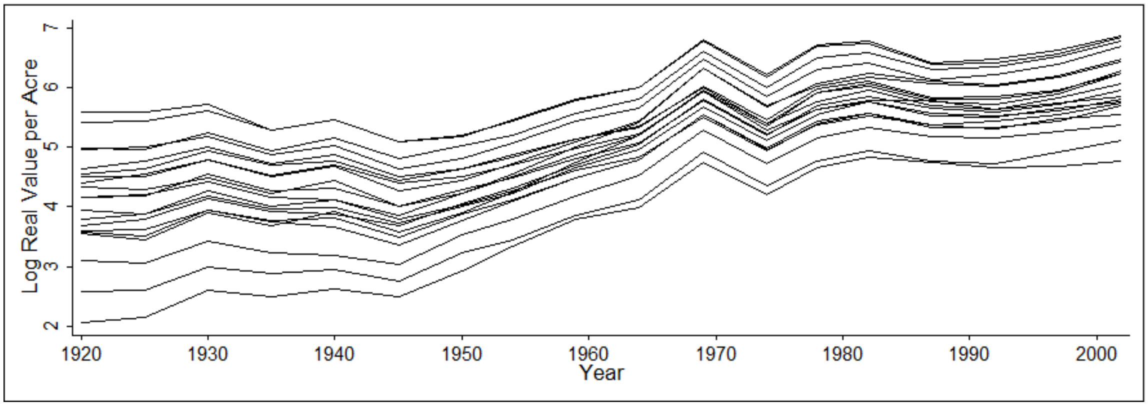
Sutch, Richard. 2010. "The Impact of the 1936 Corn Belt Drought on American Farmers' Adoption of Hybrid Corn." In *The Economics of Climate Change: Adaptations Past and Present.* , ed. G. Libecap and R.H. Steckel, 195–223. Chicago:University of Chicago Press.



(a) By Soil Type



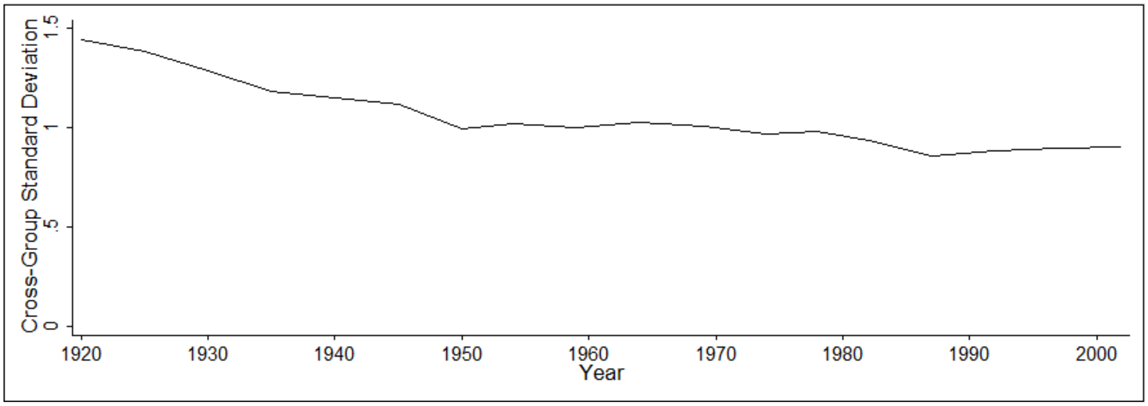
(b) By Average Temperature



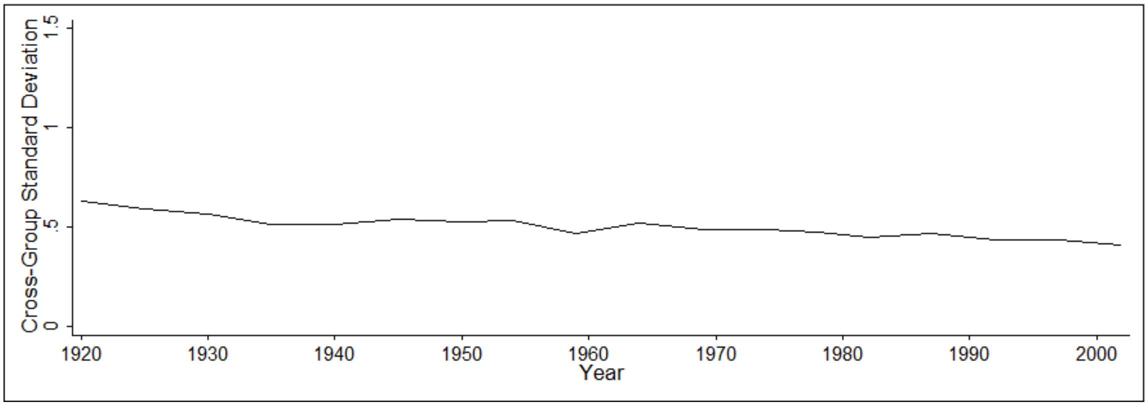
(c) By Average Precipitation

Figure 1. : Estimated Mean Land Value, by Environmental Characteristic

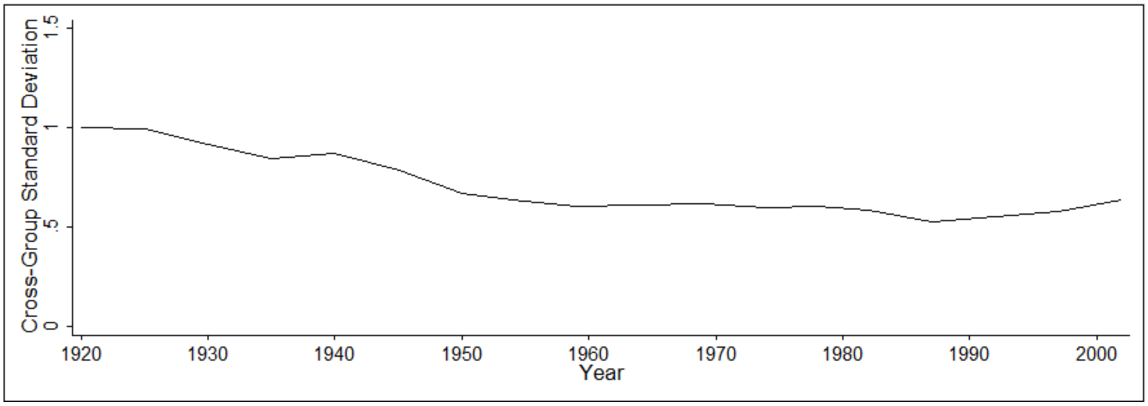
Note: In panel A, each line reflects the average log real value of agricultural land and buildings per county acre for a particular major soil group on the US Plains from 1920 to 2002 (see equation 2 in the text). In panels B and C, each line reflects average land values for counties within a particular range of average temperature and precipitation, respectively.



(a) Soil Type



(b) Average Temperature



(c) Average Precipitation

Figure 2. : Standard Deviation in Group Land Values, by Environmental Characteristic

Note: In each time period, from 1920 to 2002, panel A graphs the area-weighted standard deviation in average land values by major soil group (shown in Figure 1a). Panels B and C graph the area-weighted standard deviation in average land values by average temperature group and average precipitation group, respectively.