Online Appendix: Environmental Recovery after the Dust Bowl: Implication of Land Policies in the Great Plains

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Appendices

A Conceptual Model

The Dust Bowl changed the federal budget in a discontinuous fashion. After the initial jump in the budget allocation, the intensity of the policy was much lower. We can see this in a graph (Fig-1). The initial high jump in funding in 1930s includes the initial push in funding for better topsoil base after the Dust Bowl and also includes all institutional and legal changes made in the first Farm Bills. Later on, farmland conservation policies continued to pay farmers for topsoil conservation but the rate of payment was much lower. Our purpose is to see the persistent effect of this initial structure, and also the annual continuous effects of the policies. In this section we model an individual farmer's investment in environmental quality to understand the difference between persistent and continuous effects of the federal policies.

For a farmer, the objective is to maximize the discounted stream of profits attainable with input package Z and grassland G. The production function is denoted by f. The unit cost of production is C. The state variable is the grassland stock G. The control variable is the input Z. Assume that the post-Dust Bowl policy shifts happened at time period t_0 to t_1. We expect a persistent change in the grassland areas because of this timing. After t_1, the policy slowed down and there may still be annual immediate effects from the policy. This creates an optimal change in the state equation during the period t_1 to t_f. Farmers will participate as long as the discounted expected profit is higher than the discounted expected profit from non-participation. In characterizing relative adjustment with time, assume that a farmer chooses input decisions in every period to maximize the present value of profit. Initial shock prompts taking decisions at an extensive margin. The problem becomes:

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$$\max G_t = e^{-rt}\int_{t_0}^{t_1}[Pf^1(Z(t),G(t),t) - C^1 f(Z(t),G(t),t) + s(G(t))]dt$$
$$+ e^{-rt}\int_{t_1}^{t_f}[Pf^2(Z(t),G(t),t) - C^2 f(Z(t),G(t),t)+$$
$$s(G(t))]dt - \phi(Z(t_1),G(t_1),t) \quad (1)$$

subject to

$$G'(t) = g^1(Z(t),G(t),t), \quad t_0 \leq t \leq t_1 \quad (2)$$

$$G'(t) = g^2(Z(t),G(t),t), \quad t_1 \leq t \leq t_f \quad (3)$$

$$G(t_0) = G_0; \quad (4)$$

$$t_1, \quad G(t_1), \quad t_2, \quad G(t_2) \quad free; \quad (5)$$

f^1 and f^2 are two possibly different objective function, and ϕ is the cost of changing the state equation from f^1 to f^2 at t_1. Solution involves forming Hamiltonians H^1 for t_0 $\leq$ t $\leq$ t_1 and H^2 for t_1 $\leq$ t $\leq$ t_f. The initial push for soil base limits the available land for the second period. Hamiltonian equations are:

$$H^1 = f^1 + \lambda_1 g_1 \quad (6)$$

$$H^2 = f^2 + \lambda_2 g_2 \quad (7)$$

The necessary conditions within each time interval are:

$$H^1_z = 0; \quad \lambda'_1 = -H^1_G \quad for \quad t_0 \leq t \leq t_1 \quad (8)$$
$$H^2_z = 0; \quad \lambda'_2 = -H^2_G \quad for \quad t_1 \leq t \leq t_f \quad (9)$$

The new conditions are:

$$H^1(t_1) - \phi_t(t_1) = H^2(t_1) \quad if \quad t_0 \leq t_1 \leq t_f \quad (10)$$

$$H^1(t_1) - \phi_t(t_1) \leq H^2(t_1) \quad if \quad t_0 = t_1 \leq t_f \quad (11)$$

$$H^1(t_1) - \phi_t(t_1) \geq H^2(t_1) \quad if \quad t_0 \leq t_1 = t_f \quad (12)$$

$$\lambda^-(t_1) - \phi_G(t_1) = \lambda^+(t_1) \quad (13)$$

$$H^2(t_f) = 0; \quad \lambda_1(t_f) = 0; \quad or \quad \lambda_2(t_f) = 0 \quad (14)$$

After the Dust Bowl, at any point of time, t, acreage under grassland is a summation of persistent effect from the 1930s and the annual impact of that year's budget. Equation 10 to Equation 12 show how first-order conditions depend on farmer's production decisions. Equation 13 shows the initial budget may have a persistent effect after t_1. There are four possibilities as described in Figure 5:

- Scenario A: Initial impact from the event u does not degrade, later annual funding also has a non-durable impact. At any given point of time, environmental variables will comprise of both persistent and immediate effects of the soil conservation budget (Panel (a)).

- Scenario B: No persistent impact from the event u, grassland is only maintained by flows of funding. At any given point of time, we can only see the annual immediate effect of conservation budget (Panel (b)).

- Scenario C: No impact from the farmland conservation policies (Panel (c)).

- Scenario D: Initial spike has a persistent impact, but later funds are ineffective (Panel (d)).

Section 3 empirically examines this persistent effect of the initial institutional changes. After the initial shock, in the $t = T$, land allocation changes only at the intensive margin depending on the annual variation in the federal budget. The important insight from this framework is that there may be a persistent impact on the landscape from the initial budget. Also, the first-order condition and optimal annual grass restoration would depend on $\frac{\delta G}{\delta s}$, $\frac{\delta f}{\delta G}$, $\frac{\delta Z}{\delta G}$: how the farmer's yield function changes with land restoration, and how the federal budget affects land restoration. The results vary over space depending on the spatial variation of the initial crop intensity, farmer's capacity to adjust the land to optimize production (farm size, tenancy) and other geophysical constraints (availability of irrigation). Access to credit may also play an essential role as land conversion is expensive.

B Tables

Table A(1): Continuous Impact of Farmland Conservation on Total Grassland

VARIABLES	(1) Full	(2) < 1950	(3) < 1960	(4) < 1970	(5) < 1980
Log(Budget#Wheat)	0.0400***	-0.0200***	0.0759***	0.0492***	0.0409***
	(0.00841)	(0.00515)	(0.0160)	(0.00754)	(0.00850)
Log(Budget#Cotton)	0.0142	-0.00866	-0.00859	0.0256***	0.0147
	(0.0101)	(0.00622)	(0.0194)	(0.00909)	(0.0102)
Log(Budget#Corn)	0.0309***	-0.0269***	0.00192	0.0194**	0.0305***
	(0.00923)	(0.00566)	(0.0176)	(0.00828)	(0.00933)
Constant	-4.550***	-4.544***	-4.549***	-4.549***	-4.550***
	(0.000310)	(0.000183)	(0.000515)	(0.000295)	(0.000314)
Observations	34,440	9,020	17,220	25,420	33,620
R-squared	0.002	0.009	0.002	0.004	0.002
Number of FIPS	820	820	820	820	820
County FE	Yes	Yes	Yes	Yes	Yes

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table A(2): HTE Impact of Farmland Conservation on Total Grassland by 100th Meridian Line

VARIABLES	(1) Farmsize
Log(Budget#Wheat)	0.0173*
	(0.0105)
Log(Budget#Cotton)	0.0162
	(0.0109)
Log(Budget#Corn)	0.0239**
	(0.00965)
East Meridian Line#Log(Budget#Wheat)	0.0276
	(0.0182)
East Meridian Line#Log(Budget#Cotton)	-0.00496
	(0.0292)
East Meridian Line#Log(Budget#Corn)	0.226***
	(0.0382)
Constant	-4.380***
	(0.0185)
Observations	34,440
Number of FIPS	820
R-squared	0.012

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

[a] Note: Outcome variable is calculated from USDA agricultural census (summation of all land under soil conserving grasses for which USDA paid farmers). USDA annual finacial assistance conservation budget has been interacted with 1930's initial crop intensity. Variables have been converted to logarithm for skewness.

Table A(3): HTE Impact of Farmland Conservation on Total Grassland by Farmers' Origin

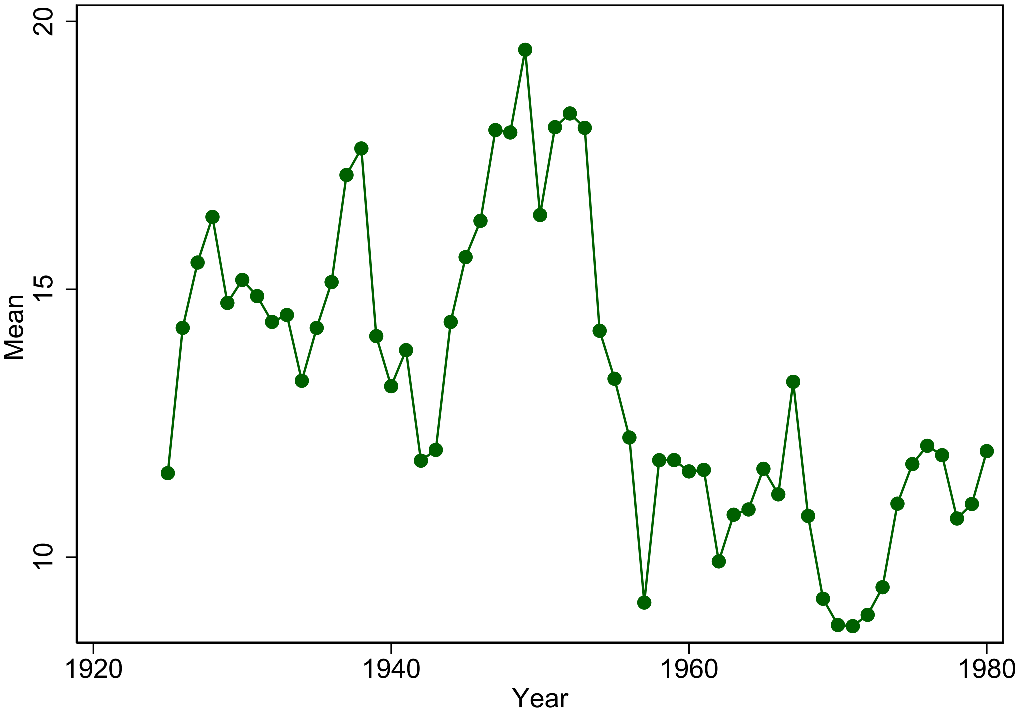
VARIABLES	(1) < 1980	(2) < 1980	(3) < 1980	(4) < 1980	(5) < 1980
Log(Budget#Wheat)#Mexican	0.000693	0.00148	0.00324	0.000127	0.000670
	(0.00395)	(0.00165)	(0.00755)	(0.00349)	(0.00400)
Log(Budget#Cotton)#Mexican	0.000113	7.47e-06	0.000120	0.000124	0.000115
	(0.000270)	(0.000113)	(0.000516)	(0.000239)	(0.000273)
Log(Budget#Corn)#Mexican	-0.000125	-6.11e-05	-0.000269	-0.000161	-0.000128
	(0.000367)	(0.000154)	(0.000702)	(0.000324)	(0.000371)
Log(Budget#Wheat)	0.0523***	-0.0100	0.0714**	0.0723***	0.0540***
	(0.0183)	(0.00771)	(0.0350)	(0.0162)	(0.0185)
Log(Budget#Cotton)	0.00461	0.0120**	0.0102	0.00315	0.00474
	(0.0111)	(0.00467)	(0.0211)	(0.00984)	(0.0112)
Log(Budget#Corn)	0.0325	0.0171	-0.0141	0.0193	0.0324
	(0.0382)	(0.0162)	(0.0736)	(0.0338)	(0.0387)
Constant	-4.614***	-5.182***	-4.585***	-4.740***	-4.600***
	(0.0179)	(0.0273)	(0.0543)	(0.0243)	(0.0188)
Observations	11,970	3,135	5,985	8,835	11,685
R-squared	0.003	0.162	0.006	0.010	0.003
Number of FIPS	285	285	285	285	285
County FE	Yes	Yes	Yes	Yes	Yes
State*Year Trend	Yes	Yes	Yes	Yes	Yes

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

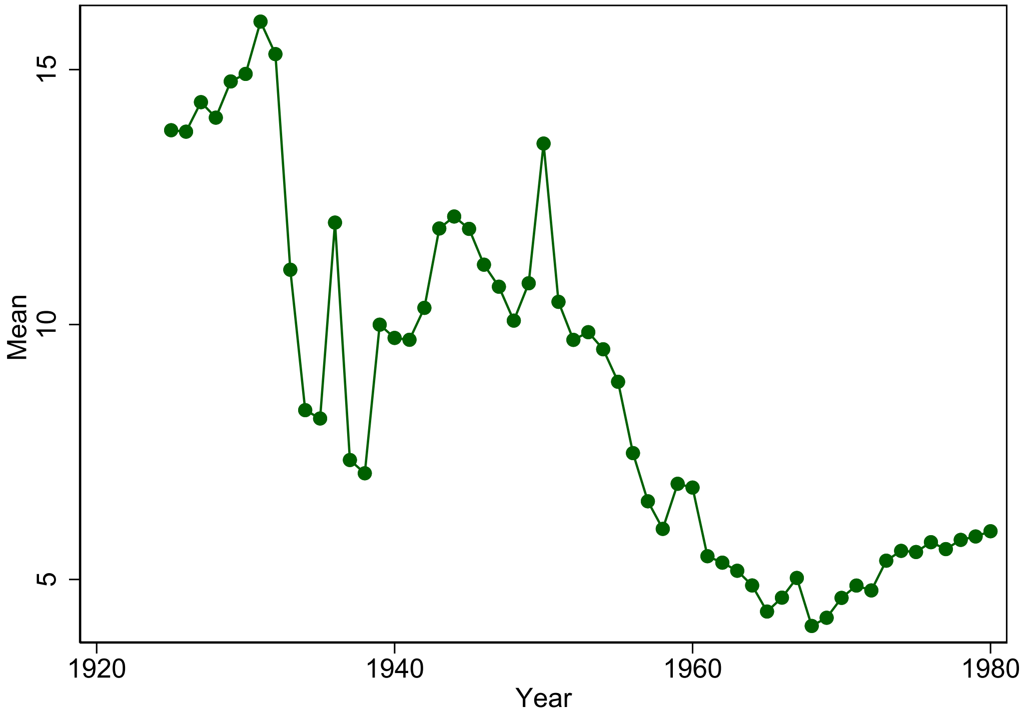
C Graphs & Figures

Figure (B1) **Aggregate Changes on the Plains: Wheat Planted Acreage**



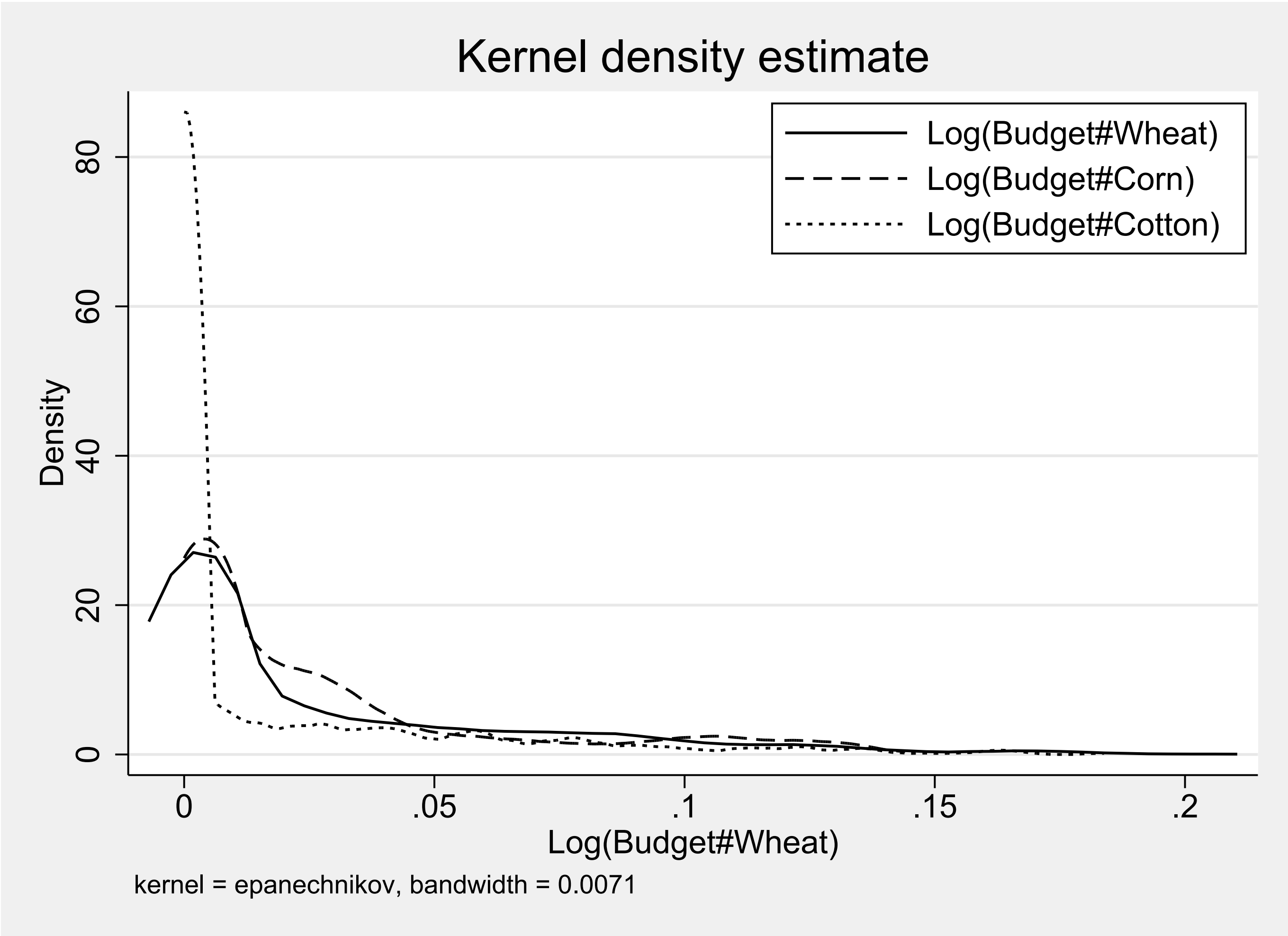
Annual planted acreage data are from the National Agricultural Statistics Service, available only for selected counties.

Figure (B2) **Aggregate Changes on the Plains: Corn Planted Acreage**



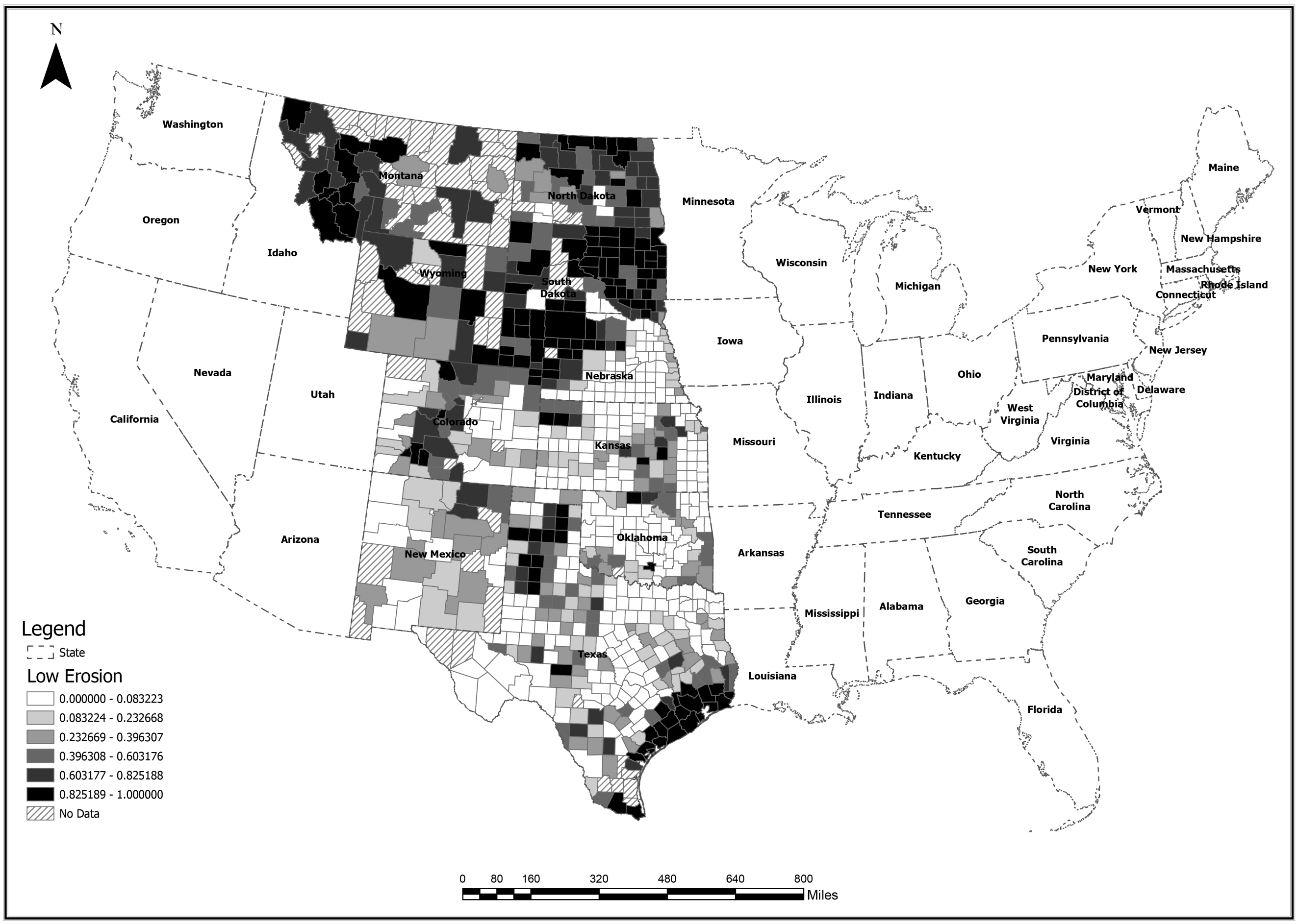
Annual planted acreage data are from the National Agricultural Statistics Service, available only for selected counties.

Figure (B3) Variation in the Conservation Exposure by Crops ($Year = 1940)



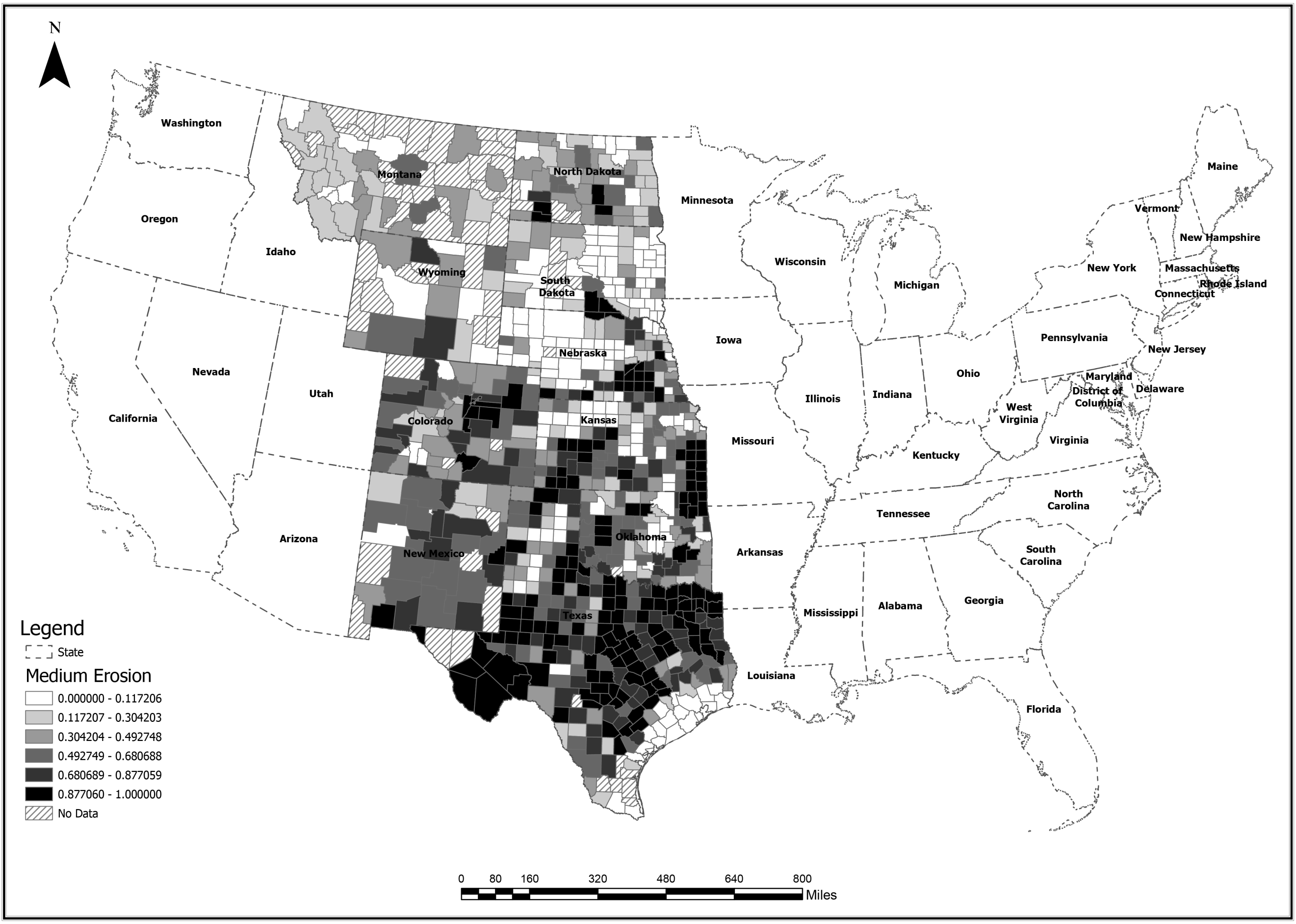
Note: This graph corresponds to the treatment variable in the regression equation 1: Log(BudgetCrop Intensity). The graph denotes variation over crops. This is extracted for year 1940 as a sample to present the underlying variation.

Figure (B4) Low Erosion Areas in 1934



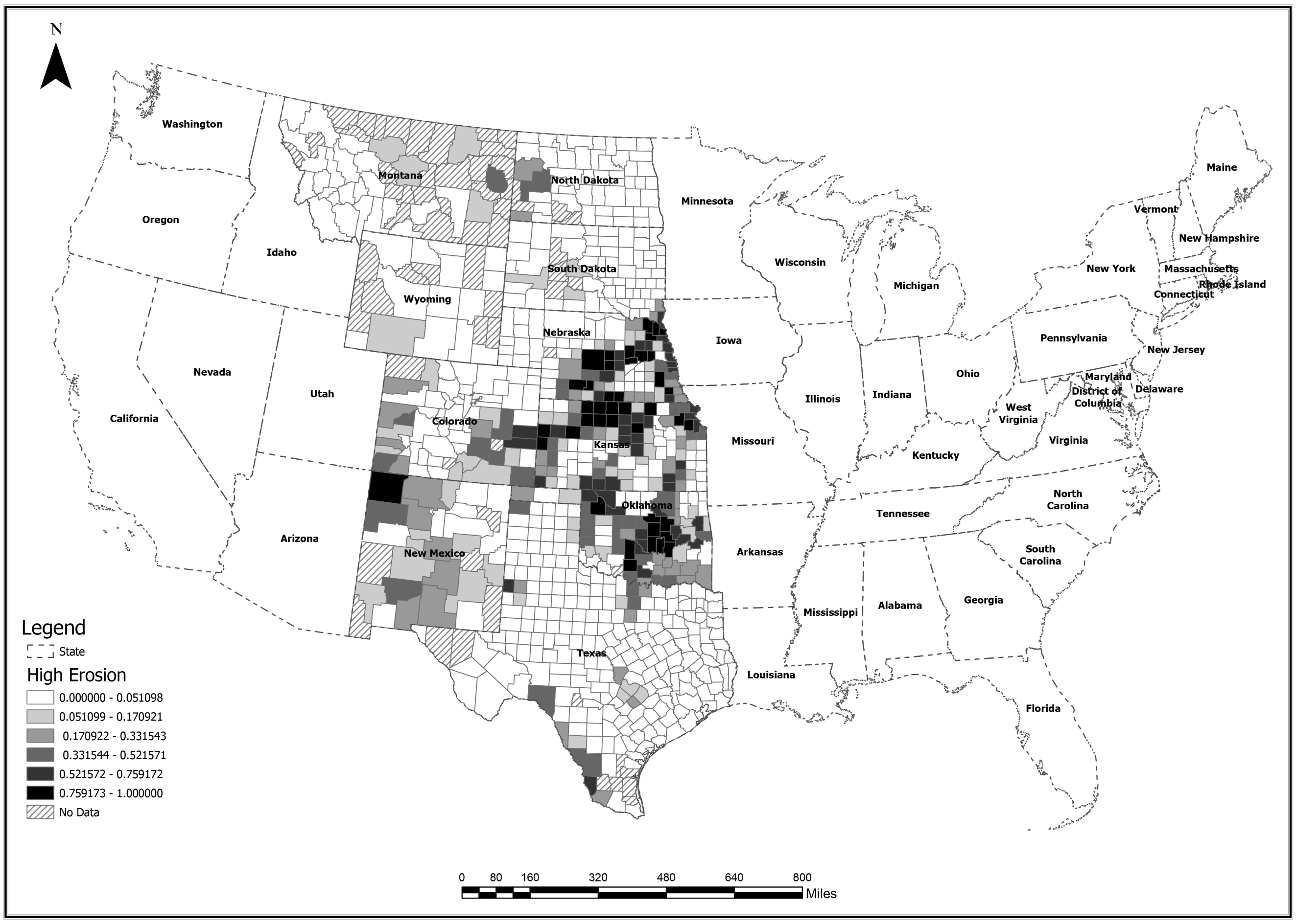
Note: This graph denotes the areas under low erosion in 1934 (Hornbeck, 2012). Map created by USDA Soil Conservation Service (currently named as Natural Resource and Conservation Service)

Figure (B5) Medium Erosion Areas in 1934



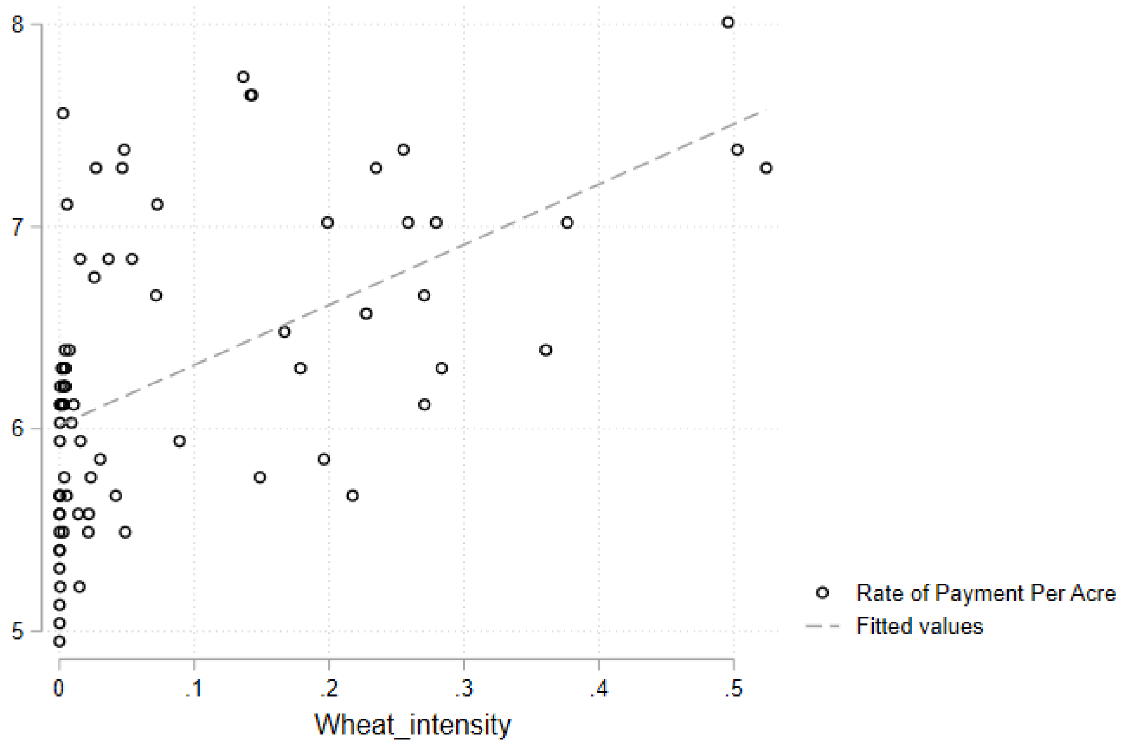
Note: This graph denotes the areas under medium erosion in 1934 (Hornbeck, 2012). Map created by USDA Soil Conservation Service (currently named as Natural Resource and Conservation Service)

Figure (B6) High Erosion Areas in 1934



Note: This graph denotes the areas under high erosion in 1934 (Hornbeck, 2012). Map created by USDA Soil Conservation Service (currently named as Natural Resource and Conservation Service)

Figure (B7) Relationship between Rate of Payment and Crop Intensity in Oklahoma



Note: Data extracted from National Archives at College Park (for more details of the data, see the appendix). Graph denotes the correlation between Oklahoma counties' rate of payment per acre and their 1930 wheat intensity. This shows that the payment rate strongly correlates with pre-policy crop intensity in Oklahoma. Wheat is Oklahoma's main crop.

Figure (B8) Histogram: 1930's Average Crop Intensity

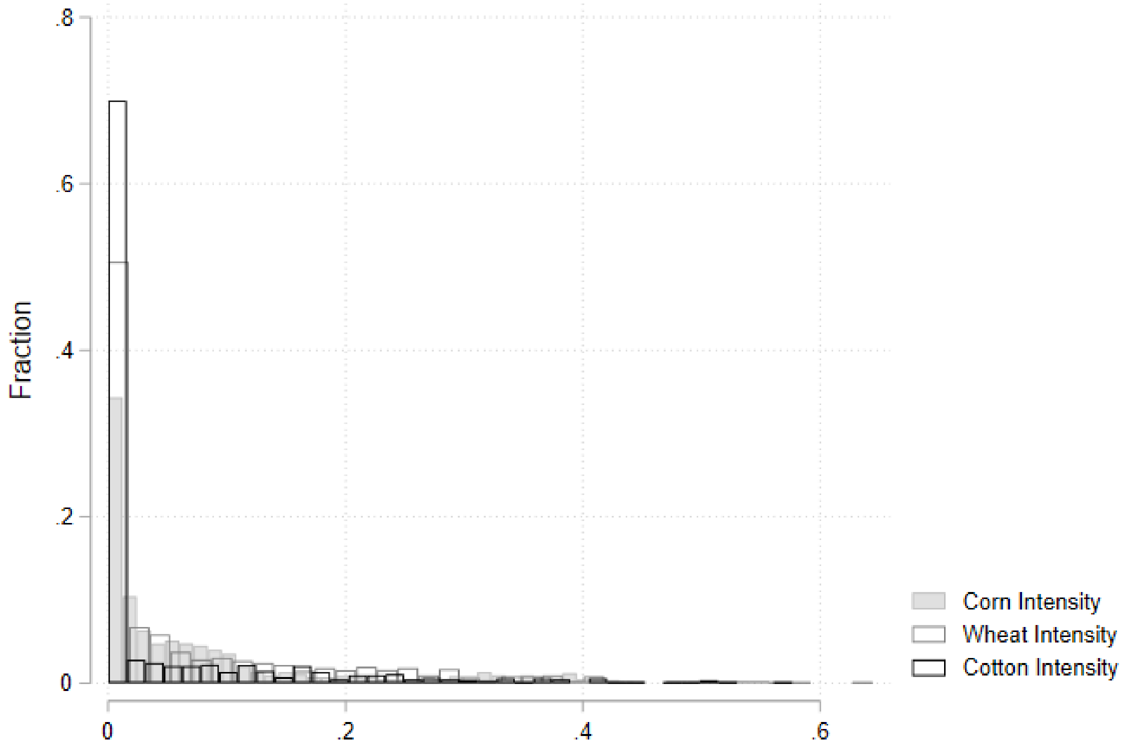
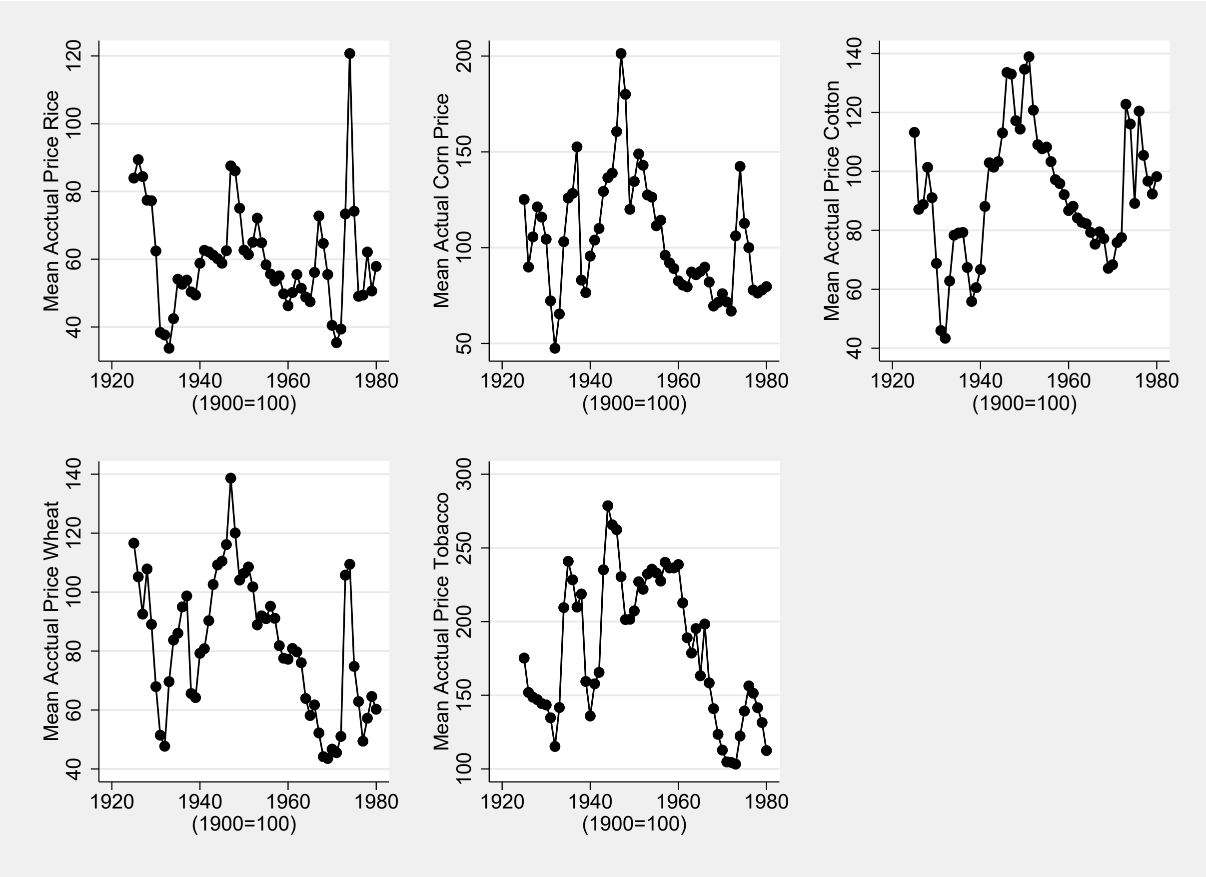


Figure (B9) **World Price Variation by Commodities**



World Price Variation by Commodities, Data from Jacks, D. (2013), "From Boom to Bust: A Typology of Real Commodity Prices in the Long Run," NBER Working Paper 18874; Base Year = 1900