Rain follows the forest: Land use policy, climate change, and adaptation

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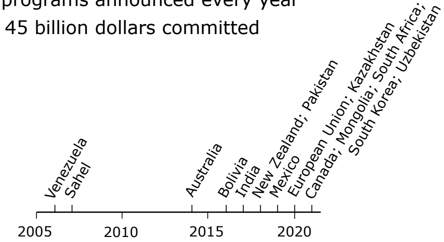
Large tree-planting programs are popular among policy-makers

- Mitigating **global climate change**
  - >50% of 196 Paris Agreement countries prioritizing land use/forestry to meet CO_2 mitigation targets (UNFCCC, 2022).
- Reducing **soil erosion and dust storms**

> New programs announced every year
> Over 45 billion dollars committed



Large tree-planting programs are popular among policy-makers

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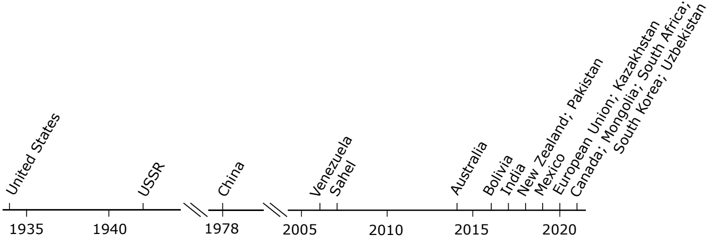
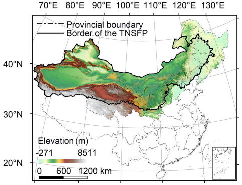
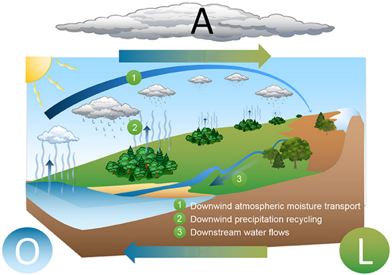
- *Long-standing* interest for reducing soil erosion and dust storms





Local and regional climate effects of afforestation

- Less attention is paid to the **local and regional climate effects**
  - Trees alter energy fluxes between land and the atmosphere
  - Changes in the **distribution** of weather events (i.e., climate change)
  - Potential impact on **precipitation**: $\uparrow$ in area, $\uparrow$ in vicinity
  - Potential impact on **temperature**: ? in area, $\downarrow$ in vicinity



Source: Creed et al., 2019

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- Policy-induced changes to climate can then have socioeconomic consequences
  - Direct impacts of climate change
  - Adaptation to climate change

This paper

Research question(s): How does large-scale tree planting affect the local & regional climate?

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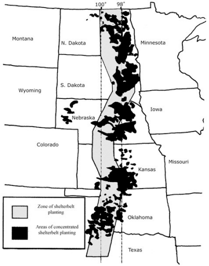
Setting: The Great Plains Shelterbelt Project

- Tree-planting program in the US Midwest (1935 - 1942)



This paper

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What are the resulting economic effects?

Setting: The Great Plains Shelterbelt Project

- Tree-planting program in the US Midwest (1935 - 1942)

We implement a diff-in-diff exploiting wind patterns and find:

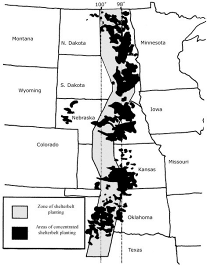
- Impact of tree planting on **local and regional climate**

  ↑ in summer precipitation and ↓ in summer temperatures

- Impact of climate on **agriculture**

  ↑ in corn production, adaptation along the extensive margin and water-intensive crop switching

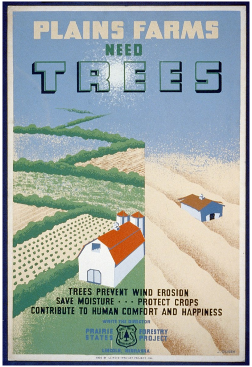
  ↓ crop failure and ↓ consolidation of smaller farms



Outline

More about the Great Plains Shelterbelt Project

- Tree-planting effort in US Midwest from 1935 - 1942



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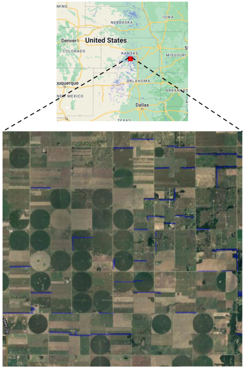
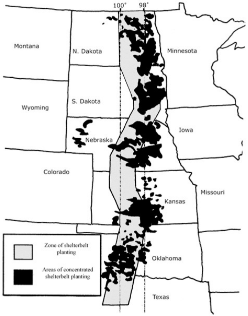


More about the Great Plains Shelterbelt Project

- Tree-planting effort in US Midwest from 1935 - 1942
- Response to soil erosion and dust storms of the Dust Bowl
- Mostly windbreaks, only some dense forested areas
- Largest afforestation program at the time with 220 million trees planted from North Dakota to Texas

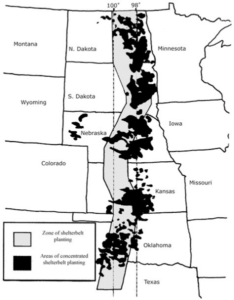


more background trees by year historical land use

Outline

We digitize historical maps of the Shelterbelt project

Shelterbelt planting: Digitized historical maps of Shelterbelt areas (Read, 1958)



Shelterbelt proportion maps

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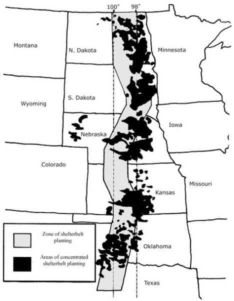

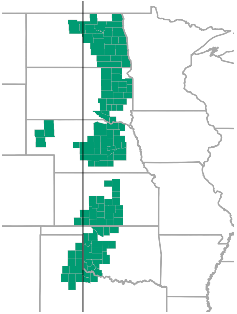

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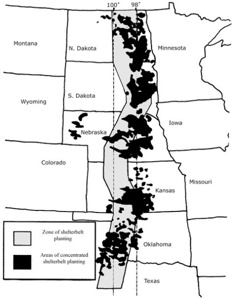
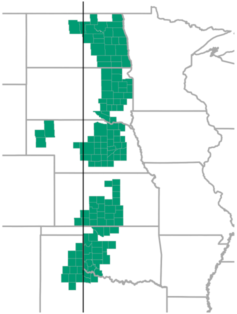
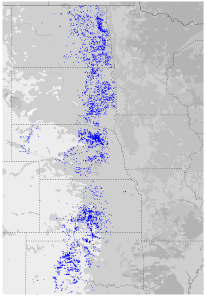






Validated with and robust to detailed Shelterbelt shapefiles constructed by Snow (2019) from digitized USGS 1950-1975 Topographic Map Quadrangles

Shelterbelt proportion maps

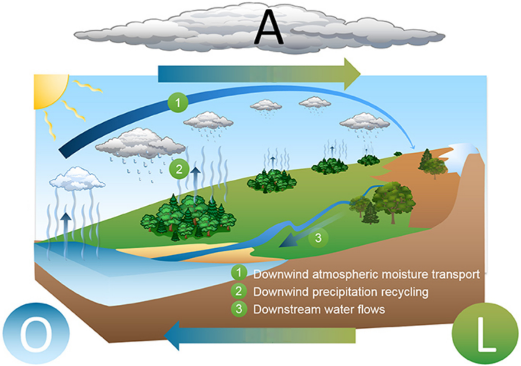
And combine digitized maps with...

- **Wind speed and direction**: Use the North American Land Data Assimilation System (NLDAS-2) to create a measure of *approximate* exposure to summer winds from the Shelterbelt ▸▸ details
- **Climate outcomes (precipitation and temperature)**: Use the NOAA Global Historical Climatology Network daily (GHCNd) station data; verify robustness to NOAA Monthly U.S. Climate Divisional Database (NClimDiv) ▸▸ details
- **Economic outcomes**: Use 5-year agricultural censuses (and annual surveys) from the USDA National Agricultural Statistics Service ▸▸ details

Outline

We construct a measure of wind exposure

Afforestation promotes downwind precipitation → wind is an important mechanism for regional changes in climate



Source: Creed et al., 2019

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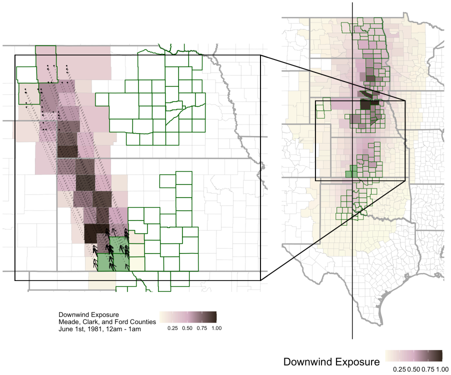
Construct an *approximate* measure of exposure to summer winds from the Shelterbelt

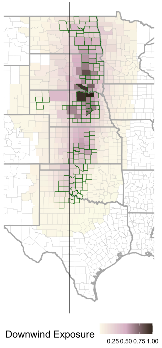


more details on wind exposure construction

We estimate a diff-in-diff model with continuous treatment

$$y_{it} = \beta\big(WindExp_i \times P_t\big) + \gamma\big(\mathbf{X}_i \times year_t\big) + \delta_{st} + \nu_i + \epsilon_{it}$$

- Outcome (y_{it}):
  1) Summer precipitation and temperature
  2) Annual yields and land use
- $WindExp_i$: Continuous wind exposure measure
- P_t : Post 1942 dummy
- $\mathbf{X}_i$: Time-invariant controls
- State-by-year (δ_{st}) and county (ν_i) fixed effects
- Binary diff-in-diff version



▸▸ pretrends ▸▸ balance ▸▸ spatial RD ▸▸ binary diff-in-diff

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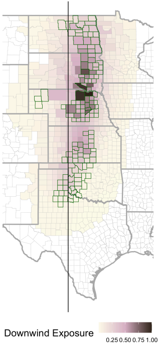

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  - Geospatial (e.g., area, distance to Shelterbelt)
  - Topography (e.g., elevation, ruggedness)
  - Erosion (e.g., Dust Bowl erosion)
  - Irrigation (e.g., historical irrigation)
- State-by-year (δ_{st}) and county (ν_i) fixed effects
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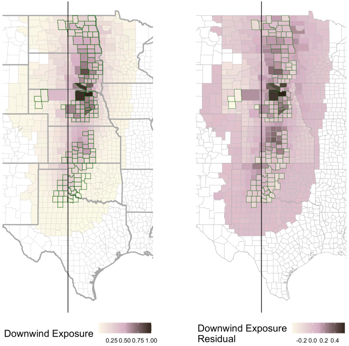

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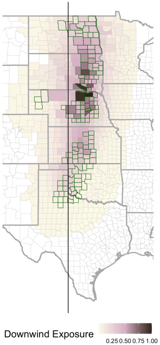

pretrends balance spatial RD binary diff-in-diff

And also implement the following alternative specifications

1. **Instrumental variable** approach
    - if strategic location of tree planting is a concern
    - instrument tree planting location by planned planting zone

IV first stage

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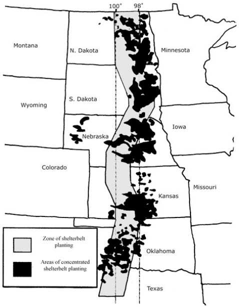

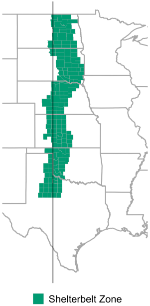

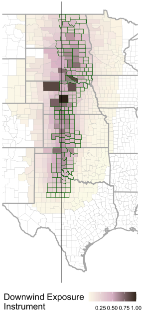

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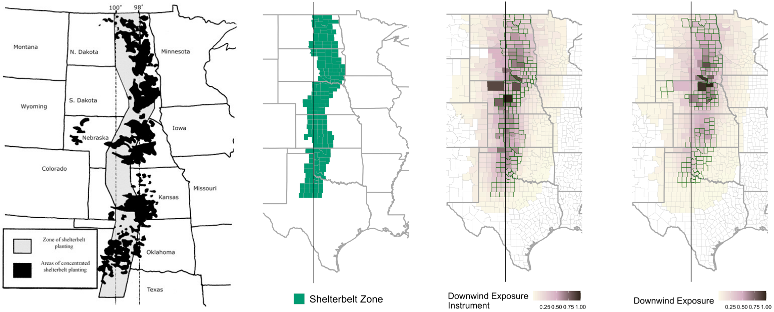

IV first stage

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   - instrument tree planting location by planned planting zone

2. **Long differences** approach
   - if specific timing of treatment effects is a concern
   - $\Delta y_i = \beta_{LD} WindExp_i + \epsilon_i$, where $\Delta y_i = \left(y_{i,\overline{1960-1965}} - y_{i,\overline{1930-1935}} \right)$

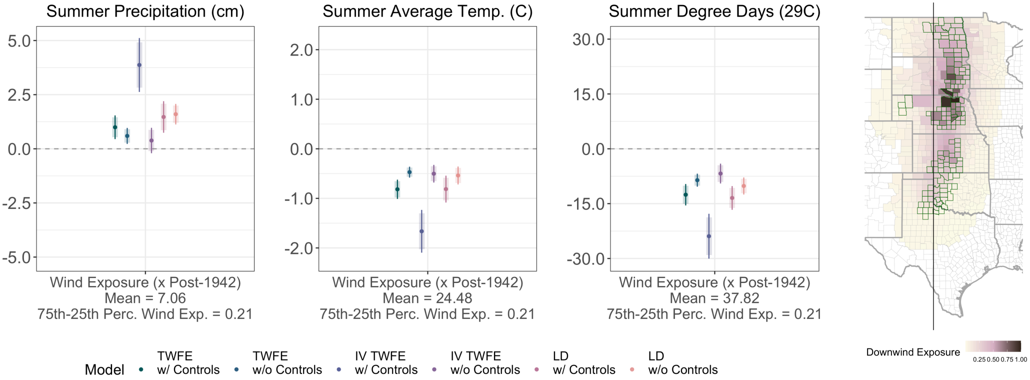
IV first stage

Outline

We find an impact on climate downwind of afforested areas

Rainfall **increased** and temperatures **decreased** in areas exposed to Shelterbelt summer winds

(avg. precipitation: +3.0%; avg. temp: -0.7%; 29C degree days: -7.0%)



binary diff-in-diff results

We implement a number of robustness checks

Potential confounds

- Drop peak Dust Bowl drought years (1934, 1936, 1939), treatment (1936-1942) details
- Repeat for longer time period details
- Alternative time periods for long differences details
- Repeat analysis at hyperlocal (weather station) level details
- Verify orthogonality of irrigation to treatment and spillovers details, heterogeneity by Ogallala vs. outside Ogallala details

Inference

- Implement Conley standard errors details

Alternative specifications

- Alternatives to state-by-year fixed effects details
- Alternative controls details

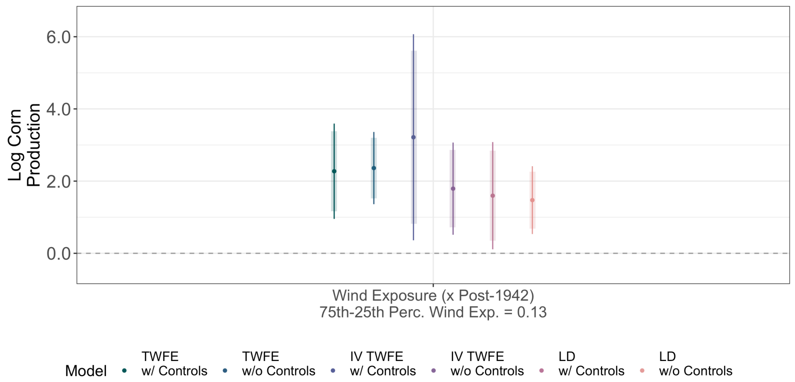
Are these climate effects realistic?

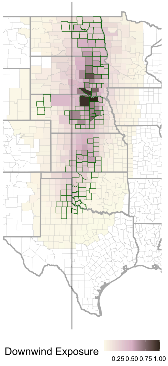
- Important to note that we study only evapotranspiration, not other parts of the water cycle
- Our estimated precipitation effect
  - 0.99cm per month from June to August for a unit of wind exposure $\times$ average wind exposure of 0.15 $\times$ 1.7 million km^2 of Shelterbelt and downwind areas
    $\rightarrow$ 1.99 **trillion** gallons of water per year
- Theoretical transpiration rate of oak trees
  - 10,000 gallons June to August $\times$ 220 million trees with 61% survival rate (Read, 1958)
    $\rightarrow$ 1.34 **trillion** gallons of water per year
- Estimated and theoretical transpiration rates are **same order of magnitude**

We then identify the impact of climate change on agriculture

Corn production **increased** in areas exposed to Shelterbelt summer winds

(29.5% increase, from 25th to 75th pc of wind exposure)

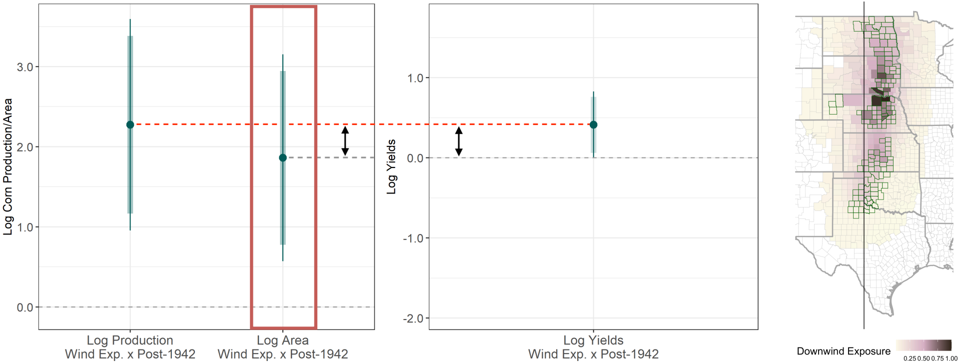




binary diff-in-diff results

We then identify the impact of climate change on agriculture

The ↑ in production was driven by the expansion in corn **acreage** harvested

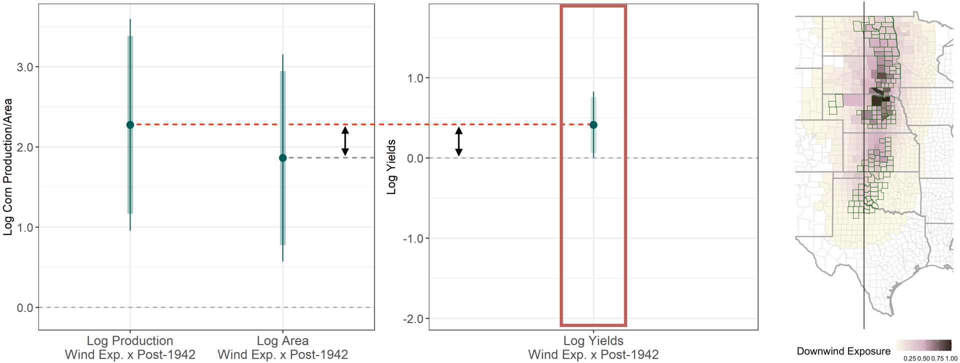


▶▶ binary diff-in-diff results

We then identify the impact of climate change on agriculture

We find a smaller increase in yields (5.4% increase from 25th to 75th pc of wind exposure)

- Net effect on corn yields similar in magnitude to physiological increase from improved climate conditions, estimated based on canonical model of Schlenker and Roberts (2009)



yield decomposition details yield increase (different models)

We find evidence of farmer adaptation to improved climate

- Increase in production driven by large increase in corn area harvested
  - Increase in corn acreage *planted* as well as harvested
  - Reallocation from wheat (less water-intensive) to corn (more water-intensive)

Table: Impact of Great Plains Shelterbelt on agricultural development, 1930 to 1964

	(1)	(2)	(3)
	Dep. var.: Cropland area (1000s acres)		
	Corn Harvested	Wheat Harvested	Total Cropland
Wind Exposure:Post 1942	36.741***	$-$47.460***	$-$15.561
	(8.293)	(10.646)	(22.853)
75th-25th Perc. Wind Exp	0.13	0.13	0.13
Observations	3,539	3,539	3,539

Notes: Dependent variables are from USDA 5-year agricultural censuses (8 censuses between 1930 and 1964). "75th-25th Perc Wind Exp" shows the difference between the 75th and 25th percentile of the continuous wind exposure measure. Standard errors clustered at the county level shown in parentheses (*p$<$0.1; **p$<$0.05; ***p$<$0.01).

area planted vs. harvested

And broader economic impacts in areas with improved climate

- Reduction in crop failures
- Fewer farm consolidations

And broader economic impacts in areas with improved climate

- Reduction in crop failures
  - Consistent with reduced extreme weather

Table: Impact of Great Plains Shelterbelt on agricultural development, 1930 to 1964

	(1)
	Dep. var.: Cropland area (1000s acres)
	Crop Failures
Wind Exposure:Post 1942	-50.561^{***}
	(17.361)
75th-25th Perc. Wind Exp	0.13
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And broader economic impacts in areas with improved climate

- Fewer farm consolidations
  - Period of widespread farm bankruptcies and increased concentration

Table: Impact of Great Plains Shelterbelt on agricultural development, 1930 to 1964

	(1)	(2)	(3)	(4)
	Dep. var.: Number of Farms, by Farm Size			
	$<$ 100 acres	100-499 acres	$\geq$ 500 acres	Total
Wind Exposure:Post 1942	196.153**	$-$60.303	$-$3.753	134.270
	(92.735)	(114.545)	(42.006)	(137.917)
	[0.035]	[0.599]	[0.929]	[0.331]
75th-25th Perc. Wind Exp	0.22	0.22	0.22	0.22
Observations	3,539	3,539	3,539	3,539

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We implement similar robustness checks

Potential confounds

- Drop treatment (1936-1942) details
- Heterogeneity by Ogallala vs. outside Ogallala details

Alternative specifications

- Alternatives to state-by-year fixed effects details
- Alternative controls details

Inference

- Implement Conley standard errors details

Other

- Climate results for ag. census counties and yields details

Outline

Summary

- We investigate the **local** and **regional** climate impacts of a mass tree planting program
- We use a difference-in-differences strategy that exploits wind direction
- Shelterbelt affected **climate** both in afforested areas and in downwind neighboring areas
- Improved growing conditions led to:
  - Increased corn **production** as well as **adaptation** through land use and crop choice
  - Decreased **crop failures** as well as reduced **farm consolidation**

The endogeneity of local and regional climate

- Economists typically take the local climate as exogenous to local economic activities
  - Idea of climate endogeneity long explored in the natural sciences, mostly with atmospheric models (Devaraju et al., 2015; Smith et al., 2023; Alkama and Cescatti, 2016; Peng et al., 2014)
  - Recent working papers in economics, on historical expansion of irrigation in the US (Braun and Schlenker, 2023) and changes in the Amazon forest cover (Araujo, 2023)
  - We provide causal evidence on the local and regional climate impacts of land use policy

And evidence of farmer adaptation to climate change

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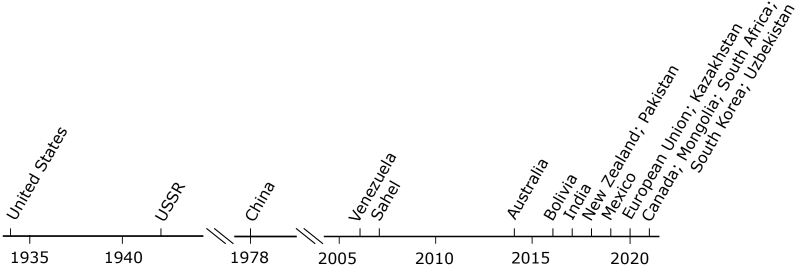
  - Recent working papers in economics, on historical expansion of irrigation in the US (Braun and Schlenker, 2023) and changes in the Amazon forest cover (Araujo, 2023)
  - We provide causal evidence on the local and regional climate impacts of land use policy
- Direct causal evidence of significant farmer adaptation to a long-term change in climate
  - Building on research provides valuable insights on how economic agents respond to productivity shocks (Hornbeck, 2012; Blakeslee et al., 2020) and adaptation to medium-to-long-term fluctuations in the monsoon regime in India (Kala, 2017; Taraz, 2017; Liu et al., forthcoming)

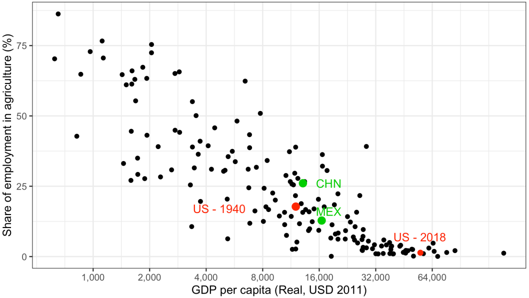
What can we say about the current tree planting mania?

- Tree planting can be a tool for both
  - Climate mitigation (by sequestering carbon)
  - Climate **adaptation** (by reducing the negative impact of global warming on agriculture)
- Improving the climate through land use policy has significant consequences for long-term agricultural development



What can we say about the current tree planting mania?

- Many countries with large-scale tree planting programs are still highly dependent on agriculture – like the US Midwest was in the 1940s
- Mollisol soils of the Great Plains are also common throughout rainfall-limited crop-growing regions with large-scale tree-planting programs



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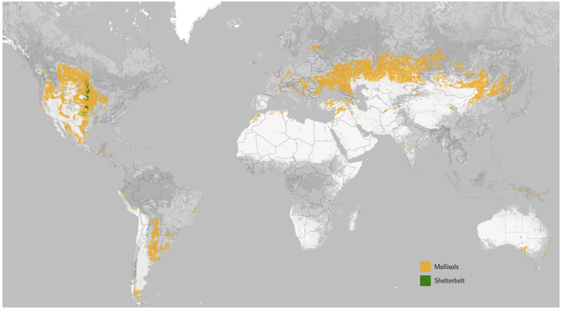

What can we say about the current tree planting mania?

- Careful design of afforestation programs is crucial for ecological resilience
  - The Great Plains Shelterbelt project used over 30 species of trees and shrubs
  - Most species were native and locally adapted

TABLE 56. Average region-wide *1954 survival* of species by site-condition classes

Species	Site-condition class						
	A1	A2	B1	B2	C1	C2	D
	percent						
Tall, fast-growing							
Cottonwood	55	44	41	37	20	5	10
Sycamore	....	84	....	2	....	....	40
White willow	95	90	....	78	....	....	....
Ailanthus	75	43	23	6	3	....	75
Siberian elm	73	73	75	60	66	40	45
Tall, medium to slow							
American elm	74	67	76	61	62	47	55
Green ash	79	75	81	79	69	73	76
Honeylocust	73	73	84	64	76	59	53
Hackberry	58	61	74	58	54	45	58
Black locust	38	60	56	45	15	32	3
Black walnut	50	50	45	29	31	16	24
Catalpa	67	80	....	38	90	36	52
Coffeetree	53	52	82	50	70	....	76
Bur oak	85	50	72	58	48	67	59
Short, fast-growing							
Russian-olive	55	51	67	58	45	45	69
Boxelder	88	83	88	....	74	....	22
Mulberry	71	71	76	51	52	57	59
Osage-orange	71	78	79	62	74	70	74
Apricot	10	48	22	14	....	28	16
Golden willow	82	78	....	57	....	....	....

TABLE 56. Average region-wide *1954 survival* of species by site-condition classes

Species	Site-condition class						
	A1	A2	B1	B2	C1	C2	D
	percent						
Shrubs							
American plum	72	73	80	46	64	62	40
Chokecherry	64	56	64	45	12	90	....
Tatarian honeysuckle	76	59	88	....	88	....	50
Caragana	63	63	56	66	43	....	48
Lilac	64	63	57	75	74	40	....
Tamarisk	60	53	76	30	77	49	45
Desertwillow	44	59	....	57	....	44	42
Skunkbush	94	50	90	65	92	....	75
Conifers							
Eastern redcedar	66	79	69	72	51	79	81
Rocky mountain juniper	48	54	49	....	31	....	50
Ponderosa pine	39	43	44	46	29	52	52
Austrian pine	70	13	59	....	....	....	19
Shortleaf pine	25	42	....	....	....	....	....
Blue spruce	24	40	63	....	58	....	....

Source: The Great Plains Shelterbelt in 1954 (Read 1958), page 114

Thank you!

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References I

Alkama, R. and A. Cescatti (2016): "Biophysical climate impacts of recent changes in global forest cover," *Science*, 351, 600–604.

Araujo, R. (2023): "When clouds go dry: an integrated model of deforestation, rainfall, and agriculture," .

Blakeslee, D., R. Fishman, and V. Srinivasan (2020): "Way Down in the Hole: Adaptation to Long-Term Water Loss in Rural India," *The American Economic Review*, 110, 200–224.

Braun, T. and W. Schlenker (2023): "Cooling Externality of Large-Scale Irrigation," *NBER Working Paper*.

Creed, I. F., J. A. Jones, E. Archer, M. Claassen, D. Ellison, S. G. McNulty, M. van Noordwijk, B. Vira, X. Wei, K. Bishop, J. A. Blanco, M. Gush, D. Gyawali, E. Jobbágy, A. Lara, C. Little, J. Martin-Ortega, A. Mukherji, D. Murdiyarso, P. O. Pol, C. A. Sullivan, and J. Xu (2019): "Managing Forests for Both Downstream and Downwind Water," *Frontiers in Forests and Global Change*, 2.

Devaraju, N., G. Bala, and A. Modak (2015): "Effects of large-scale deforestation on precipitation in the monsoon regions: remote versus local effects," *Proceedings of the National Academy of Sciences*, 112, 3257–3262.

Haines, M., P. Fishback, and P. Rhode (2018): "United States Agriculture Data, 1840 - 2012," .

Hornbeck, R. (2012): "The enduring impact of the American Dust Bowl: Short-and long-run adjustments to environmental catastrophe," *The American Economic Review*, 102, 1477–1507.

References II

Kala, N. (2017): "Learning, adaptation, and climate uncertainty: Evidence from Indian agriculture," *MIT Center for Energy and Environmental Policy Research Working Paper*, 23.

Liu, M., Y. Shamdasani, and V. Taraz (forthcoming): "Climate Change and Labor Reallocation: Evidence from Six Decades of the Indian Census," *American Economic Journal: Economic Policy*.

Peng, S.-S., S. Piao, Z. Zeng, P. Ciais, L. Zhou, L. Z. X. Li, R. B. Myneni, Y. Yin, and H. Zeng (2014): "Afforestation in China cools local land surface temperature," *Proceedings of the National Academy of Sciences*, 111, 2915–2919.

Read, R. A. (1958): "Great Plains shelterbelt in 1954," *Great Plains Agricultural Council*.

Schlenker, W. and M. J. Roberts (2006): "Nonlinear Effects of Weather on Corn Yields," *Applied Economic Perspectives and Policy*, 28, 391–398.

——— (2009): "Nonlinear temperature effects indicate severe damages to US crop yields under climate change," *Proceedings of the National Academy of Sciences*, 106, 15594–15598.

Smith, C., J. C. A. Baker, and D. V. Spracklen (2023): "Tropical deforestation causes large reductions in observed precipitation," *Nature*, 615, 270–275.

Snow, M. (2019): "The Shelterbelt "Scheme": Radical Ecological Forestry and the Production of Climate in the Fight for the Prairie States Forestry Project," Ph.D. thesis, University of Minnesota.

Taraz, V. (2017): "Adaptation to climate change: Historical evidence from the Indian monsoon," *Environment and Development Economics*, 22, 517–545.

UNFCCC (2022): "Nationally determined contributions under the Paris Agreement Synthesis, Fourth session Sharm el-Sheikh, 6–18 November 2022, report by the secretariat," .

Appendix

Appendix: The Great Plains Shelterbelt Project

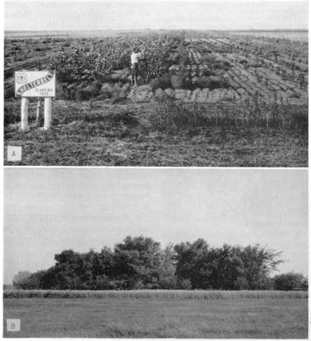

Figure: Shelterbelt in North Dakota, 1 year (top) and year 21 (bottom). Source: Read 1958

Appendix: Trees planted by year of program

Figure: Trees planted by year of program (1940-1941 values are estimates based on total)

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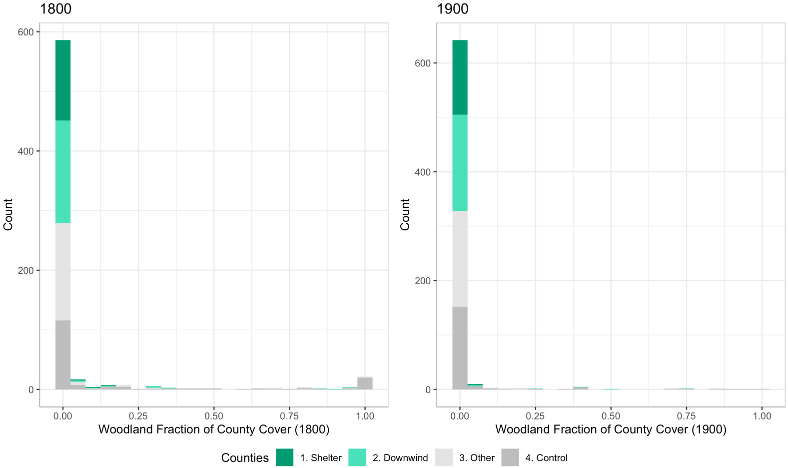
Appendix: Historical land use



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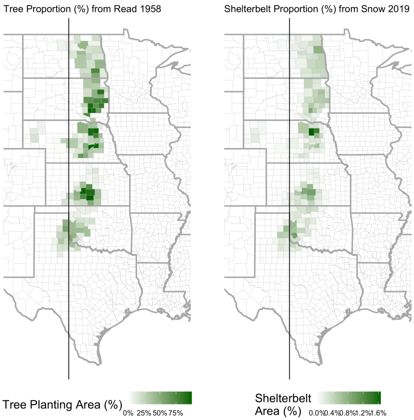
Appendix: Shelterbelt measures



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Appendix

Appendix: Data details

Wind speed and direction: North American Land Data Assimilation System (NLDAS-2)

- We create a measure of *approximate* exposure to summer winds from the Shelterbelt
- Problem: High-resolution, spatially-consistent hourly data available only beginning 1979
- Solution: Use 1981-2010 data to approximate summer winds
  - Validate with NOAA Integrated Surface Dataset for interpolated station data from 1930s
  - Highly correlated - captures prevailing wind patterns not changing much over time

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Appendix: Data details

Climate outcomes: Precipitation and temperature

- Requirements: historical (pre-1940), daily (for degree days)
- Standard historical products are at monthly level (e.g., NOAA NClimDiv, PRISM)
- We build our dataset from daily station data

  Inspired by Schlenker and Roberts (2006)
  - NOAA Global Historical Climatology Network daily (GHCNd)
  - Keep set of stations with $<$ 5% missing observations between 1930 - 1965
  - Balanced panel: fill missing values from closest reporting stations
  - Interpolate to 0.1 degree grid, compute degree degrees
  - Average at the county level example

  > County-level daily precipitation, min and max temperature, degree days
- We verify robustness to NOAA Monthly U.S. Climate Divisional Database (NClimDiv)

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Appendix: Data details

Economic outcomes: From the USDA National Agricultural Statistics Service

- Agricultural Surveys - Every year
  - Corn yields
- Censuses of Agriculture - Every 5 years (Haines et al., 2018)
  - Corn yields
  - Corn and wheat acreage
  - Farm, harvest, and pasture acreage

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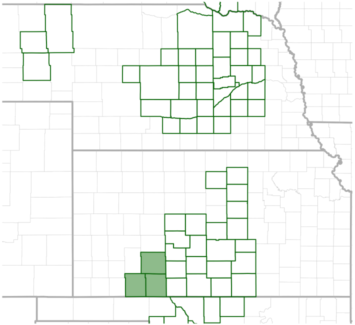
Appendix

Appendix: Wind exposure details

- Example of the process, repeated for each Shelterbelt county and hour:



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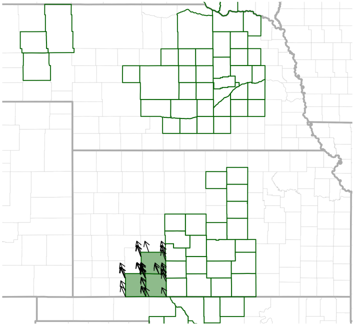
Appendix: Wind exposure details

- Example of the process, repeated for each Shelterbelt county and hour:



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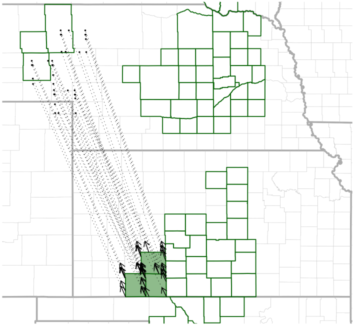
Appendix: Wind exposure details

- Example of the process, repeated for each Shelterbelt county and hour:



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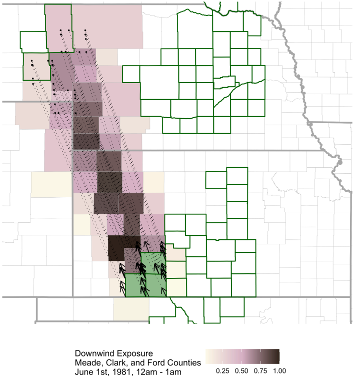
Appendix: Wind exposure details

- Example of the process, repeated for each Shelterbelt county and hour:



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Appendix: Wind exposure details

- Sum up for each summer month hour, and each year from 1981-2010, for time-invariant measure of Shelterbelt exposure correlation with interpolated 1938-1942 data

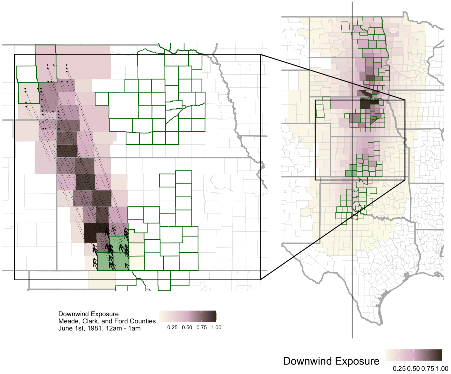

Figure: Final wind exposure measure

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Appendix: Wind exposure details

Details on downwind exposure construction:

1. Start with hourly summer (June - August) wind speed and direction for each Shelterbelt county for years 1981 - 2010
2. For each hour:
   a. From each vertex, v_{ic}, of each Shelterbelt county c (with total vertices V_c), project where a particle would travel if it was blown by winds of the given direction/speed constantly for 1 day
   b. For all unique outgoing-incoming county pairs, sum the particles originating from the outgoing county and divide by the total number of vertices of the outgoing county (V_c). This is the wind exposure from one county
   c. For all counties, sum up the total wind exposure from *all* Shelterbelt counties
3. Sum up for all hours and all years.
4. Divide by the maximum value to normalize; this is each country's downwind exposure measure

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results using 1938-1942 interpolated weather station data

Appendix: Interpolated wind data

Alternate wind exposure metric using interpolated 1938 - 1942 weather station data highly correlated with main measure (0.92 correlation)

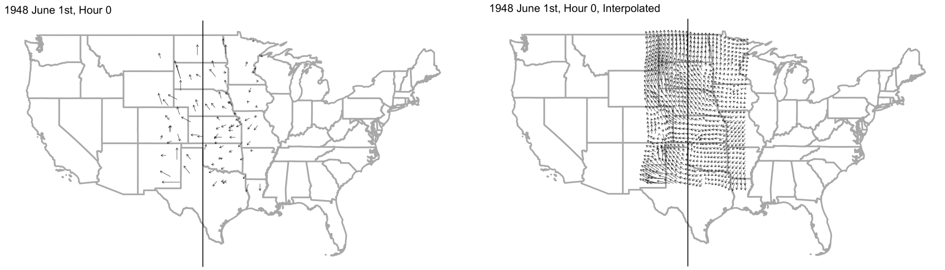

Figure: Interpolation example

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Appendix: Interpolated wind data

Alternate wind exposure metric using interpolated 1938 - 1942 weather station data highly correlated with main measure (0.92 correlation)

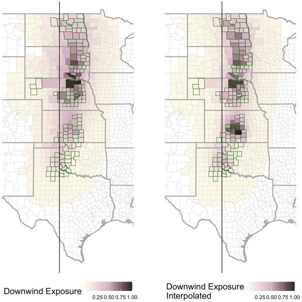

Figure: Exposure to wind: 1981-2010 (left) and 1938-1942 interpolated (right)

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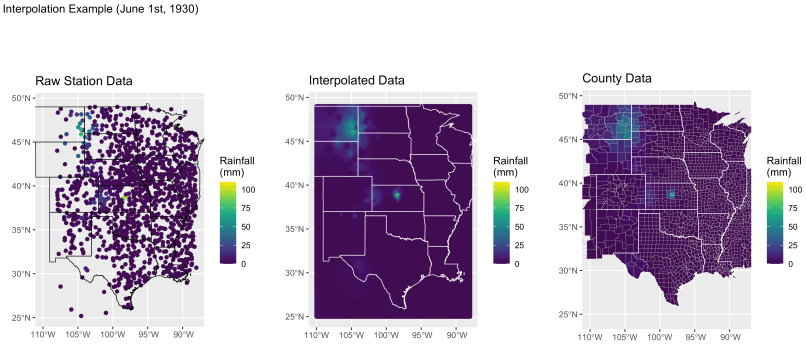
Appendix: GHCNd interpolation



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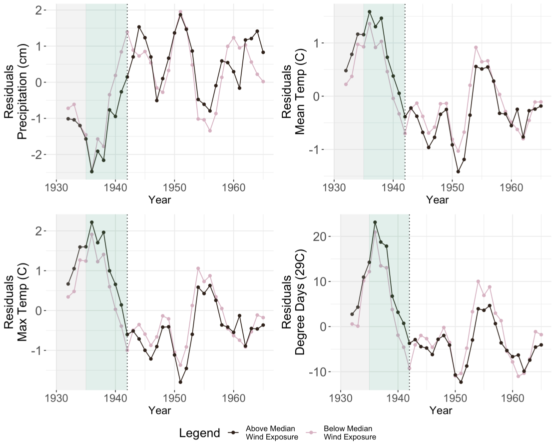
Appendix

Appendix: Identification

Continuous diff-in-diff, county fixed effects:

Climate:



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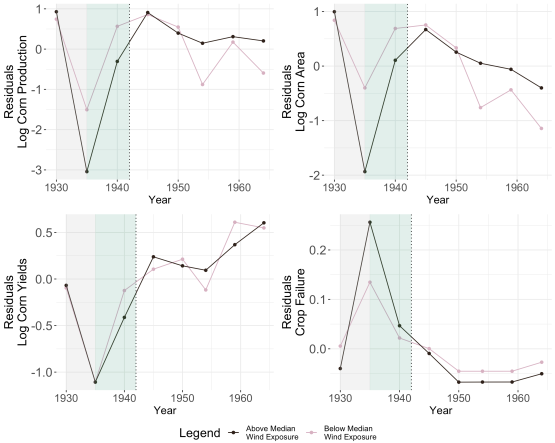
Appendix: Identification

Continuous diff-in-diff, county fixed effects:

Yields:



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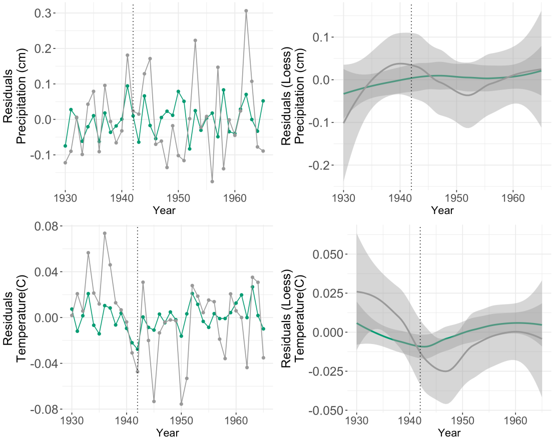
Appendix: Identification

Binary diff-in-diff, country fixed effects:

Climate:



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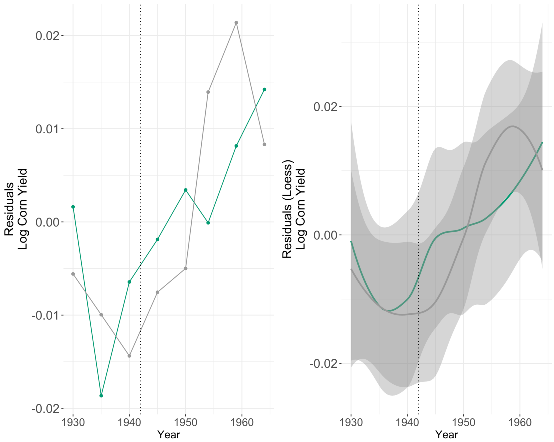
Appendix: Identification

Binary diff-in-diff, country fixed effects:

Yields:



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Appendix: Identification

Table: Balance table

Outcomes	Sample Mean	Without Controls		With Controls	
		Coef.	P-Val.	Coef.	P-Val.
	(1)	(2)	(3)	(4)	(5)
Panel A: Climate Outcomes					
Precipitation (cm)	7.1	-1.212	<0.001	-0.366	0.110
Mean Temp (C)	24.5	-2.167	<0.001	-0.046	0.860
Max Temp (C)	32	-1.306	0.017	0.307	0.292
Degree Days (29C)	37.8	-7.1	0.069	1.957	0.321
Panel B: Agricultural Outcomes					
Log Production	11.6	-1.321	0.113	1.424	0.167
Log Area	9	-0.67	0.359	1.23	0.206
Log Yields	2.6	-0.651	0.001	0.195	0.341

Notes: Table provides summary statistics and shows balance of outcomes by levels of wind exposure. Sample of the 678 counties with centroids within 300km of the centroids of Shelterbelt counties (Panel A), and their subset of 478 counties having agricultural census data and excluding directly afforested counties (Panel B). The outcomes are listed in Column (1). Column (2) reports their sample average. Columns (3) and (4) report, respectively, the OLS point estimate and associated p-value from regressing the outcome, averaged over the baseline period 1935-1942, on the county's wind exposure measure. Columns (5) and (6) also report the OLS point estimate and associated p-value when regressing the outcome on the wind exposure measure, when adding controls to the regression. These controls are: indicators for being a Shelterbelt county, for having above-median distance to the nearest Shelterbelt county, county size, share of county overlapping with the Ogallala aquifer, share of county irrigated in 1935, indicators for having medium or high Dust Bowl erosion levels, elevation, ruggedness, latitude and longitude (indicators for the sample quartiles, and their interactions) and state fixed effects.

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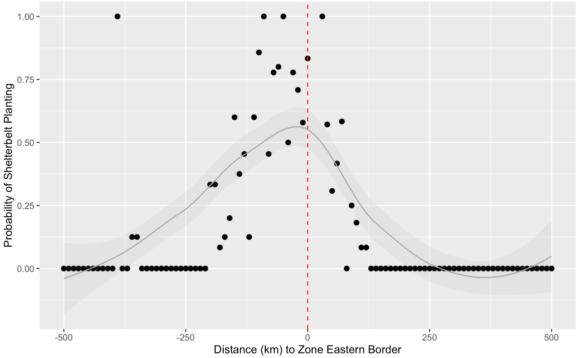
Appendix: Shelterbelt planting in and around 100-mile zone

The original 100-mile zone was not respected for Shelterbelt planting

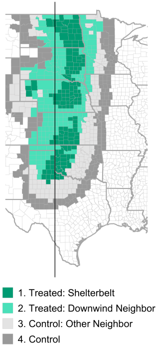


back (diff-in-diff continuous) back (diff-in-diff dummy)

Appendix: Identification, binary diff-in-diff

$$y_{it} = \beta_1 \left(S_i \times P_t\right) + \beta_2 \left(D_i \times P_t\right) + \beta_3 \left(U_i \times P_t\right) + \gamma \left(\mathbf{X}_i \times year_t\right) + \delta_{st} + \nu_i + \epsilon_{it}$$

- Outcome (y_{it}):
  1) Summer precipitation and temperature
  2) Annual yields and land use
- Treatment dummies:
  - S_i : Shelterbelt county dummy
  - D_i : Downwind neighbor county dummy
  - U_i : Other neighbor county dummy
    (Excluded category: "Pure control county")
- P_t : Post 1942 dummy
- X_i: Time-invariant controls
- State-by-year (δ_{st}) and county (ν_i) fixed effects



pretrends back

Appendix: Identification, binary diff-in-diff

$$y_{it} = \beta_1 (S_i \times P_t) + \beta_2 (D_i \times P_t) + \beta_3 (U_i \times P_t) + \gamma (\mathbf{X}_i \times year_t) + \delta_{st} + \nu_i + \epsilon_{it}$$

- Outcome (y_{it}):
  1) Summer precipitation and temperature
  2) Annual yields and land use
- Treatment dummies:
  - S_i : Shelterbelt county dummy
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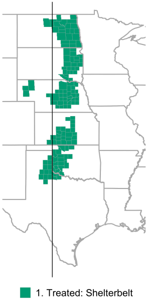

pretrends back

Appendix: Identification, binary diff-in-diff

$$y_{it} = \beta_1(S_i \times P_t) + \beta_2(D_i \times P_t) + \beta_3(U_i \times P_t) + \gamma(\mathbf{X}_i \times year_t) + \delta_{st} + \nu_i + \epsilon_{it}$$

- Outcome (y_{it}):
  1) Summer precipitation and temperature
  2) Annual yields and land use
- Treatment dummies:
  - S_i : Shelterbelt county dummy
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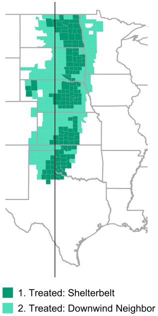
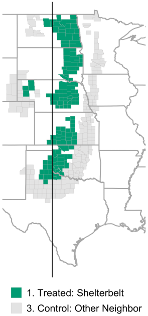


pretrends back

Appendix: Identification, binary diff-in-diff

$$y_{it} = \beta_1 (S_i \times P_t) + \beta_2 (D_i \times P_t) + \beta_3 (U_i \times P_t) + \gamma (\mathbf{X}_i \times year_t) + \delta_{st} + \nu_i + \epsilon_{it}$$

- Outcome (y_{it}):
  1) Summer precipitation and temperature
  2) Annual yields and land use
- Treatment dummies:
  - S_i : Shelterbelt county dummy
  - D_i : Downwind neighbor county dummy
  - U_i : Other neighbor county dummy
    (Excluded category: "Pure control county")
- P_t : Post 1942 dummy
- X_i: Time-invariant controls
- State-by-year (δ_{st}) and county (ν_i) fixed effects



pretrends back

Appendix: Identification, binary diff-in-diff

$$y_{it} = \beta_1 (S_i \times P_t) + \beta_2 (D_i \times P_t) + \beta_3 (U_i \times P_t) + \gamma (\mathbf{X}_i \times year_t) + \delta_{st} + \nu_i + \epsilon_{it}$$

- Outcome (y_{it}):
  1) Summer precipitation and temperature
  2) Annual yields and land use
- Treatment dummies:
  - S_i : Shelterbelt county dummy
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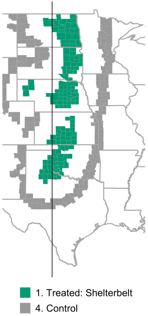
- X_i: Time-invariant controls
- State-by-year (δ_{st}) and county (ν_i) fixed effects



pretrends back

Appendix: Identification, IV first stage

Table: Shelterbelt IV: First Stage

	Dependent variable:
	Wind Exposure
Wind Exposure Instrument	0.486***
	(0.046)
	[0.000]
Observations	598
F Statistic	91.7***
Note:	*p<0.1; **p<0.05; ***p<0.01

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Appendix

Appendix: Downwind yields, production, and area harvested

Table: Impact of Great Plains Shelterbelt on corn yields, production, and area, 1930 to 1965

	Dependent variable:		
	Log Yields	Log Production	Log Area
	(1)	(2)	(3)
Wind Exposure:Post 1942	0.243	2.956***	2.713***
	(0.152)	(0.489)	(0.458)
	[0.111]	[0.000]	[0.000]
75th-25th Perc. Wind Exp	0.22	0.22	0.22
Observations	3,597	3,597	3,597

Notes: Agricultural census data. Excludes directly afforested areas. Standard errors shown in parentheses and are clustered at the county level, p-values shown in brackets (* $p<0.1$; ** $p<0.05$; *** $p<0.01$). All columns include county and state by year fixed effects, and time-invariant controls interacted by year.

→ Increase in corn area harvested.

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Appendix: Economic outcomes and farmer adaptation

Table: Impact of Great Plains Shelterbelt on agricultural land use, 1930 to 1965

	Dependent variable:				
	Cropland (1000ac)	Pastureland (1000ac)	Farmland (1000ac)	Corn Share (% of Cropland)	Wheat Share (% of Cropland)
	(1)	(2)	(3)	(4)	(5)
Wind Exposure:Post 1942	23.364	-113.407	-86.539^{**}	0.108^{***}	-0.045^{*}
	(22.986)	(143.571)	(39.806)	(0.021)	(0.026)
	[0.310]	[0.430]	[0.031]	[0.000]	[0.090]
75th-25th Perc. Wind Exp	0.22	0.22	0.22	0.22	0.22
Observations	3,728	3,728	3,728	3,723	3,562

Notes: Agricultural census data. Standard errors shown in parentheses and are clustered at the county level, p-values shown in brackets (*p$<$0.1; **p$<$0.05; ***p$<$0.01). All columns include county and state by year fixed effects, and time-invariant controls interacted by year.

→ Significant reallocation of inputs following change in return to one output.

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Appendix

Appendix: Decomposition of climate impacts

Objective: Decompose Shelterbelt downwind impacts on yields into:

- Mechanical effect of climate change
- Adaptation (+ non-climate Shelterbelt downwind effects)

Approach: Estimate mechanical effect of climate change

- What are expected log yields given actual climate? ($\hat{y_{it}}^1$)
- What are expected log yields given counterfactual climate, absent Shelterbelt? ($\hat{y_{it}}^0$)
- Compute ATE_{mecha}: average of ($\hat{y_{it}}^1 - \hat{y_{it}}^0$)

Identification:

- Compare ATE_{mecha} with directly estimated treatment effect on log yields
- Focus on downwind neighbors
- Difference comes from adaptation (or omitted variables, i.e. dust)

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Appendix: Decomposition of climate impacts

- We use canonical Schlenker and Roberts (2009) model
$$y_{it} = \mu + \delta_1 DD10_{it} + \delta_2 DD29_{it} + \delta_3 DD39_{it} + \theta_1 precip_{it} + \theta_2 precip_{it}^2 + d_i + z_{it} + \nu_{it}$$
- We want to estimate:
  - $ATE_{mecha} = \delta_1 TE_{DD10} + \delta_2 TE_{DD29} + \delta_3 TE_{DD39} + \theta_1 TE_{precip} + 2\theta_2 TE_{precip}\overline{precip_{it}} - \theta_2 TE_{precip}^2$
- Inputs required:
  - $\delta_1, \delta_2, \delta_3, \theta_1, \theta_2$: from weather-yield relationship
  - TE_{DD10}, TE_{DD29}, TE_{DD39}, TE_{precip} from downwind treatment effects of Shelterbelt (β_2)
  - Average precipitations in sample of interest (non-linearity)

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Appendix: Decomposition of climate impacts

- We estimate the climate-yield relationship according to Schlenker and Roberts (2009)

$$y_{it} = \mu + \delta_1 DD10_{it} + \delta_2 DD29_{it} + \delta_3 DD39_{it} + \theta_1 precip_{it} + \theta_2 precip_{it}^2 + d_i + z_{it} + \nu_{it}$$

- y_{it}: log yields
- DDX_{it}: XC degree days
- $precip_{it}$: precipitation
- d_i: county fixed effects
- z_{it}: quadratic time trends by state

Table: Climate-yield relationship

	Log Yields
Degree Days 10C	-0.001
	(0.002)
Degree Days 29C	−0.006
	(0.005)
Degree Days 39C	−0.093**
	(0.037)
Precipitation	0.040*
	(0.007)
Precipitation (Quad.)	−0.002***
	(0.001)
Sample	Wind Exp < 0.01, Post-1942
Observations	1,474

Notes: *p<0.1; **p<0.05; ***p<0.01. Standard errors shown in parentheses.

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Appendix: Decomposition of climate impacts

Table: Changes in climate and implied changes in corn yields

	Dependent variable:				
		Degree Days		Precipitation	Log Yields
	10C	29C	39C	(cm)	Implied
	(1)	(2)	(3)	(4)	(5)
Wind Exposure:Post 1942	-45.856^{***}	-23.778^{***}	-2.080^{***}	1.161	**0.429**
	(7.282)	(2.953)	(0.228)	(0.921)	-
	[0.000]	[0.000]	[0.000]	[0.209]	-
75th-25th Perc. Wind Exp	0.13	0.13	0.13	0.13	0.13
Observations	3,539	3,539	3,539	3,539	-

Notes: Columns (1) - (4) of the table show results for estimating a continuous TWFE regression for 464 counties, with centroids within 300km of the centroids of Shelterbelt counties, dropping directly afforested areas. Main independent variables are variables used to estimate the weather-yield relationship based on Schlenker and Roberts (2009). Regressions include county and state-by-year FE. Standard errors clustered at the county level shown in parentheses; p-values shown in brackets (*p$<$0.1; **p$<$0.05; ***p$<$0.01).

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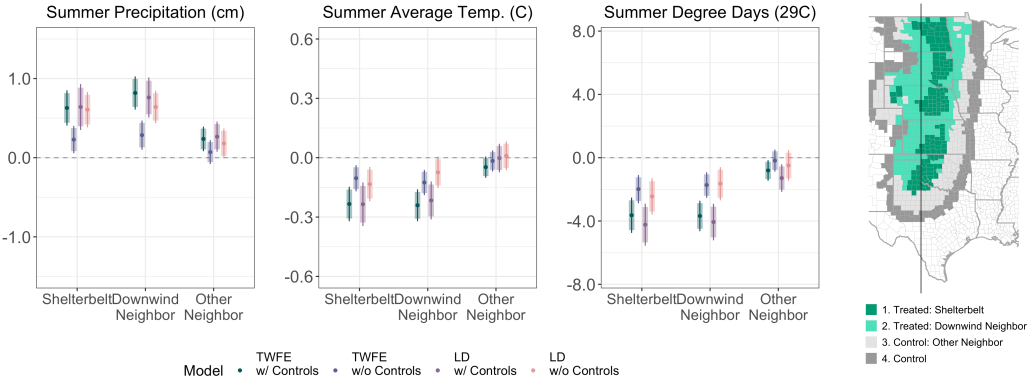
Appendix

Appendix: Binary treatment variables

Rainfall **increased** and temperatures **decreased** in afforested and downwind areas



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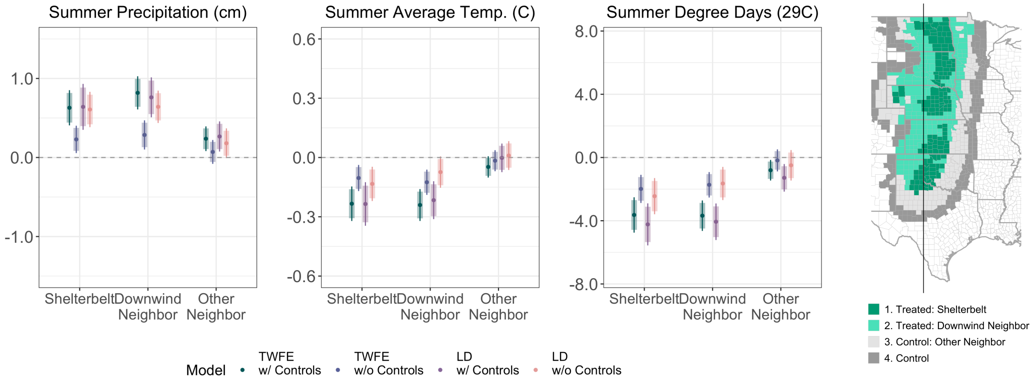
Appendix: Binary treatment variables

But no significant changes in other neighboring counties (placebo check)



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Appendix: Drought indices

Table: Impact of Great Plains Shelterbelt on Jun-Aug crop water availability, 1930 to 1965

	Dependent variable:		
	Palmer Drought Severity Index (PDSI)		
	(1)	(2)	(3)
Wind Exposure:Post 1942	0.994***	2.289***	1.092***
	(0.162)	(0.227)	(0.136)
	[0.000]	[0.000]	[0.000]
Mean	0.12	0.12	0.12
Std.Dev.	1.83	1.83	1.83
75th-25th Perc. Wind Exp	0.3	0.3	0.3
County FE	Y	Y	Y
State x Year FE	Y	-	Y
Year FE	-	Y	-
Controls x Year	Y	Y	-
Observations	21,528	21,528	24,408

Notes: Standard errors shown in parentheses and are clustered at the county level, p-values shown in brackets (*p$<$0.1; **p$<$0.05; ***p$<$0.01).

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Appendix: Drop peak drought years

Table: Impact of Great Plains Shelterbelt on Jun-Aug county climate, 1930 to 1965

	Dependent variable:			
	Precipitation (cm)	Mean Temp (C)	Max Temp (C)	Degree Days (29C)
	(1)	(2)	(3)	(4)
Wind Exposure:Post 1942	1.225***	−0.840***	−1.338***	−13.232***
	(0.317)	(0.093)	(0.136)	(1.324)
	[0.000]	[0.000]	[0.000]	[0.000]
Mean	7.58	24.16	31.49	32.95
Std.Dev.	2.64	2.6	2.63	18.1
75th-25th Perc. Wind Exp	0.21	0.21	0.21	0.21
Observations	24,408	24,408	24,408	24,408

Notes: Standard errors shown in parentheses and are clustered at the county level, p-values shown in brackets (* $p<0.1$; ** $p<0.05$; *** $p<0.01$). All columns include county and state by year fixed effects, and time-invariant controls interacted by year. Separate variable included (not shown) for Wind Exposure:Peak, where Peak is set to 1 for 1934, 1936, and 1939.

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Appendix: Drop 1936-1941

Table: Impact of Great Plains Shelterbelt on Jun-Aug county climate, 1930 to 1965

	Dependent variable:			
	Precipitation (cm)	Mean Temp (C)	Max Temp (C)	Degree Days (29C)
	(1)	(2)	(3)	(4)
Wind Exposure:Post 1942	0.841^{***}	-0.866^{***}	-1.370^{***}	-13.010^{***}
	(0.291)	(0.107)	(0.153)	(1.586)
	[0.005]	[0.000]	[0.000]	[0.000]
Mean	6.72	24.67	32.23	39.49
Std.Dev.	2.61	2.8	2.81	23.25
75th-25th Perc. Wind Exp	0.21	0.21	0.21	0.21
Observations	24,408	24,408	24,408	24,408

Notes: Standard errors shown in parentheses and are clustered at the county level, p-values shown in brackets ($^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$). All columns include county and state by year fixed effects, and time-invariant controls interacted by year. Separate variable included (not shown) for Wind Exposure:Treatment, where Treatment is set to 1 for 1936-1941.

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Appendix: 1910 - 1965

Table: Impact of Great Plains Shelterbelt on Jun-Aug county climate, 1930 to 1965

	Dependent variable:			
	Precipitation (cm)	Mean Temp (C)	Max Temp (C)	Degree Days (29C)
	(1)	(2)	(3)	(4)
Wind Exposure:Post 1942	0.175	-0.346^{***}	-0.647^{***}	-5.571^{***}
	(0.215)	(0.068)	(0.111)	(0.919)
	[0.416]	[0.000]	[0.000]	[0.000]
Mean	7.55	23.77	31.17	31.77
Std.Dev.	2.92	3.1	3.18	22.76
75th-25th Perc. Wind Exp	0.21	0.21	0.21	0.21
Observations	37,968	37,968	37,968	37,968

Notes: Standard errors shown in parentheses and are clustered at the county level, p-values shown in brackets (*p$<$0.1; **p$<$0.05; ***p$<$0.01). All columns include county and state by year fixed effects, and time-invariant controls interacted by year.

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Appendix: Alternative long differences

Table: Impact of Great Plains Shelterbelt on Jun-Aug county climate

	Dependent variable:			
	Precipitation (cm)	Mean Temp (C)	Max Temp (C)	Degree Days (29C)
	(1)	(2)	(3)	(4)
Panel A: 1925-1930 vs. 1960-1965				
Wind Exposure	1.585***	−0.451***	−0.854***	−9.025***
	(0.569)	(0.160)	(0.217)	(1.964)
	[0.006]	[0.006]	[0.000]	[0.000]
Panel B: 1930-1935 vs. 1950-1955				
Wind Exposure	1.247***	−1.139***	−1.803***	−17.096***
	(0.453)	(0.123)	(0.186)	(1.617)
	[0.007]	[0.000]	[0.000]	[0.000]
Mean	6.92	24.78	32.31	40.12
Std.Dev.	2.65	2.83	2.84	23.89
75th-25th Perc. Wind Exp	0.21	0.21	0.21	0.21
Observations	678	678	678	678

Notes: Standard errors clustered at the county level shown in parentheses; p-values shown in brackets (* $p<0.1$; ** $p<0.05$; *** $p<0.01$). Controls include county-level crop suitability, soil characteristics, Dust Bowl erosion measures, and 1935 irrigation intensity. State FE included.

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Appendix: Hyperlocal analysis

- Repeat our analysis at a hyperlocal level, using individual weather station data and the shapefile of the exact location and area of surviving Shelterbelt plantings
- Our treatment variable is equal to the area afforested within a 25km radius of each weather station within the region

Table: Impact of Great Plains Shelterbelt on Jun-Aug county climate, 1930 to 1965

	Dependent variable:			
	Precipitation (cm)	Mean Temp (C)	Max Temp (C)	Degree Days (29C)
	(1)	(2)	(3)	(4)
Afforested Area (1000 ac) : Post-1942	0.306**	−0.127**	−0.140*	−0.030*
	(0.151)	(0.055)	(0.077)	(0.016)
	[0.047]	[0.025]	[0.077]	[0.067]
Observations	2,880	1,872	1,872	1,872

Notes: $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$. Standard errors shown in parentheses and are clustered at the station level.

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Appendix: Irrigation

Irrigation in later decades is not correlated with Shelterbelt tree planting

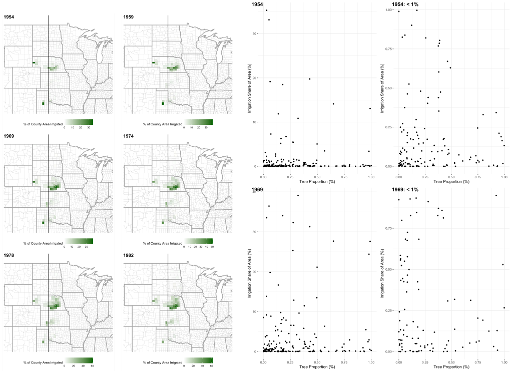

Figure: Irrigation and Shelterbelts

correlation with wind exposure measure back

Appendix: Irrigation

Irrigation in later decades is also not correlated with summer wind exposure from Shelterbelt counties

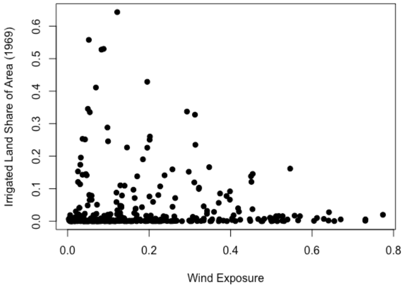

Figure: Irrigation and summer wind exposure to Shelterbelts

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Appendix: Ogallala vs. outside Ogallala

Table: Impact of Great Plains Shelterbelt on Jun-Aug county climate, 1930 to 1965

	Dependent variable:			
	Precipitation (cm)	Mean Temp (C)	Max Temp (C)	Degree Days (29C)
	(1)	(2)	(3)	(4)
Wind Exposure:Post 1942:Ogallala	0.935***	−0.705***	−1.096***	−10.523***
	(0.339)	(0.109)	(0.154)	(1.604)
	[0.006]	[0.000]	[0.000]	[0.000]
Wind Exposure:Post 1942:Outside Ogallala	1.090***	−0.997***	−1.694***	−15.807***
	(0.286)	(0.110)	(0.172)	(1.581)
	[0.000]	[0.000]	[0.000]	[0.000]
Mean	7.06	24.48	31.97	37.82
Std.Dev.	2.82	2.82	2.94	23.37
75th-25th Perc. Wind Exp	0.21	0.21	0.21	0.21
Ogallala Counties	232	232	232	232
Outside Ogallala Counties	446	446	446	446
Observations	24,408	24,408	24,408	24,408

Notes: Standard errors shown in parentheses and are clustered at the county level, p-values shown in brackets (*p<0.1; **p<0.05; ***p<0.01). All columns include county and state by year fixed effects, and time-invariant controls interacted by year.

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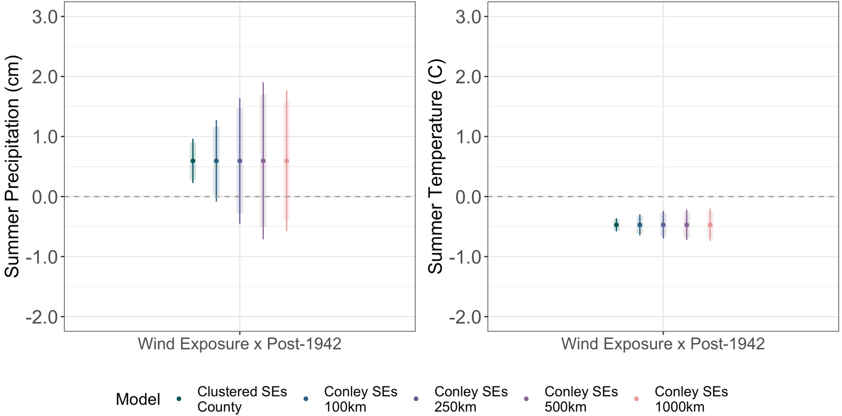
Appendix: Conley standard errors



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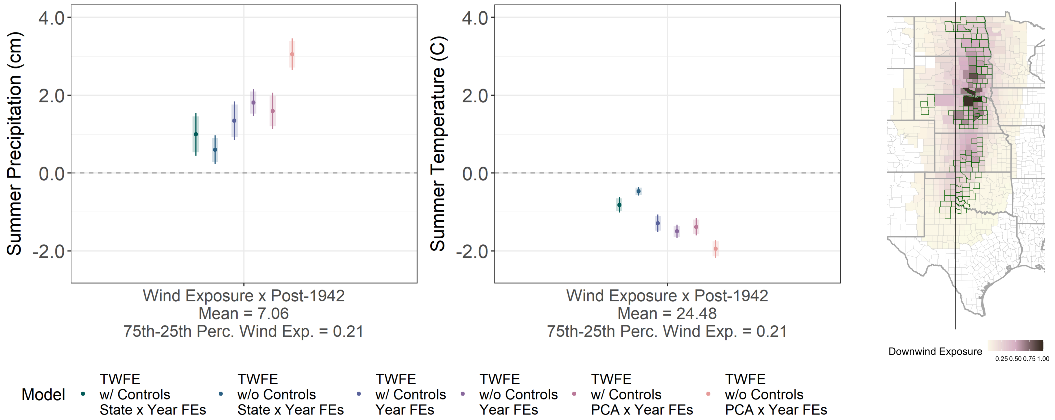
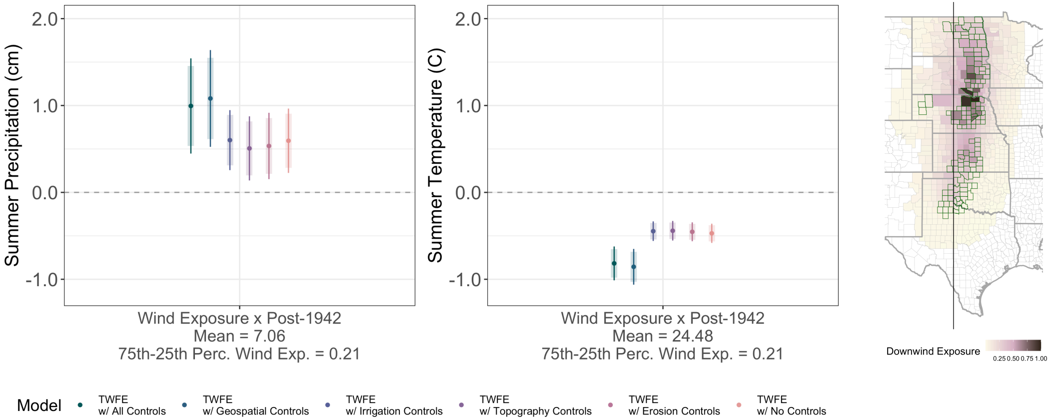
Appendix: Alternatives to state-by-year fixed effects



Appendix: Alternative controls



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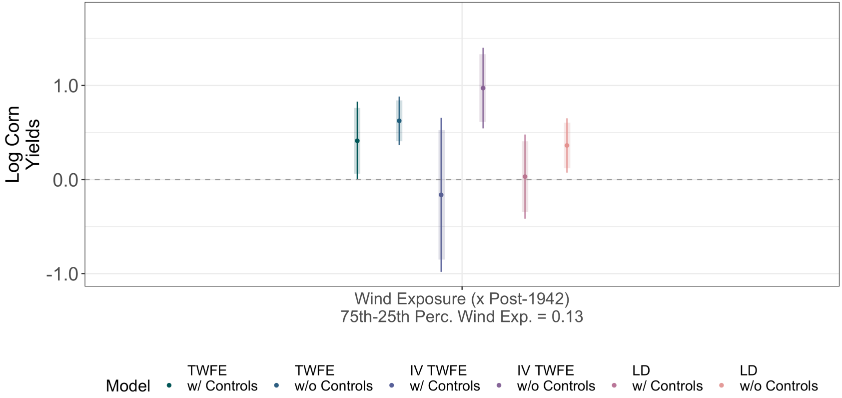
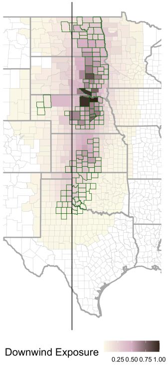
Appendix: Corn yields





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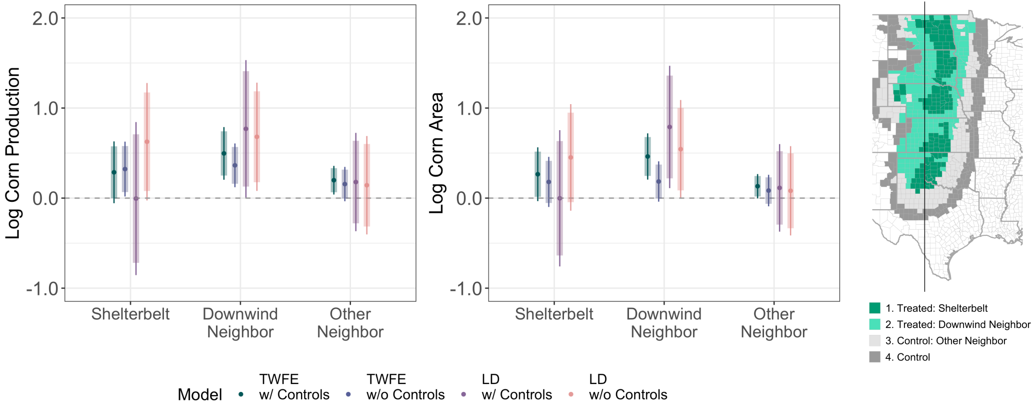
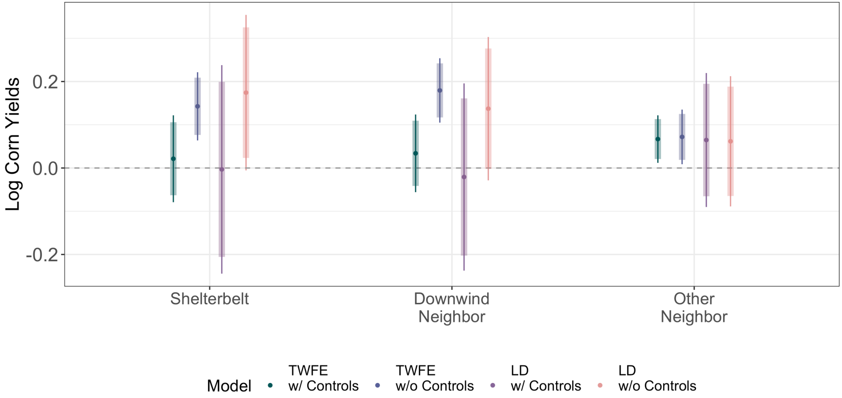
Appendix: Agricultural results using a binary treatment variable

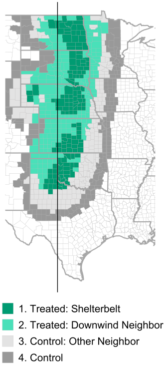
Corn production and area increased in afforested areas as well as in downwind neighbor counties



yield increase (different models) back

Appendix: Corn yields





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Appendix: Corn area planted vs. harvested

Table: Corn Area Planted vs. Harvested - USDA NASS Survey Data

	Dependent variable:							
	Corn Area (1000s Acres)							
	Log Yields		Planted		Harvested		Failure	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Wind Exp.:Post 1942	0.745***	0.810***	20.033**	25.093***	27.107***	28.909***	−7.049**	−3.794
	(0.158)	(0.243)	(9.638)	(9.283)	(7.697)	(8.807)	(3.066)	(4.205)
	[0.000]	[0.002]	[0.040]	[0.008]	[0.001]	[0.002]	[0.023]	[0.369]
Contrls	-	Y	-	Y	-	Y	-	Y
Observations	8,280	7,812	5,249	4,863	5,266	4,877	5,249	4,863

Notes: Standard errors shown in parentheses and are clustered at the county level, p-values shown in brackets (*p$<$0.1; **p$<$0.05; ***p$<$0.01). Columns include county and state by year fixed effects, and time-invariant controls interacted by year (even columns). Separate variable included (not shown) for Wind Exposure:Treatment, where Treatment is set to 1 for 1936-1941.

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Appendix: Drop 1936-1941

Table: Impact of Great Plains Shelterbelt on corn yields, production, and area, 1930 to 1965

	Dependent variable:		
	Log Production	Log Area	Log Yields
	(1)	(2)	(3)
Wind Exposure:Post 1942	2.433***	2.229***	0.204
	(0.826)	(0.825)	(0.219)
	[0.004]	[0.008]	[0.351]
75th-25th Perc. Wind Exp	0.22	0.22	0.22
Observations	3,539	3,539	3,539

Notes: Standard errors shown in parentheses and are clustered at the county level, p-values shown in brackets (*p$<$0.1; **p$<$0.05; ***p$<$0.01). All columns include county and state by year fixed effects, and time-invariant controls interacted by year. Separate variable included (not shown) for Wind Exposure:Treatment, where Treatment is set to 1 for 1936-1941.

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Appendix: Ogallala vs. outside Ogallala

Table: Impact of Great Plains Shelterbelt on corn yields, production, and area, 1930 to 1965

	Dependent variable:		
	Log Production	Log Area	Log Yield
	(1)	(2)	(3)
Wind Exposure:Post 1942 :Ogallala	1.854**	1.463*	0.391*
	(0.905)	(0.848)	(0.222)
	[0.042]	[0.085]	[0.080]
Wind Exposure:Post 1942 :Outside Ogallala	2.237***	1.982***	0.256
	(0.727)	(0.716)	(0.248)
	[0.003]	[0.006]	[0.304]
75th-25th Perc. Wind Exp	0.22	0.22	0.22
Ogallala Counties	134	134	134
Outside Ogallala Counties	345	345	345
Observations	3,710	3,710	3,710

Notes: Standard errors shown in parentheses and are clustered at the county level, p-values shown in brackets (* p<0.1; ** p<0.05; *** p<0.01). All columns include county and state by year fixed effects, and time-invariant controls interacted by year.

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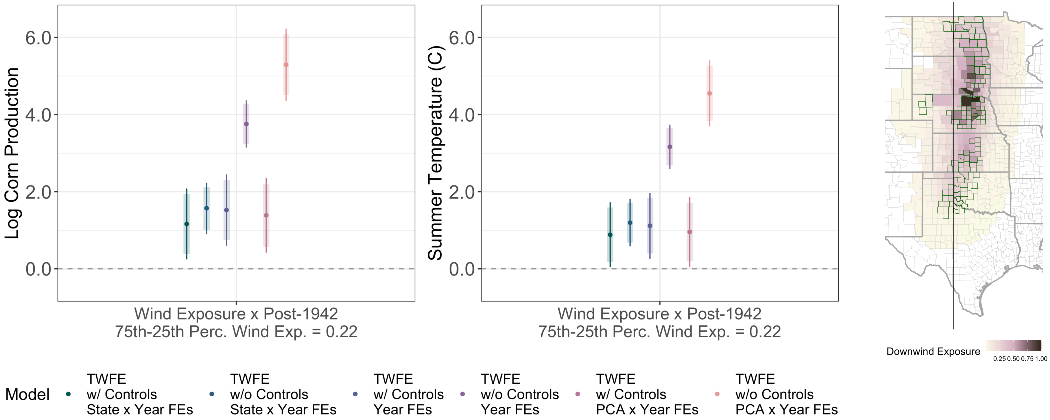
Appendix: Alternatives to state-by-year fixed effects



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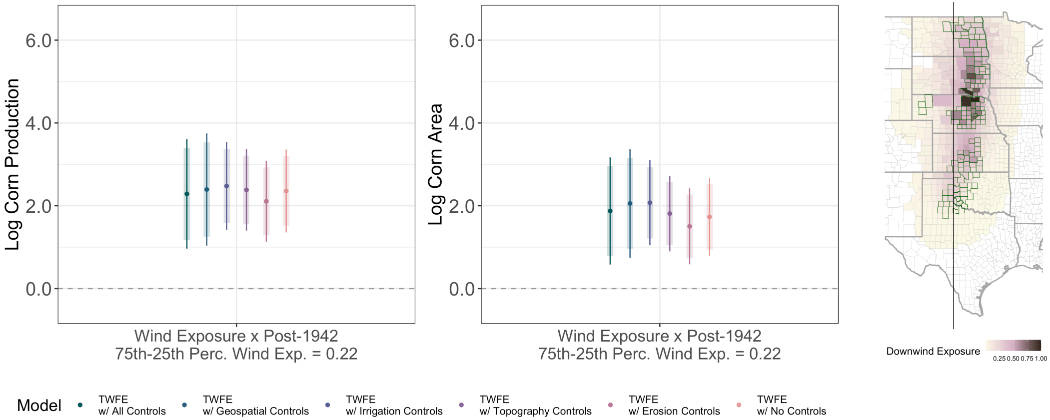
Appendix: Alternative controls



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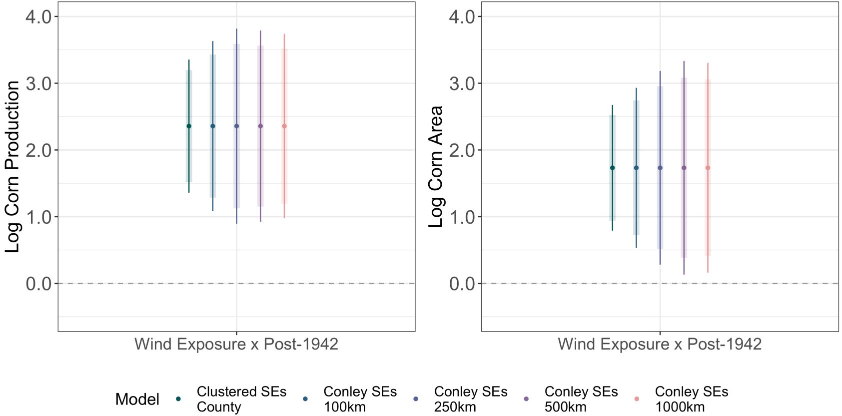
Appendix: Conley standard errors



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Appendix: Climate results for only census counties and years

Table: Impact of Great Plains Shelterbelt on Jun-Aug county climate, 1930 to 1965

	Dependent variable:			
	Precipitation (cm)	Mean Temp (C)	Max Temp (C)	Degree Days (29C)
	(1)	(2)	(3)	(4)
Non-Shelterbelt Counties Only, with Agricultural Census Available				
Wind Exposure:Post 1942	1.161	-1.472^{***}	-2.295^{***}	-23.778^{***}
	(0.921)	(0.238)	(0.326)	(2.953)
	[0.209]	[0.000]	[0.000]	[0.000]
Mean	7.65	23.79	31.09	31.89
Std.Dev.	2.99	2.46	2.51	16.77
75th-25th Perc. Wind Exp	0.13	0.13	0.13	0.13
Observations	3,539	3,539	3,539	3,539

Notes: Table shows results for estimating TWFE regression. Sample of the 678 counties with centroids within 300km of the centroids of Shelterbelt counties. Dependent variables are June - August annual averages. Main independent variable is wind exposure (w_i), which measures approximate exposure to winds from afforested areas, interacted by a post-treatment dummy. "75th-25th Perc Wind Exp" shows the difference between the 75th and 25th percentile of the continuous wind exposure measure in the sample. Time-invariant controls, interacted by year, include county-level crop suitability, soil characteristics, Dust Bowl erosion measures, and 1935 irrigation intensity. County and state-by-year FE included. Standard errors clustered at the county level shown in parentheses; p-values shown in brackets (*p<0.1; **p<0.05; ***p<0.01).

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