A Productivity Indicator for Adaptation to Climate Change

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Introduction

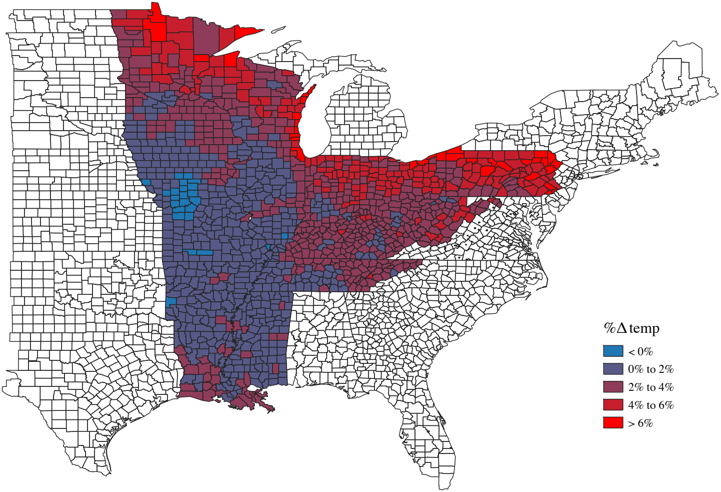
There is increasing focus on adaptation to climate change, both in research and policy.

- Shift from short term weather fluctuations to longer term climate change (Schlenker and Roberts, 2009; Burke and Emerick, 2016; Wang et al., 2017).
- Incorporate weather conditions into production technology estimation (O'Donnell, 2016; Njuki et al., 2018;2020, Chambers and Pieralli, 2020; Chambers et al., 2020).
- On average, findings for climate change effects on productivity are negative for US agriculture over recent decades.

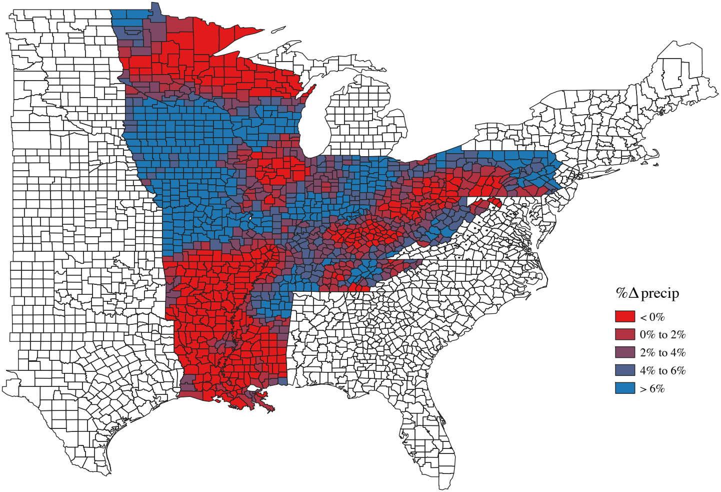
Introduction

- Existing measures consider adaptation mainly in terms of efficiency change, relative to the weather-adjusted frontier.
- We use the Luenberger productivity indicator to also consider technology adaptation components.
- Our adaptation indicator measures the difference in productivity, with and without changing climate conditions.
- We also incorporate a bad, Nitrogen loading, which is affected by changing climate conditions.
- We apply our adaptation indicator to agricultural production in the US Eastern Mississippi River Basin (EMRB) for years 1987-2012.

Changing 30-Year Climate Normals, 1990-2010



Changing 30-Year Climate Normals, 1990-2010



Climate and the Production Metatechnology

We consider two alternative production metatechnologies for time t:

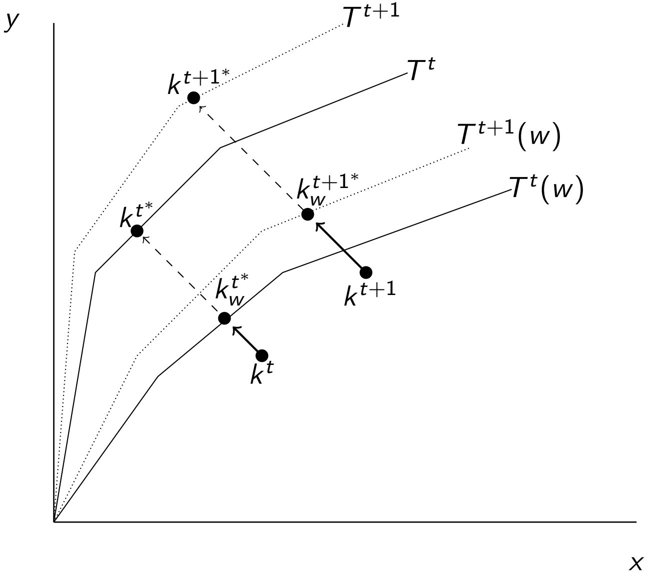
$$T^t = \left\{(x^t, y^t, u^t) : x^t \text{ can produce } y^t \text{ and } u^t \text{ in time } t\right\},$$

$$T^t(w^t) = \left\{(x^t, y^t, u^t; w^t) : x^t \text{ can produce } y^t \text{ and } u^t \text{ given } w^t \text{ in time } t\right\}$$

- $x^t = (x_1^t, ..., x_N^t)$: production inputs
- $y^t = (y_1^t, ..., y_M^t)$: production outputs
- $u^t = (u_1^t, ..., u_J^t)$: undesirable output
- $w^t = (w_1^t, ..., w_L^t)$: climate conditions

Note, the metatechnology in time t encompasses all preceding time periods.

Technical Change, With and Without Climate



Metatechnology for Goods and Bads

Taking an output orientation yields the output sets:

$$P^t(x^t) = \left\{(y^t, u^t) : x^t \,\text{can produce}\, y^t \,\text{and}\, u^t \,\text{in time}\, t\right\},$$

$$P^t(x^t; w^t) = \left\{(y^t, u^t) : x^t \,\text{can produce}\, y^t \,\text{and}\, u^t, \,\text{given}\, w^t \,\text{in time}\, t\right\}.$$

Optimal Production

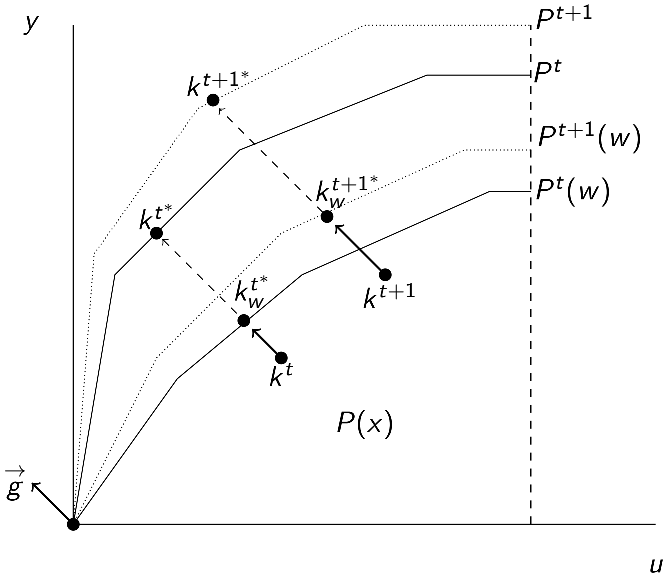
We use the directional output distance function to represent the alternative metatechnologies,

$$\vec{D}_O^t(x^t, y^t, u^t; g_y, g_u) = \max \{\beta : (y^t + \beta g_y, u^t - \beta g_u) \in P^t(x^t)\},$$

$$\vec{D}_O^t(x^t, y^t, u^t; w^t, g_y, g_u) = \max \{\beta : (y^t + \beta g_y, u^t - \beta g_u) \in P^t(x^t; w^t)\},$$

- $\vec{g} = (g_y, g_u)$ specifies the direction of desirable output expansion and undesirable output contraction.
- $\vec{D}_O(x, y, u; g_y, g_u) = 0$ on the frontier and $\vec{D}_O(x, y, u; g_y, g_u) > 0$ increases with inefficiency.

Inefficiency With and Without Climate



Luenberger Productivity Indicator

We begin with the Luenberger productivity indicator,

$LUEN(t, t+1) =$

$$\frac{1}{2}\left[\vec{D}_O^{t+1}(x^t, y^t, u^t; g_y, g_u) - \vec{D}_O^{t+1}(x^{t+1}, y^{t+1}, u^{t+1}; g_y, g_u)\right]$$
$$+\frac{1}{2}\left[\vec{D}_O^{t}(x^t, y^t, u^t; g_y, g_u) - \vec{D}_O^{t}(x^{t+1}, y^{t+1}, u^{t+1}; g_y, g_u)\right],$$

which can be decomposed (Chambers et al., 1996) to separate measures of efficiency change and technology change.

- $LUEN(t, t+1) = LECH(t, t+1) + LTCH(t, t+1)$.

Adaptation Indicator

Our adaptation indicator (AI) measures the difference in productivity with and without weather differences.

- $AI(t, t+1) = LUEN_{(w)}(t, t+1) - LUEN(t, t+1)$.

This yields corresponding efficiency and technology change components,

- $AIEC(t, t+1) = LECH_{(w)}(t, t+1) - LECH(t, t+1)$,
- $AITC(t, t+1) = LTCH_{(w)}(t, t+1) - LTCH(t, t+1)$.

To interpret, a negative AI value implies lower productivity, relative to productivity without weather differences, while positive AI values imply higher relative productivity.

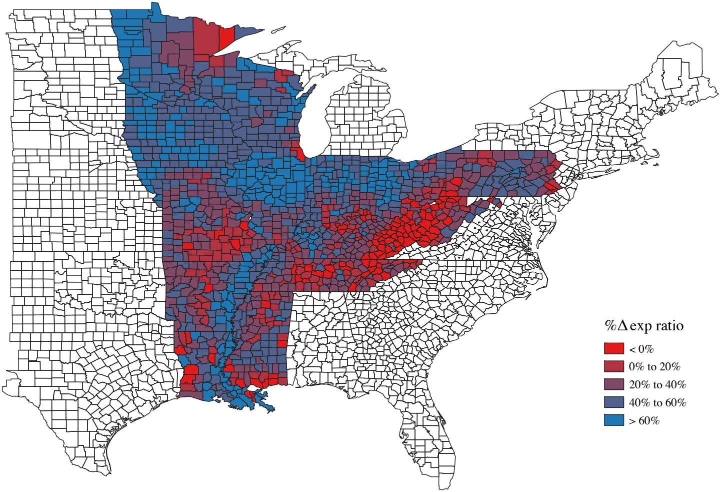
Long Differences Approach

- Distinguish long term trends from short term weather variation (Burke and Emerick, 2016).
- Let $\Theta = (\Theta_{S_1}, ..., \Theta_{S_P})$ represent a vector of P successive climate time periods, each of length S_p, $p = 1, ..., P$.
- Let $\bar{x}^{\Theta_{S_p}}$, $\bar{y}^{\Theta_{S_p}}$, $\bar{u}^{\Theta_{S_p}}$, and $\bar{w}^{\Theta_S}$ represent climate period average values
- 5-year climate periods and 30-year climate normals, based on USDA Census of Agriculture years: 1987-1992, 1997-2002, and 2007-2012. We refer to these as the 1990, 2000, and 2010 climate periods.
- Employ Luenberger framework to measure change between climate periods.

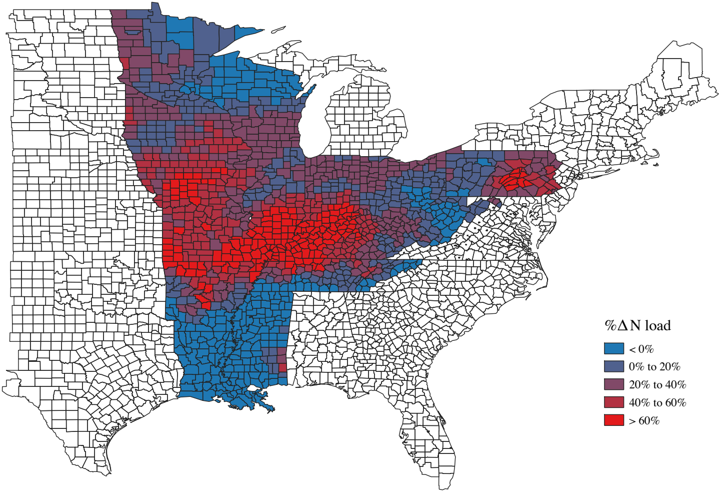
Application to Mississippi River Basin

- Limit analysis to areas east of the 100th Meridian (EMRB).
- USDA Census of Agriculture county-level sales and expenditures, 1987-2012.
- Nitrogen loading data estimated for all subbasins of the lower 48 states, spanning 1987 - 2012 (Ballard et al., 2019).
- Climate variables for temperature and precipitation collected from PRISM Climate Group for years 1950-2010.
- Use GIS to match production, N loading, and climate data annually to the county level.
- Nonparametric estimation using linear programming methods known as data envelopment analysis (DEA).

Changing Production, 1990-2010



Changing Nitrogen Loading, 1990-2010



Weather Indices for Agriculture

Following Wang et al. (2017), we construct two weather index measures, the Oury (1965) aridity index for crop production and a temperature humidity index (THI) for livestock:

$$\text{Oury} = \frac{\text{Precipitation}}{1.07^{\text{Temperature}}},$$

$$\text{THI} = (\text{Dry Bulb Temp}) + (0.36 * \text{Dew Point Temp}) + 41.2.$$

- Temperature in degrees Celsius and precipitation in millimeters.
- Restrict Oury to growing season months (Apr-Aug) and THI annual average.
- Construct 30-year climate normals for each weather index.

EMRB Climate Period Variable Means, 1990 - 2010

Variable	1990	2000	2010
Acres	189,510.20	188,804.60	189,767.5
Sales (1,000s)	48,145.37	55,686.67	65,029.61
Expenditures (1,000s)	37,185.06	40,071.73	42,482.98
Monthly Temp (C)	19.74	19.96	20.26
Monthly Precip (mm)	102.29	104.27	105.89
Monthly Oury	28.64	28.41	28.14
Monthly THI	54.86	55.01	55.33
Nitrogen Load (kg/km2)	377.45	523.93	404.75

- Note, all sales and expenditure values are reported in 1990-1992 USD.
- Values represent sample means for 1,214 counties.

Climate Period Inefficiency Means, 1990 - 2010

We estimate four technology models, with and without climate (w) and nitrogen loading (N) variables.

Inefficiency	1990	2000	2010
Distance	0.289	0.378	0.381
Distance (w)	0.231	0.301	0.310
Distance (N)	0.256	0.319	0.303
Distance (N;w)	0.200	0.253	0.255

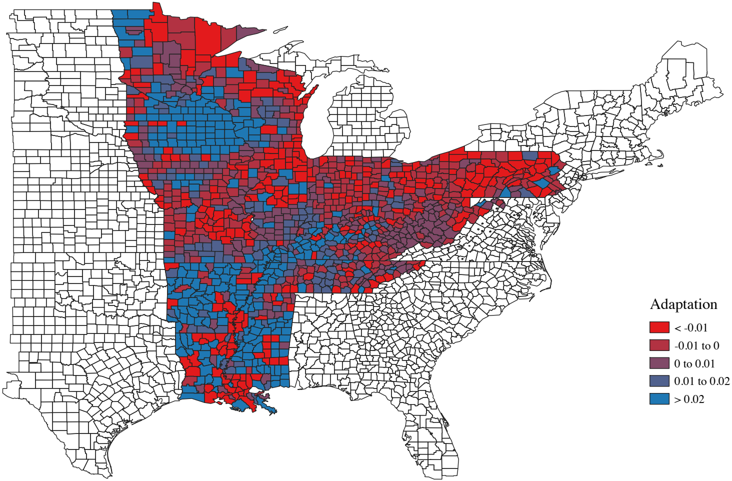
- Note, all data were mean-weighted for estimation purposes, so that values can be interpreted as % of sample mean.
- Mean inefficiency increases over time, across models.

Productivity and Adaptation Means, 1990 - 2010

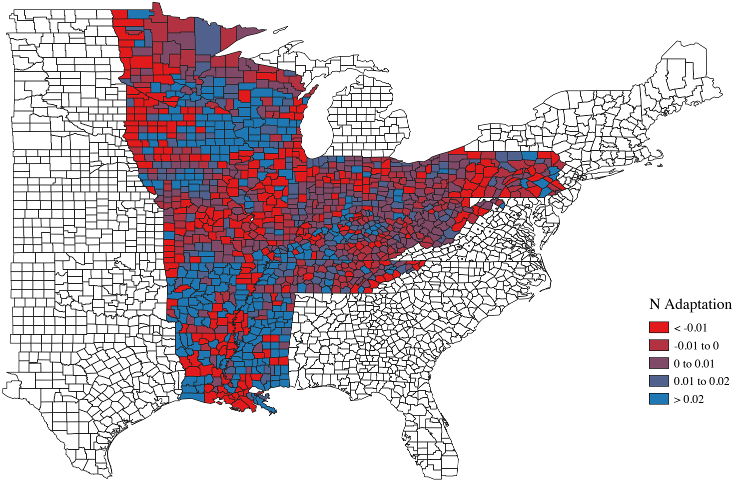
	Production Only		Production and N loading	
Productivity	1990-2000	2000-2010	1990-2000	2000-2010
LECH	-0.090	-0.003	-0.063	0.016
LTCH	0.153	0.107	0.117	0.062
LUEN	0.063	0.104	0.054	0.078
LECH (w)	-0.069	-0.010	-0.053	-0.002
LTCH (w)	0.145	0.135	0.128	0.108
LUEN (w)	0.075	0.125	0.075	0.106
Adaptation				
AIEC	0.020	-0.007	0.009	-0.018
AITC	-0.009	0.028	0.012	0.045
AI	0.012	0.021	0.021	0.028

- $LUEN(t, t+1) = LECH(t, t+1) + LTCH(t, t+1)$.
- $AI(t, t+1) = LUEN_{(w)}(t, t+1) - LUEN(t, t+1)$.

Adaptation Indicator (Production Only), 1990-2010



Adaptation Indicator (N-Loading), 1990-2010



Conclusion

- We develop a Luenberger-based indicator for adaptation, with a differences in differences interpretation.
- We construct a new data set, matching historical agricultural production to both climate and nitrogen loading.
- Our main findings include:
  - Overall productivity gains, driven mainly by technical progress.
  - Overall adaptation gains, driven both by adaptation efficiency and technical progress.
  - We find adaptation gains concentrated in the upper Midwest and lower South.
- We limit the analysis to county-level aggregate production data.
- Future extensions include:
  - More recent years
  - Stochastic frontier analysis
  - Go West?