# Integrating Weather into Agricultural Total Factor Productivity Measurement

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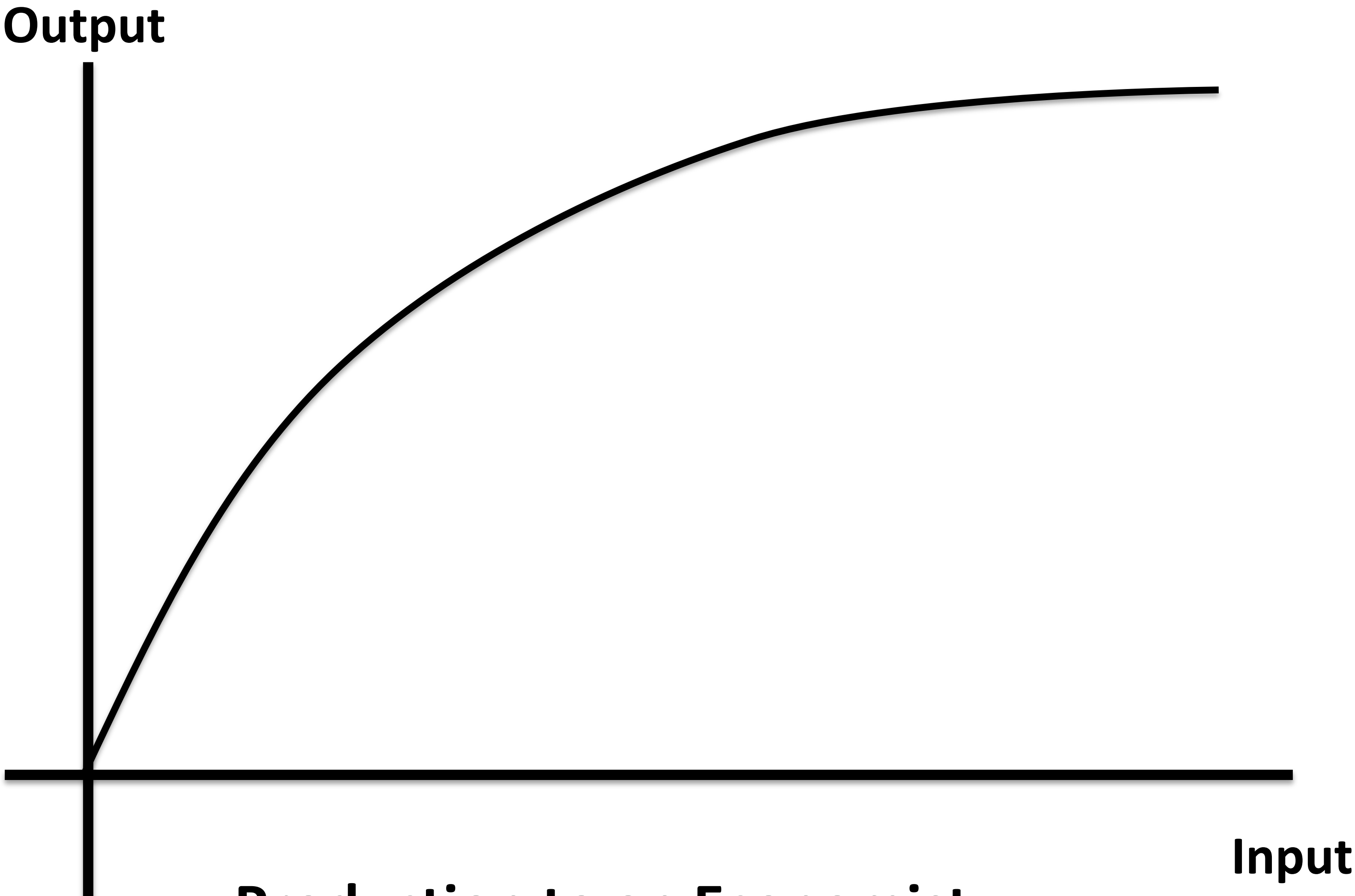
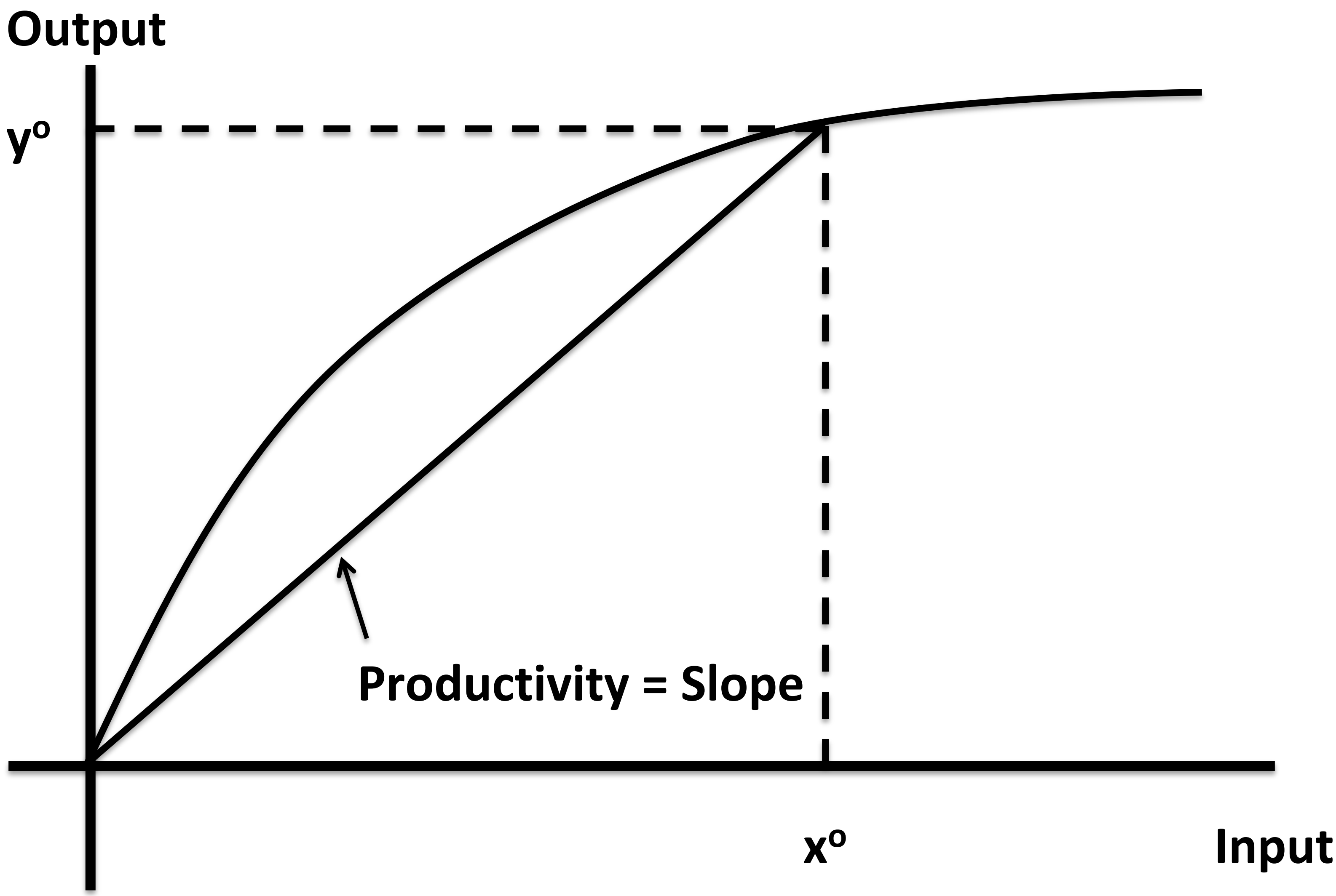
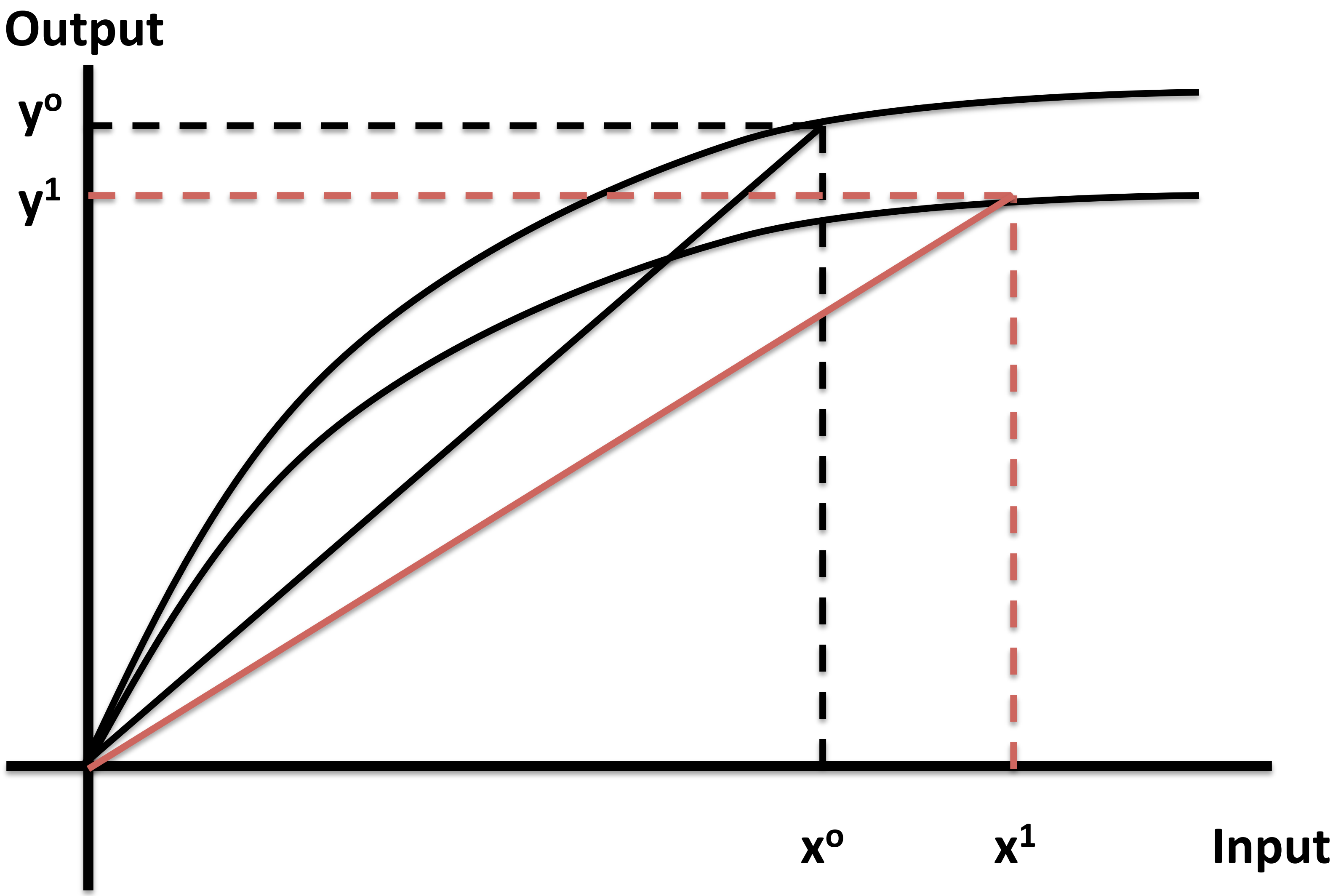



Production to an Economist




**Productivity As Average Product**




$$\Delta\text{Productivity} = \Delta x + \Delta\text{Frontier}$$

# Background

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- Observation (originally Barton and Cooper 1948 but reconfirmed since): aggregate input base in US agriculture remained constant since 1914, actually declined slightly since 1948, but stupendous output growth

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- Abramovitz (1956) talking about related phenomenon for industrial output growth

  This result is surprising in the lopsided importance which it appears to give to productivity increase, and it should be, in a sense, sobering, if not discouraging, to students of economic growth. Since we know little about the causes of productivity increase, the indicated importance of this element may be taken to be some sort of *measure of our ignorance* about the causes of economic growth in the United States and some sort of indication of where we need to, concentrate our attention.

# How to Account for Output Growth (cont'd)

- Schultz (1956) growth theory goal (attributes to Griliches)
  ..a strong and satisfactory linkage between input and output over time. In our efforts to do this, we would do well to place before us and keep in mind the characteristics of an ideal input-output formula for this purpose. It would be one where output over inputs, excluding of course, changes in their quality, stayed at or close to one. The closer we come to a one-to-one relationship in our formulation the more complete would be our (economic) explanation.

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  "Simply relabelling these changes as Technical Progress or Advance of Knowledge leaves the problem of explaining growth in total output unsolved."
- Jorgenson and Griliches helped solve the puzzle outside of agriculture, but for agriculture puzzle remains, productivity growth has averaged roughly 1.4% a year since 1948 in US agriculture

# Today's Presentation

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- Numerous collaborators: Simone Pieralli, Ariel Ortiz-Bobea, Xin-Zhong Liang, You Wu, et al.
- Three Related but Distinct Efforts

  1. Examining Weather Effects on Measured Agricultural TFP: Correlation Analysis

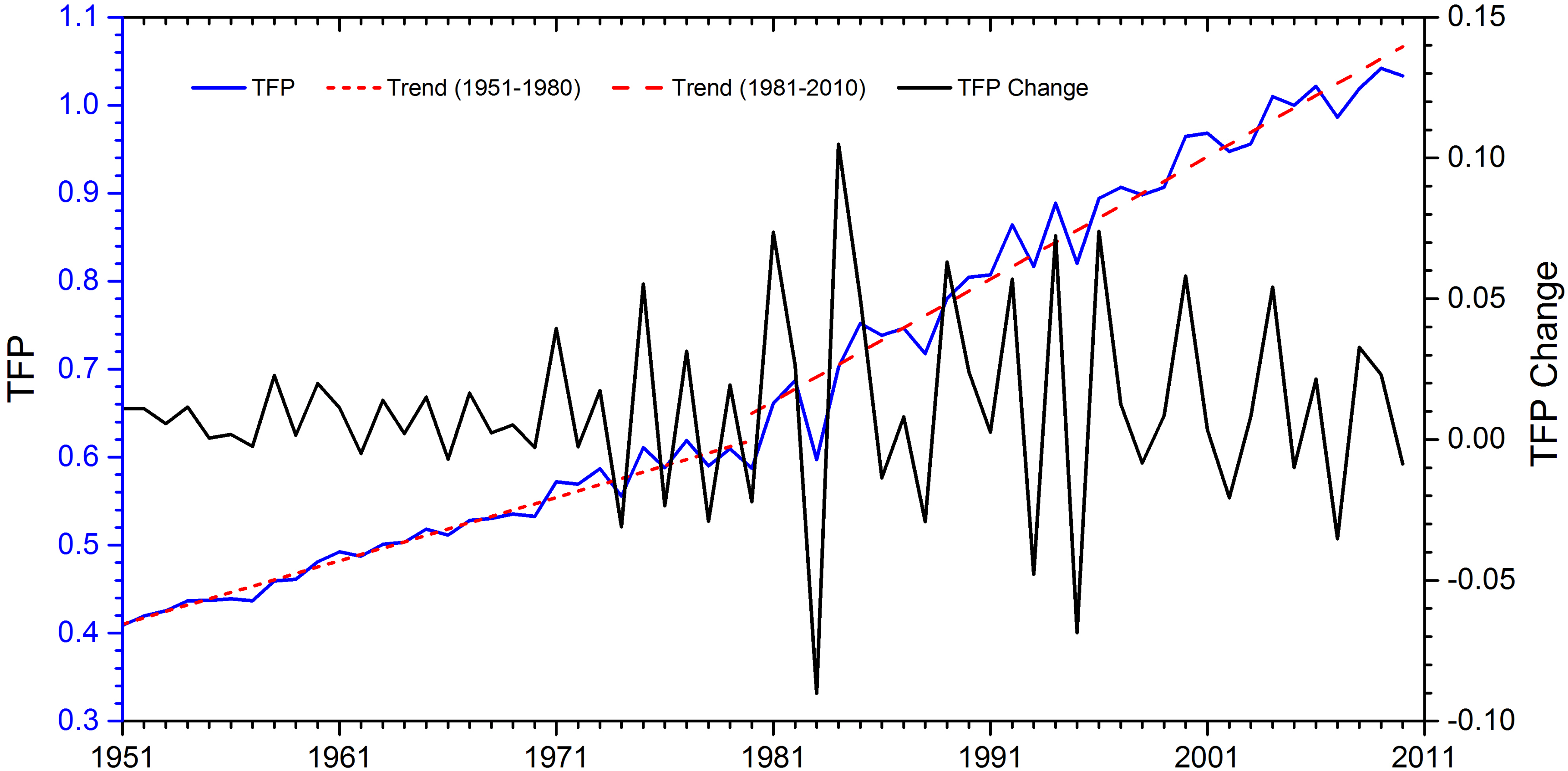
     a) US state-level agricultural TFP (1960-2004,*Science Advances, 2019*)

     b) US national-level agricultural TFP (*PNAS*, 2017)

  2. Incorporating Weather as Random Input into Productivity Measurement

# Linking Climate, Agriculture, and the Economy

Liang et al. (2017), PNAS, http://www.pnas.org/content/114/12/E2285.full




**Evolution of U.S. agricultural total factor productivity.** TFP, *blue scale on right*, TFPC, *black, scale on left* 1951-2010, TFP's linear trend estimates for 1951-1980 and 1981-2010 (*red dashed*).

# Weather Effects on Measured TFP: State-level

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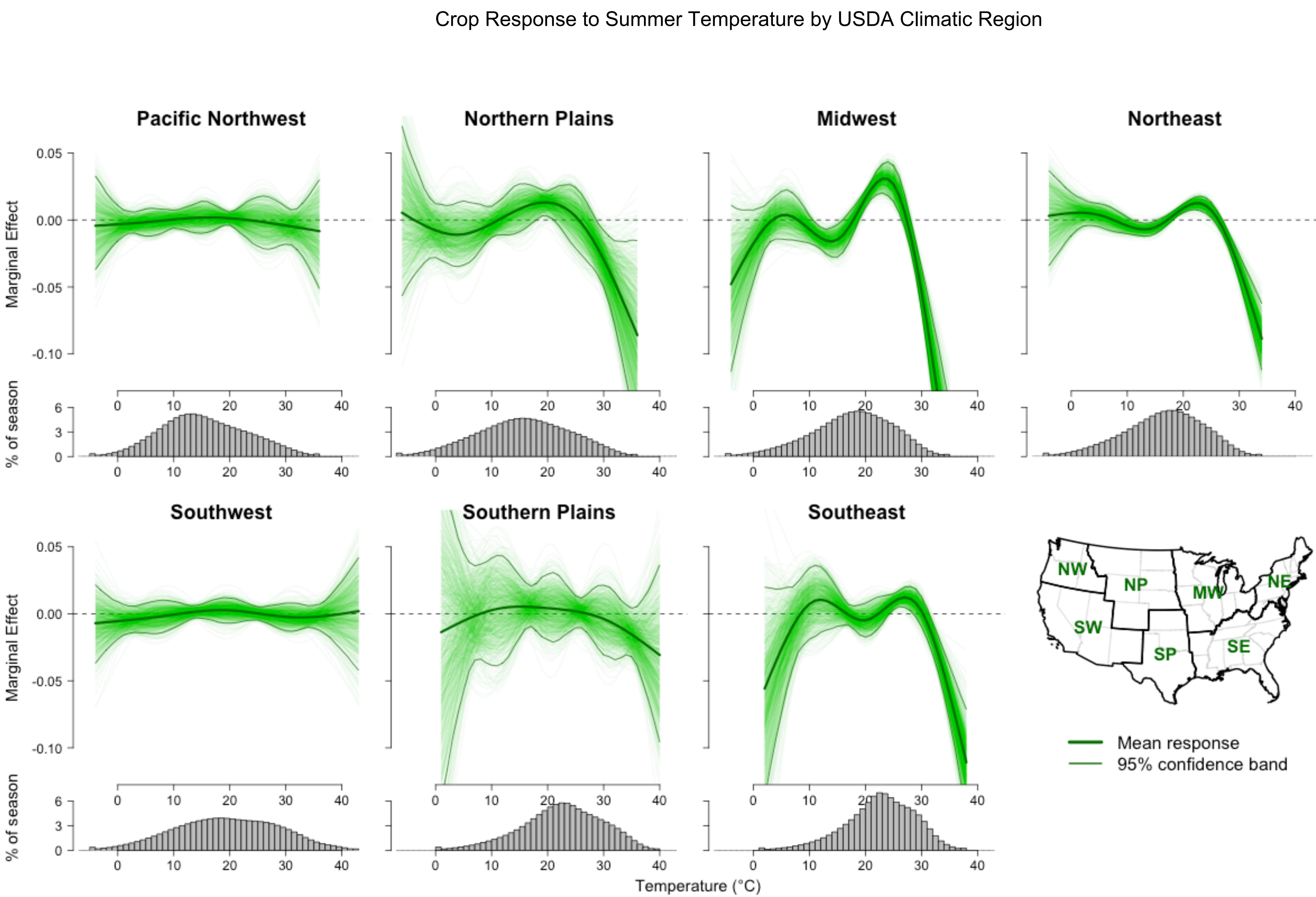
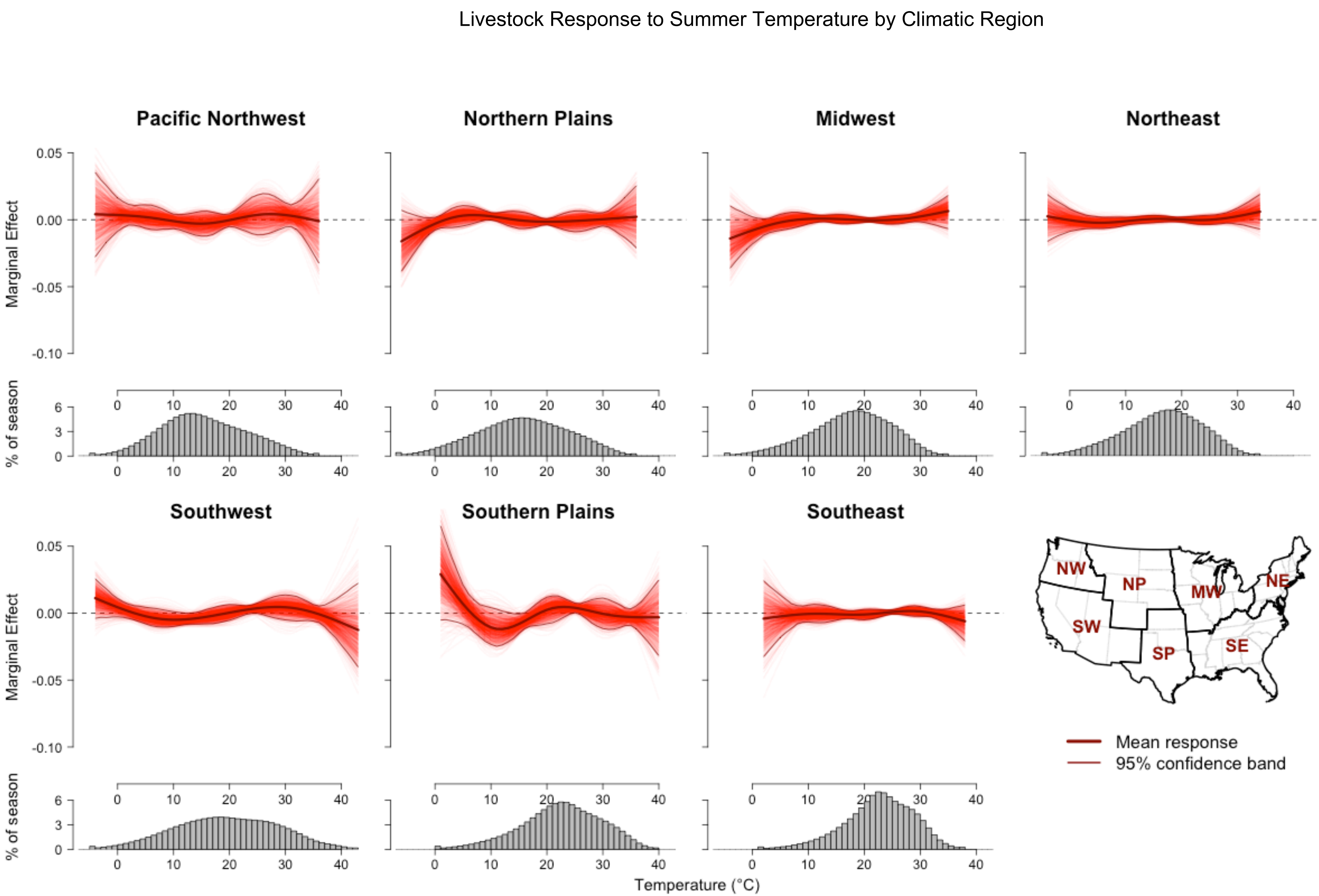
- Focus on whether finely-gridded weather data are correlated with measured TFP change
- Data: USDA state-level panel on $(y, x)$, PRISM climate data (precipitation), and Schlenker and Roberts (temperature)
- Method: parallels RBC research, filter aggregate data using Hodrick-Prescott ($\lambda = 6.25$) filter; regression analysis between innovations around filtered series and weather variates; projections using RCP 8.5 from IPCC AR5 (2014) (most drastic temperature increase)



Crop Response to Summer Temperature by USDA Climatic Region
Pacific Northwest
Northern Plains
Midwest
Northeast
Southwest
Southern Plains
Southeast
Marginal Effect
% of season
Temperature (°C)
NW
NP
MW
NE
SW
SP
SE
Mean response
95% confidence band



Livestock Response to Summer Temperature by Climatic Region
Pacific Northwest
Northern Plains
Midwest
Northeast
Southwest
Southern Plains
Southeast
Marginal Effect
% of season
Temperature (°C)
NW
NP
MW
NE
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SP
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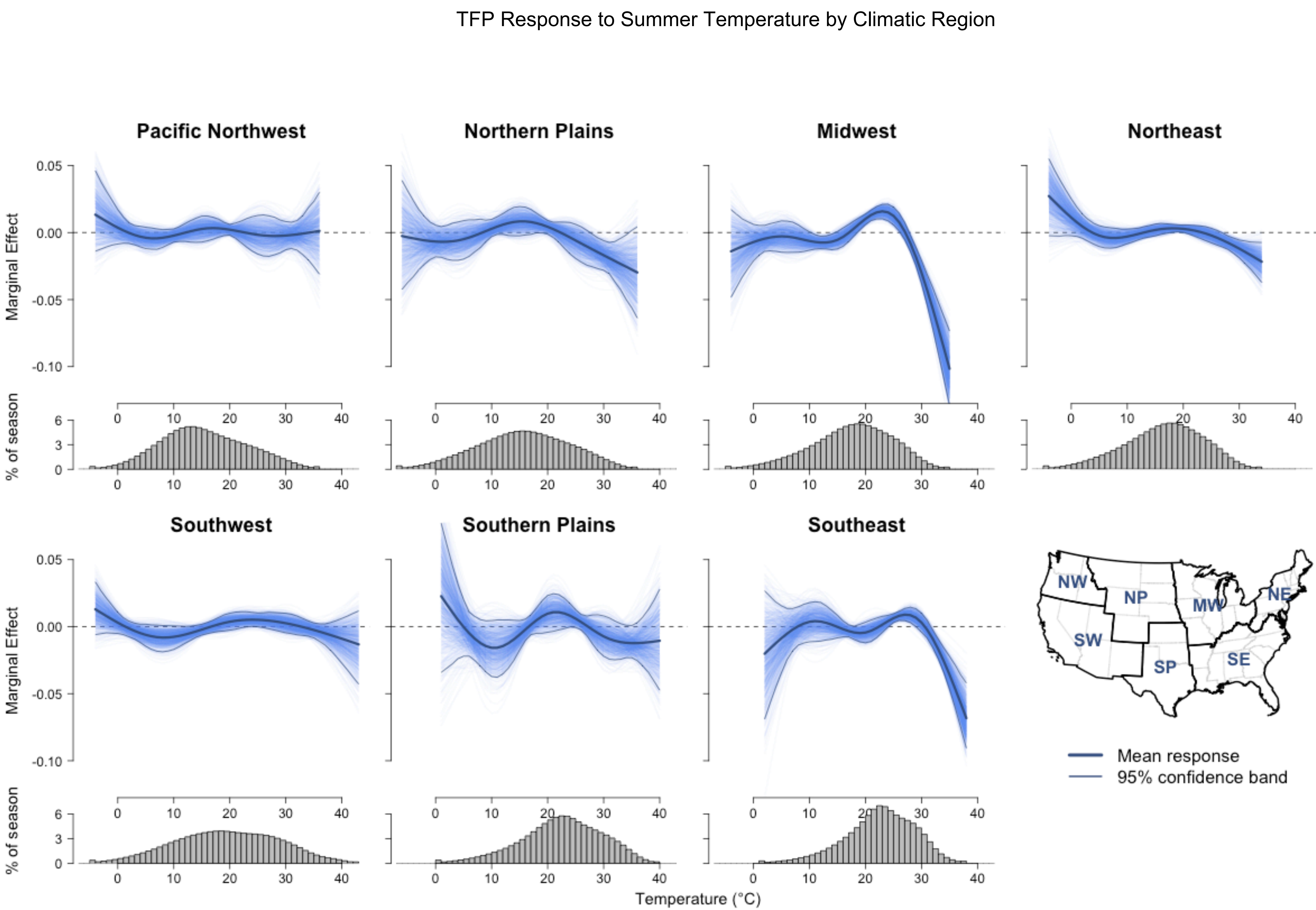

TFP Response to Summer Temperature by Climatic Region
Pacific Northwest
Northern Plains
Midwest
Northeast
Southwest
Southern Plains
Southeast
Marginal Effect
% of season
0.05
0.00
-0.05
-0.10
0
10
20
30
40
6
3
Temperature (°C)
NW
NP
MW
NE
SW
SP
SE
Mean response
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# Lessons from State-level Analysis

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- Big Regional Differences: Southwest, which includes California (small effect), Midwest (large effect)
- Adaptation will need to occur in Midwest field crops (corn and soybeans)

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- Data: USDA Ag TFP (1948-2014) and detailed weather data

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- Source: Liang, Wu, Chambers et al. (2017) PNAS
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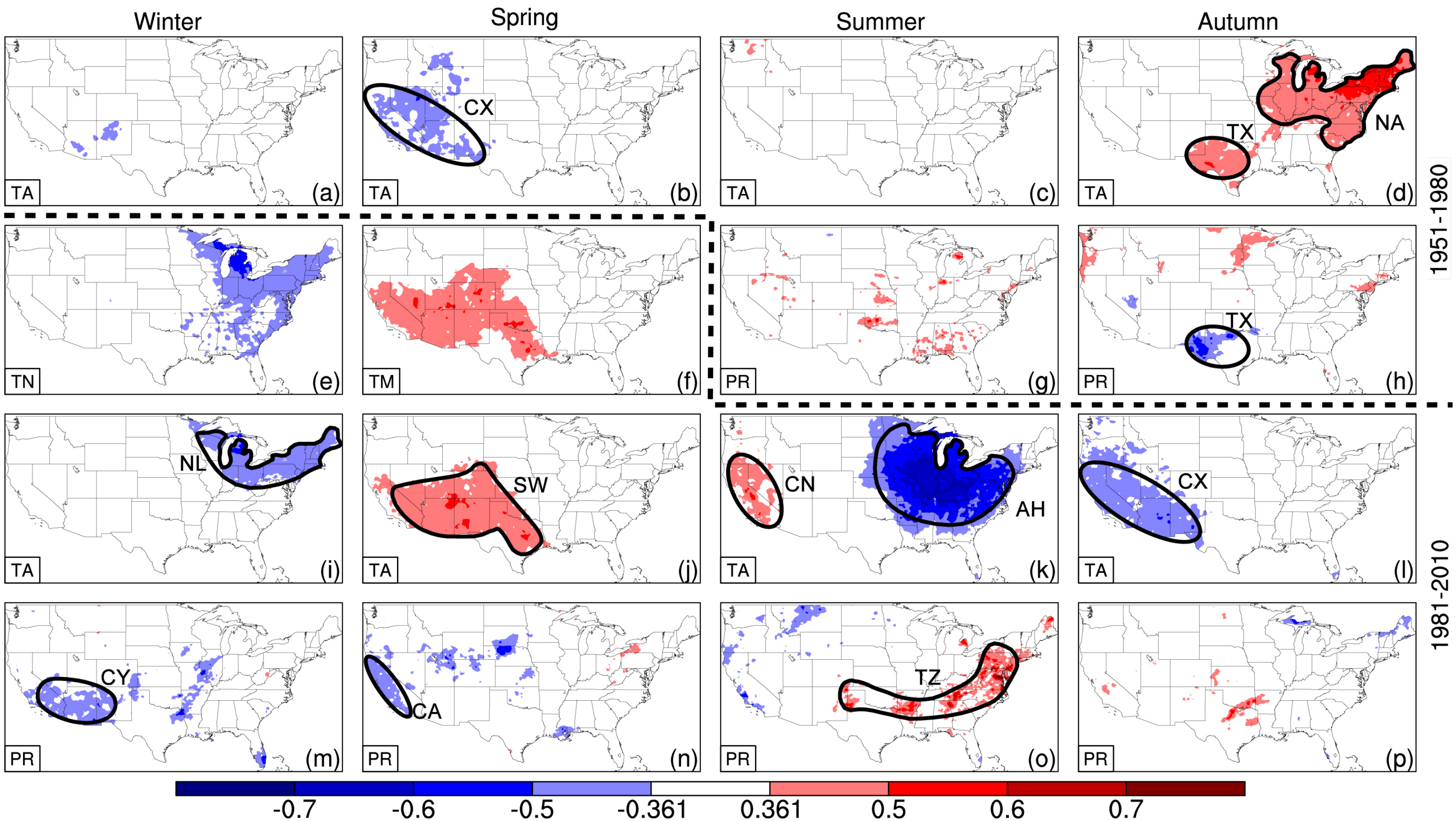
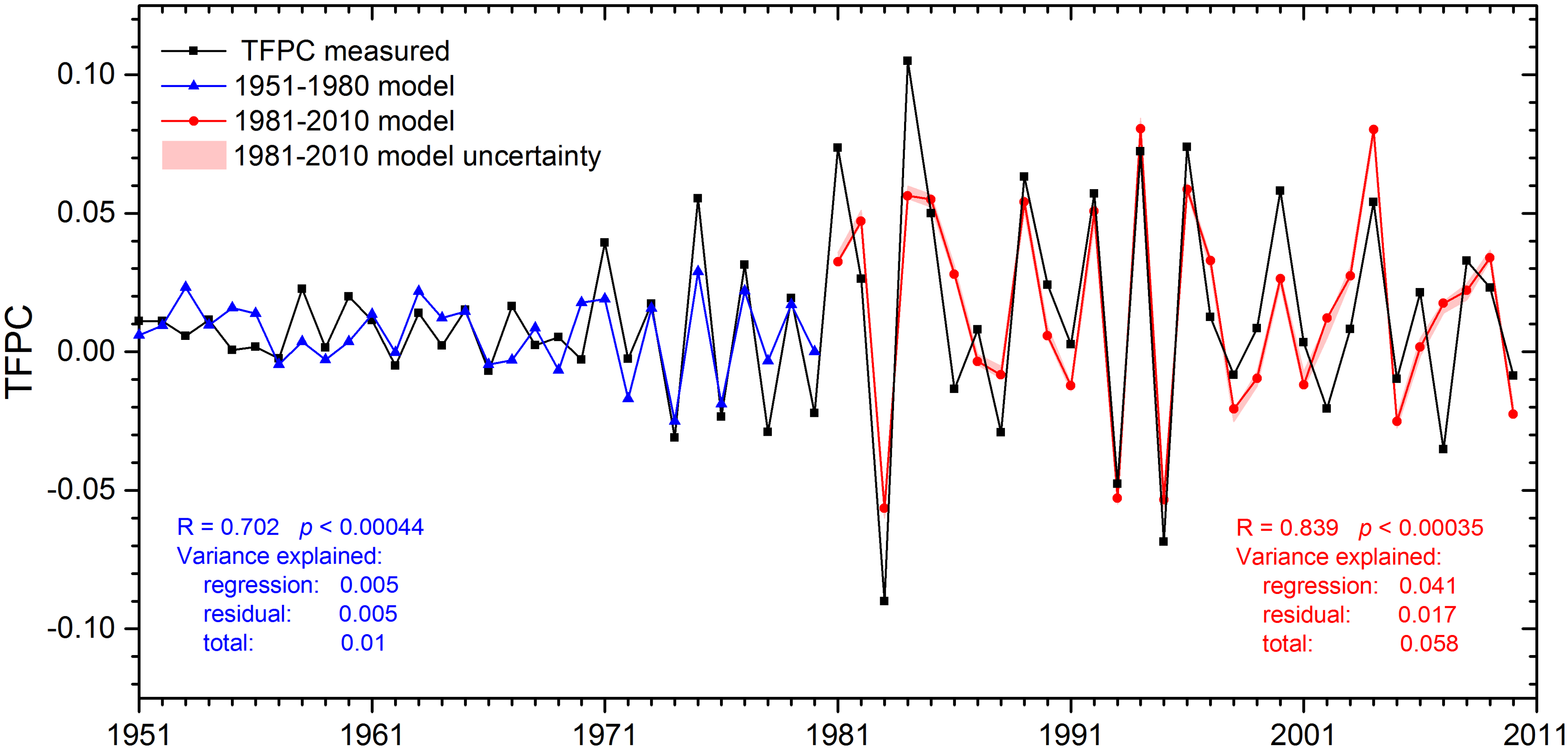
- Method: Calculate Annual Change in TFP, empirically relate TFP change with seasonal and geographic distributions of climate variables, then project




- National-level agricultural total factor productivity change (TFPC) is quantifiably linked to climate variability in U.S. specific crop-growing regions
- Historical model can explain ~70% of TFPC variance from 1981-2010
- TFPC-climate correlations have become stronger over the past three decades




**Measured and simulated TFPC variations.** The simulations include those by model [1] for 1951-1980 and by model [2] for 1981-2010. Also shown are the correlation coefficient (R) of the simulated with measured TFPC, the *p*-value of the regression, and the explained, residual and total variance for each period. The shaded area represents uncertainty in the 1981-2010 regression model, showing the 25th-75th percentile range of sub-model simulations when using 28-year bootstrap samples.

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- Earlier: weather variates less important empirically
- Later: weather variates more important empirically (up to 70% of variation appears explainable)

# US state-level analysis 1960-2004

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- Source: Chambers and Pieralli, "The Contributions of Weather, Technological Change, and Adaptation to Agricultural Productivity Growth", 2019
- Data: USDA state-level panel on $(y, x)$ and Schlenker and Roberts $(w)$ data
- Method: Data Envelopment Analysis approximation to $T(t)$, Radial Output Distance Function Compositions

# Weather as a Random Input

- Definition of an Aggregate Technology

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- Decompose measured TFP change

$$\frac{y_t/x_t}{y_0/x_0}=T_{t,0}\cdot W_{t,0}\cdot X_{t,0}\cdot E_{t,0}$$

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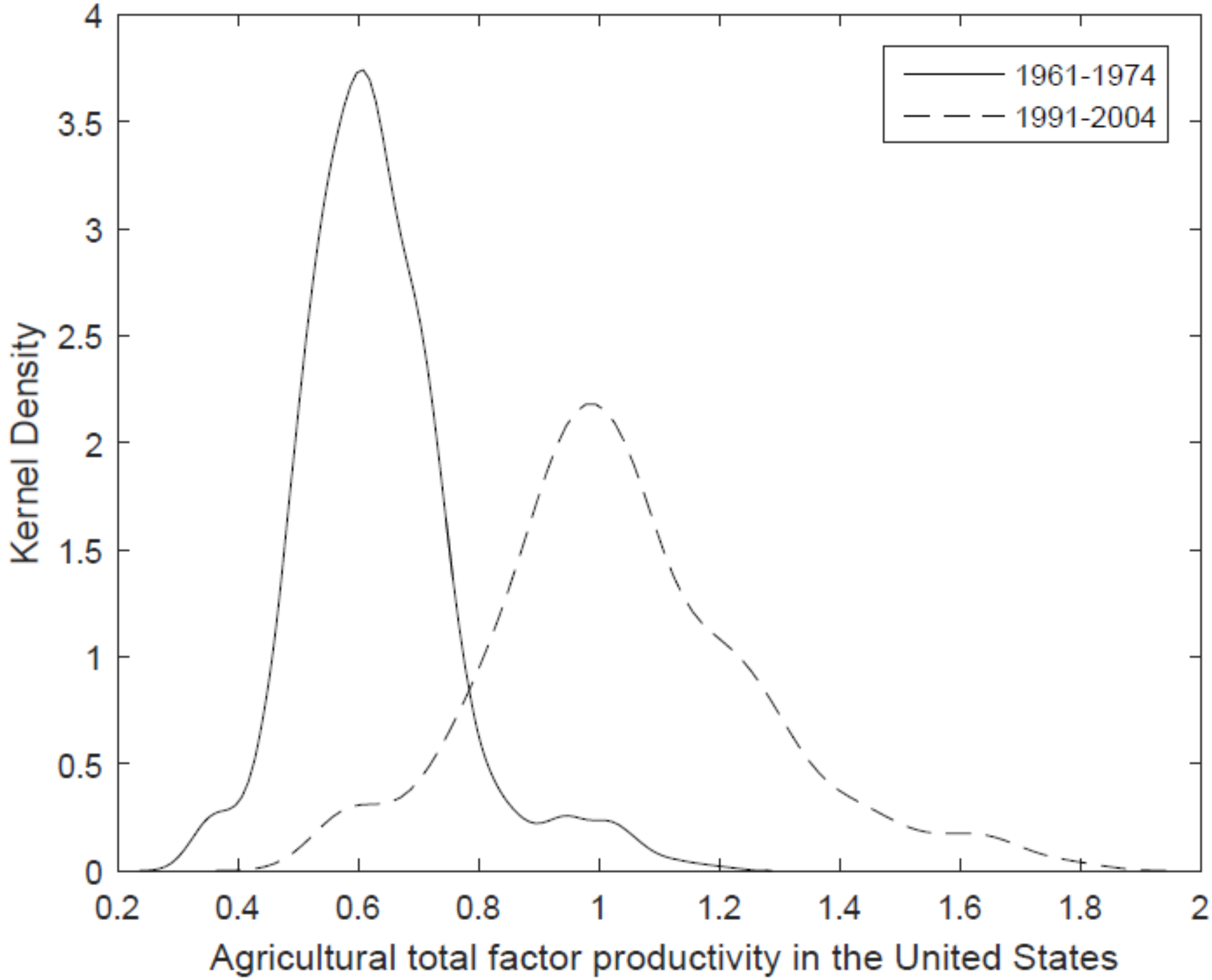
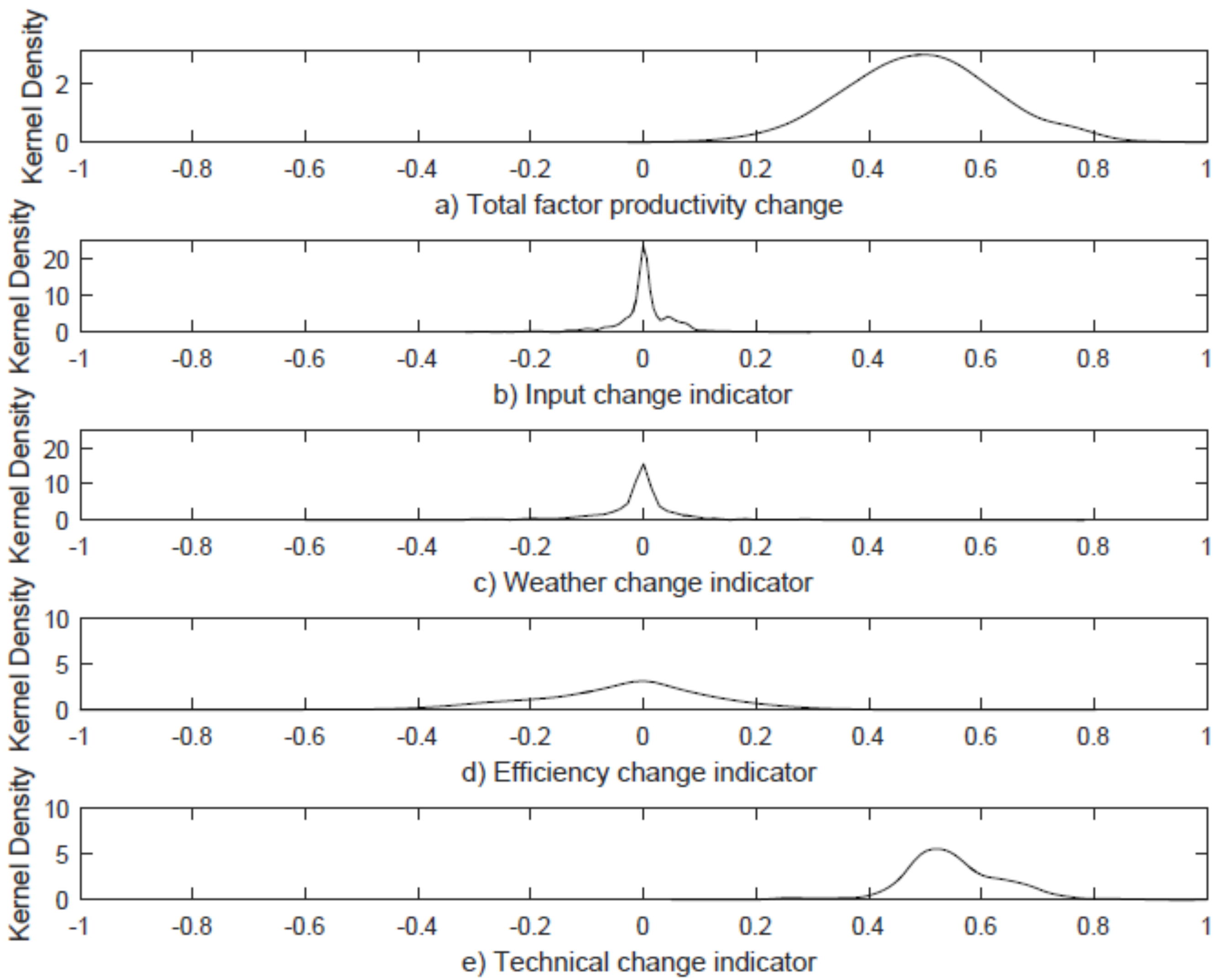
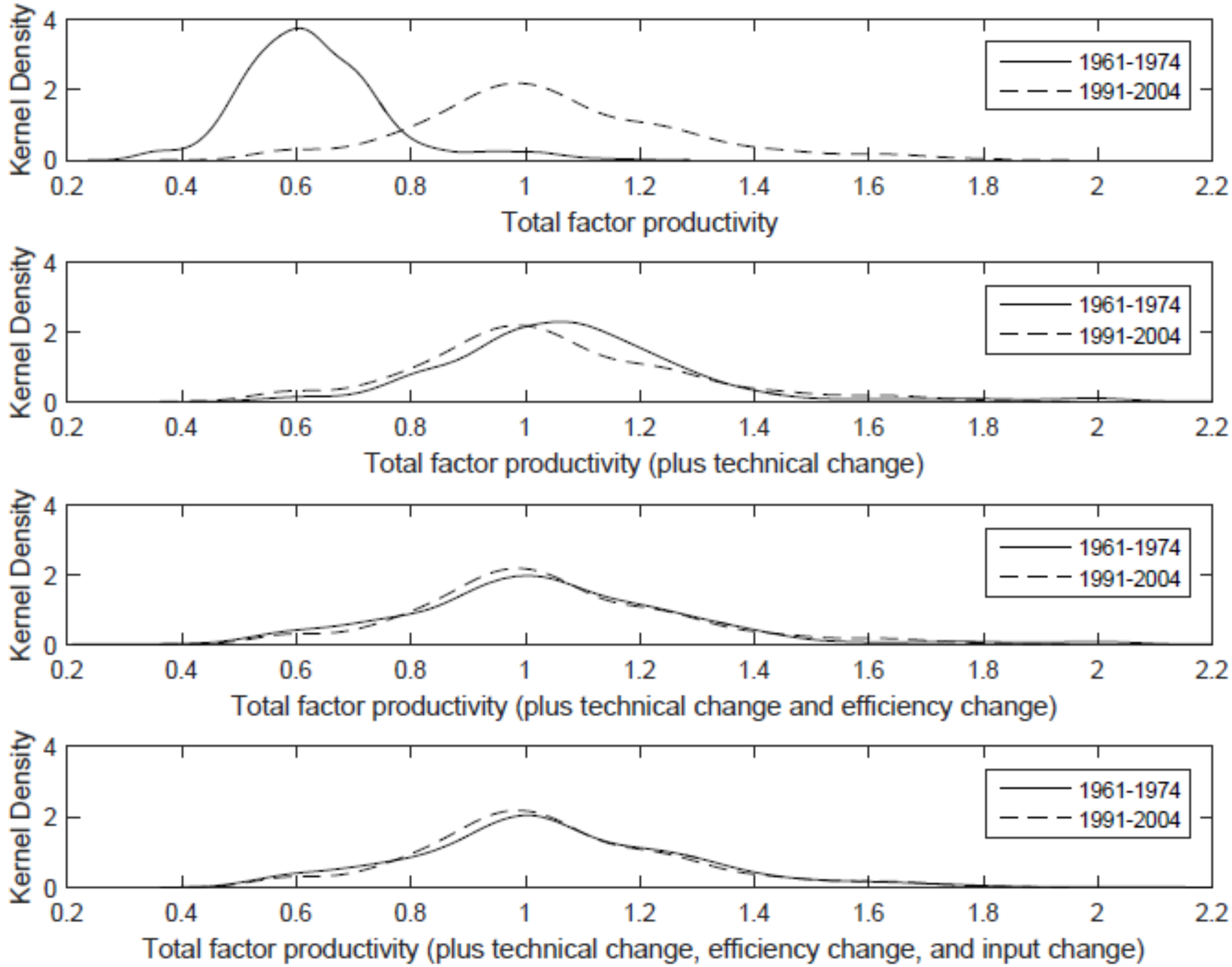
- $T_{t,0}$ is technical change, $W_{t,0}$ production change due to weather effects, $X_{t,0}$ index of input change (scale effect), and $E_{t,0}$ efficiency change (adaptation to best practice technology)
- *Empirical Fact: For aggregate US agriculture $X_{t,0} \approx 0$ for last century. Current level of measured US aggregate $X$ is less than in 1948*



1961-1974
1991-2004
Kernel Density
Agricultural total factor productivity in the United States
0
0.5
1
1.5
2
2.5
3
3.5
4
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2


Kernel Density
a) Total factor productivity change
b) Input change indicator
c) Weather change indicator
d) Efficiency change indicator
e) Technical change indicator
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1

Counterfactual Decomposition



# Other and Ongoing Efforts

- Chambers, Pieralli, and Sheng (2019): The Millennium Droughts and Australian Agricultural Productivity Performance

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- Chambers, Pieralli, and Sheng (2019): The Millennium Droughts and Australian Agricultural Productivity Performance
- Ortiz-Bobea, Lobell, Chambers, et al. FAO world panel

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- Adaptation is possible and likely will occur (Olmstead and Rhode, *PNAS*, 2011).