# Water Scarcity and Local Economic Activity

## A Global Analysis

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# Motivation

- Globally robust **nonlinear relationship between temperature and economic growth**:
  - at **national** and **subnational levels** (Burke et al., 2015; Burke and Tanutama, 2019; Kalkuhl and Wenz, 2020; Kotz et al., 2021)

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  - at **national** and **subnational levels** (Burke et al., 2015; Burke and Tanutama, 2019; Kalkuhl and Wenz, 2020; Kotz et al., 2021)
- Climate change alters other dimensions, too:
  - changes in Earth's water cycle cause **changes in water availability** (IPCC, 2021)

# Motivation

- Water availability affects:
  - human health (Maccini and Yang, 2009)
  - migration (Bohra-Mishra et al., 2014)
  - urbanization (Henderson et al., 2017)
  - likelihood of civil conflict (Harari and La Ferrara, 2018)
  - formation of human capital (Shah and Steinberg, 2017)

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  - formation of human capital (Shah and Steinberg, 2017)
- **Empirical puzzle** (Damania, 2020; Damania et al., 2020; Garrick and Hahn, 2021):

  Macroeconomic assessments find only **insignificant effects on economic growth rates**

  $\rightarrow$ Major Issue:
  - **spatial aggregation** of water-related climate measures (Damania et al., 2020)

# Water Availability and Economic Growth

| | Unit | Coverage | Outcome | Rainfall measure | Response | Heterogenous sensitivity | Sectoral sensitivity | Channel |
|---|---|---|---|---|---|---|---|---|
| Damania et al., 2020 | Cells to ADM1 | Global | GDP growth (Downscaled GDP) | Total annual | Concave | Low income | | Agriculture (?) |
| Russ, 2020 | Cells | Global | Growth in economic activity (Nighttime lights) | Water runoff anomalies | Negative shock ↓ | Middle income | | ~~Agriculture (?)~~ Hydropower (?) |
| Holtermann, 2020 | NUTS3 | Europe | GDP growth | WASP | Concave | No | No | |
| Kotz et al., 2022 | ADM1 | 77 Countries | GDP growth | Total annual | ↑ (diminishing returns) | Low income | Manuf. & Serv. | |
| | | | | WASP | Concave | No | Pos. anomaly: Agriculture | |
| | | | | # of wet days | ↓ | High income | Manuf. & Serv | |
| | | | | Extreme rainfall | ↓ | No | Manuf. & Serv | |
| Marbler, 2022 | ADM1 | 77 Countries | GDP growth | Growing season anomalies | Concave | 1st to 4th income quintile | Agriculture | Agriculture |
| | | | | Non-growing season anomalies | No effect | No effect | No effect | No effect |

# The Objective of this Paper

- Enhance the understanding of **how** **water availability affects *overall* local economic activity**

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  1. **Are there spatial spillover effects?** [e.g., like in the case of conflicts (Harari and La Ferrara, 2018)]
  2. **Can irrigation mitigate the effects of anomalous water availability on economic activity?** [e.g., like in the case of conflicts (Gatti et al., 2021) and migration (Benonnier et al., 2021)]
- Spatial econometric analysis at the level of $0.25^{\circ}$ grid cells over the entire globe

# Findings

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2. **Irrigation mitigates the negative impacts and the spatial diffusion of dry growing season conditions**

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- **Climate change** is projected to increase **variability of the water cycle** (IPCC AR6 WG1 Chapter 8)
  $\rightarrow$ More and/or intensified **water scarcities** and **water surpluses**

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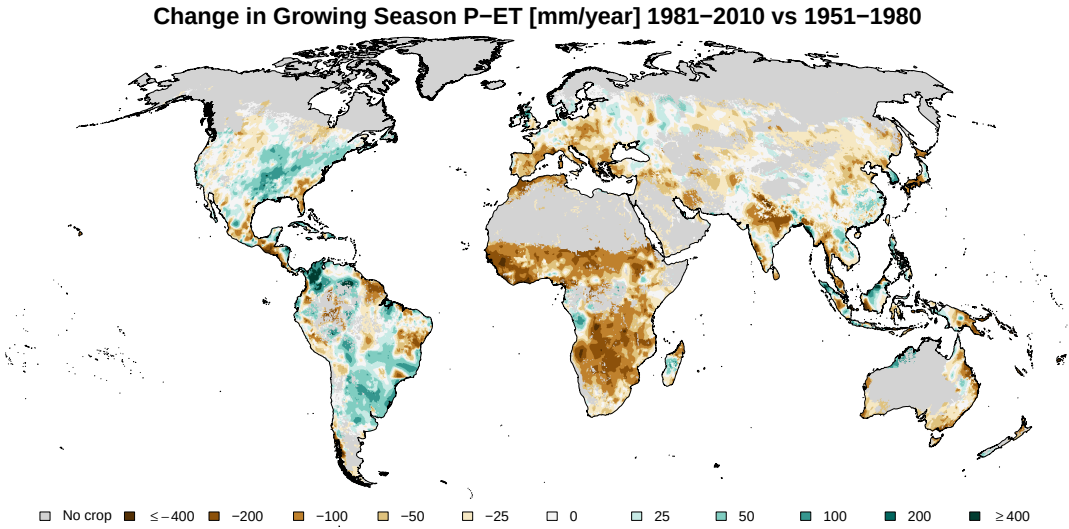
- **Adaptation decisions** rely on **consistent information** on **economic impacts**
  (e.g., Watkiss et al., 2015)
- Atmospheric **water availability** during agricultural growing seasons **is already changing**:

# Historical Change in Atmospheric Water Availability



# Framework

**Estimation of baseline model** (Marbler, 2022)

1. *Estimation* of economic activity responses to anomalies in water availability **most relevant** and **least relevant** for *agricultural production*
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1. *Consecutively* expose a larger area around the grid cell to water availability anomalies
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**The Mitigating Effects of Irrigation**

1. Estimation of response functions **specific to *agricultural system*** (**Rainfed** and **Irrigated**)
2. Repetition of spatial analysis distinguishing between spillovers from **rainfed** and **irrigated** areas

# Data: Water Availability

**Climatic water balance (WB):** WB

- Combines **water supply** (=*precipitation*) with **water demand** (=*evapotranspiration*) to measure **water availability** (e.g. Konapala et al., 2020; Vicente-Serrano et al., 2015):

$$WB_{idt} = Precipitation_{idt} - Potential\ Evapotranspiration_{idt}$$

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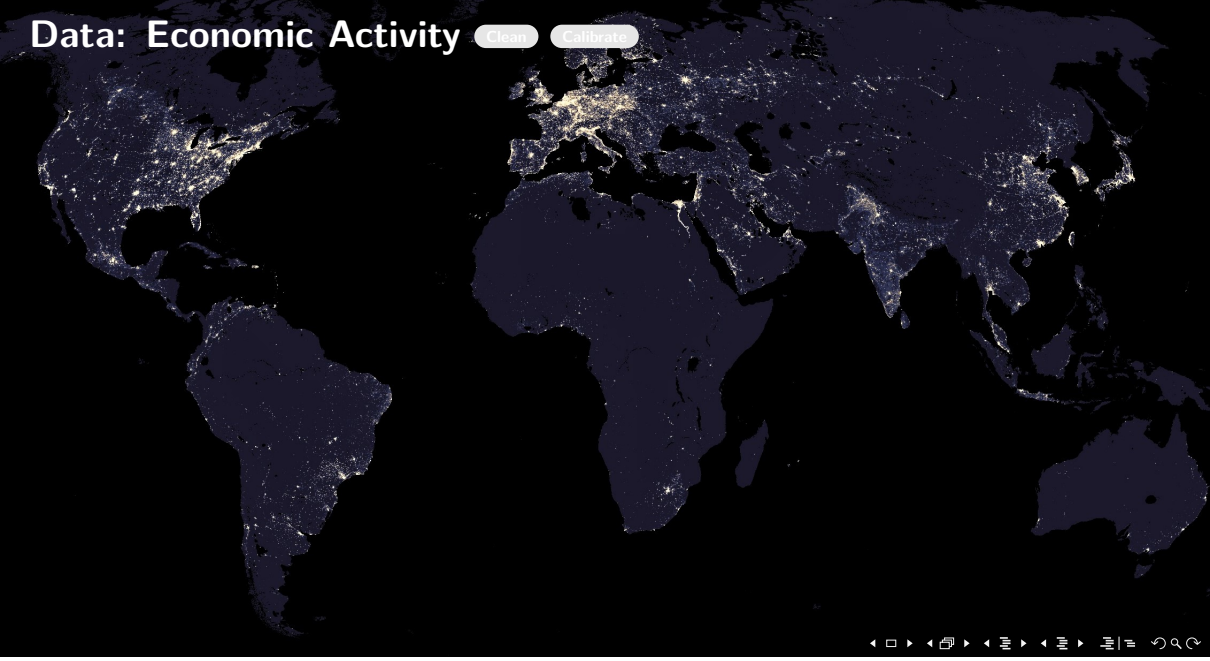
**Standardized Water Balance Anomaly (SWBA)**: Climate GS Climate nGS

- $SWBA_{it}^{S} = \frac{WB_{it}^{S} - \overline{WB_{i}^{S}}}{\sigma(WB_{i}^{S})}$, where $S =$ **GS**, **nGS**
- SDs by which each grid cell's (**non-**) **growing season** WB deviates from long-term norm

# Data: Economic Activity

Clean Calibrate



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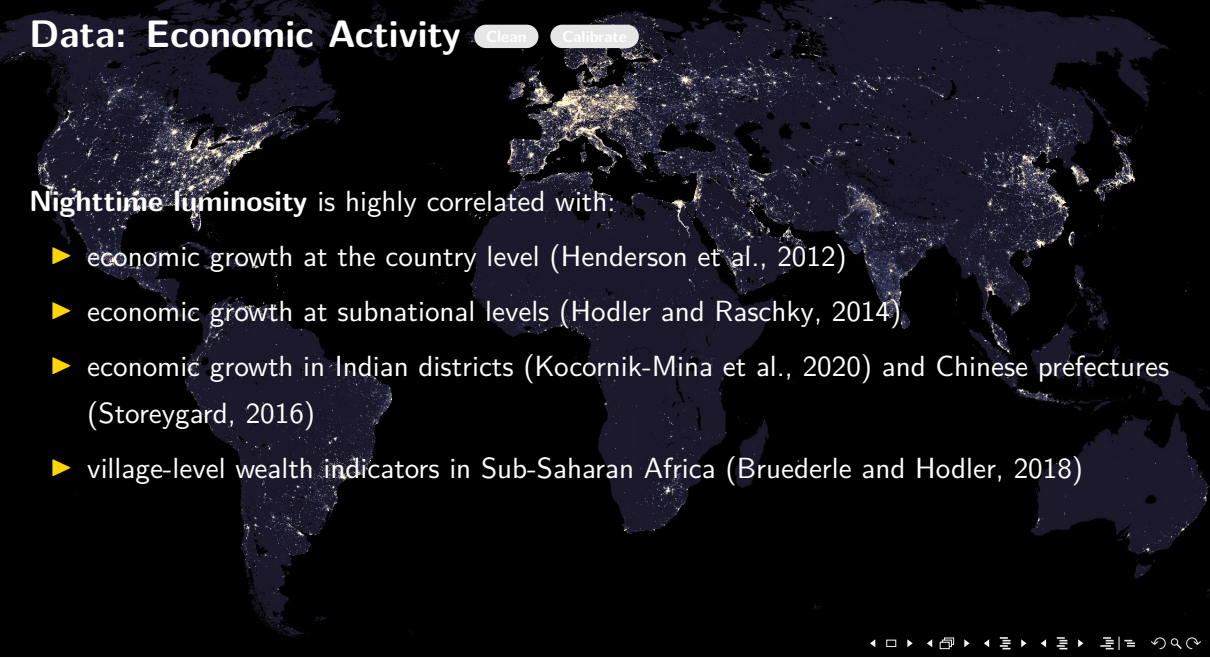

**Nighttime luminosity** is highly correlated with:

- economic growth at the country level (Henderson et al., 2012)
- economic growth at subnational levels (Hodler and Raschky, 2014)
- economic growth in Indian districts (Kocornik-Mina et al., 2020) and Chinese prefectures (Storeygard, 2016)
- village-level wealth indicators in Sub-Saharan Africa (Bruederle and Hodler, 2018)

# Data and Empirical Strategy

- Sample: $\sim$ 2 million observations
  - $\sim 100,000$ grid cells
  - $2,902$ states
  - 193 countries
  - 21 years (1993-2013)
- Outcome variable: Annual growth rate of economic activity
- Main regressor: Standardized seasonal water balance anomalies (SWBA)

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**Empirical Strategy:**

Exploit **random natural variation** in **precipitation** and **evapotranspiration** as source for **exogenous** year-by-year realizations of **water availability shocks** during the **growing season** and **non-growing season**.

# The Water Balance – Economic Activity Relationship: Baseline Specification

$$\Delta Y_{ict} = \sum_{l=0}^{2}\sum_{p=1}^{2}\left[\underbrace{\beta_{t-l}^{p,GS} SWBA\_GS_{ict-l}^{p}}_{\textbf{growing season}} + \underbrace{\beta_{t-l}^{p,nGS} SWBA\_nGS_{ict-l}^{p}}_{\textbf{non-growing season}}\right] + \underbrace{\alpha_i + \phi_{at}}_{\text{fixed effects}} + \underbrace{\mu_{ac} \times \tau + \mu_{ac} \times \tau^2}_{\text{trends}} + \epsilon_{ict}, \quad (1)$$

- $i$ = grid cell; $c$ = country; $t$ = year; $a$ = agricultural system;
- $GS$ = **growing season**, $nGS$ = **non-growing season**
- $g = \Delta \ln(\text{Economic Activity})$
- Standard errors: two-way clustered at grid cell and country-by-year level

# Results: The Water Balance – Economic Activity Relationship

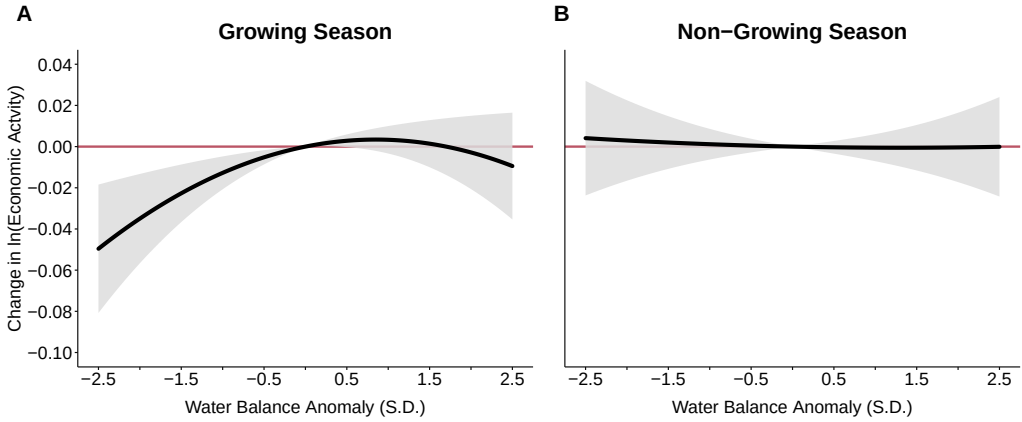
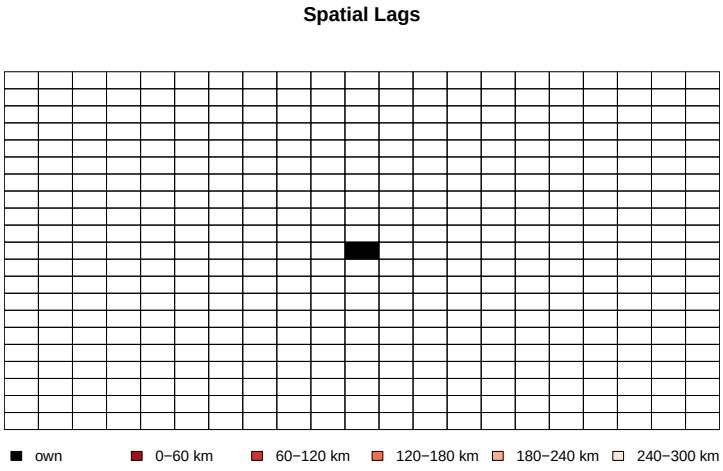



Figure: **Growing season** and **non-growing season** water balance effect on growth in economic activity.

# The Water Balance – Economic Activity Relationship: Spatial Structure



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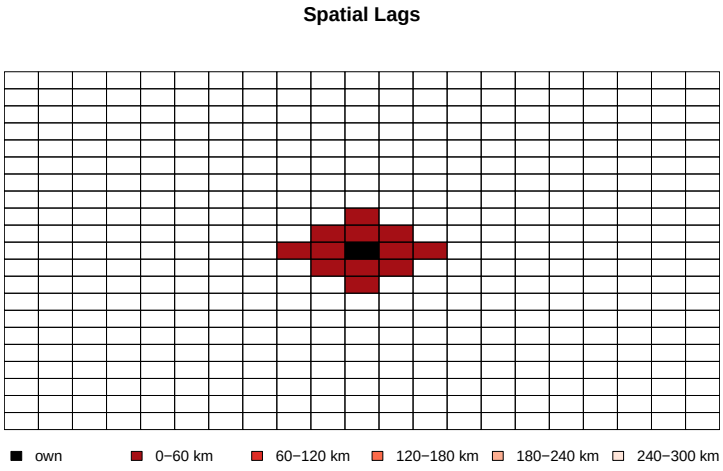

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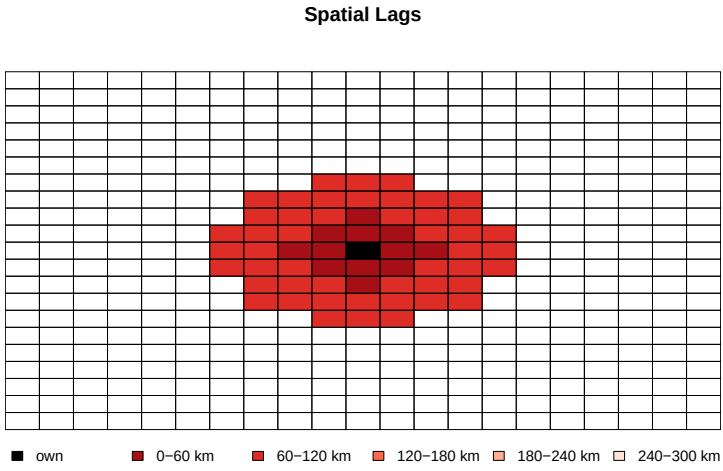

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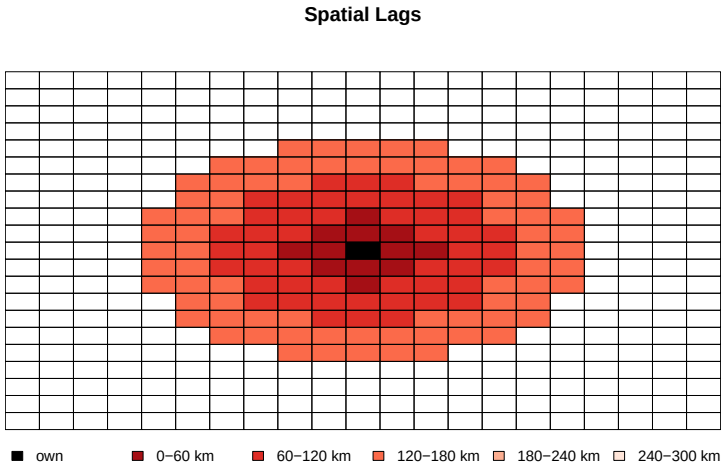

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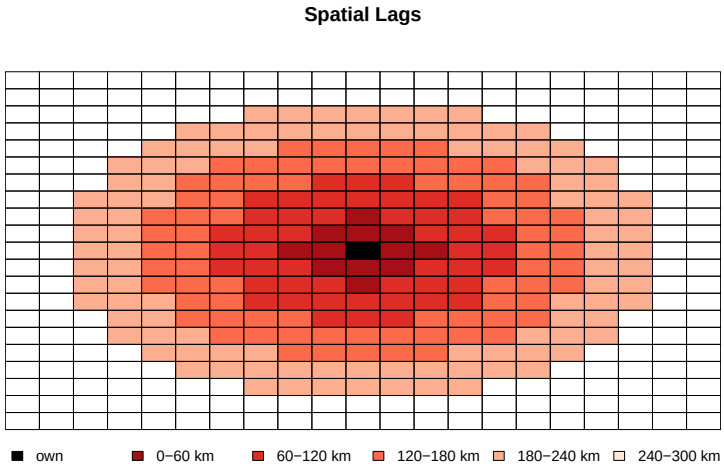

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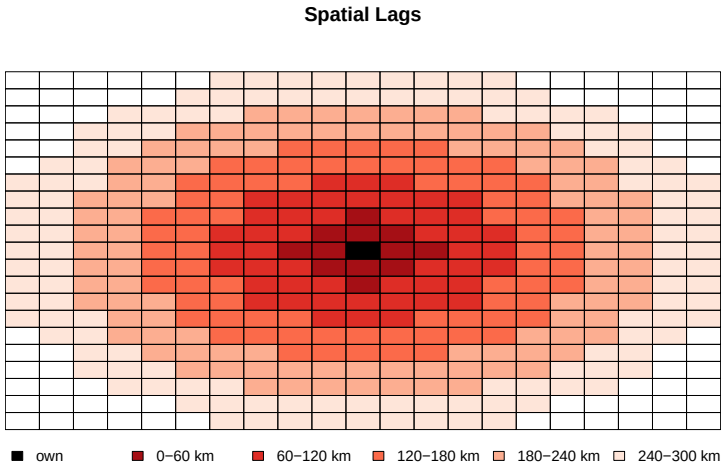
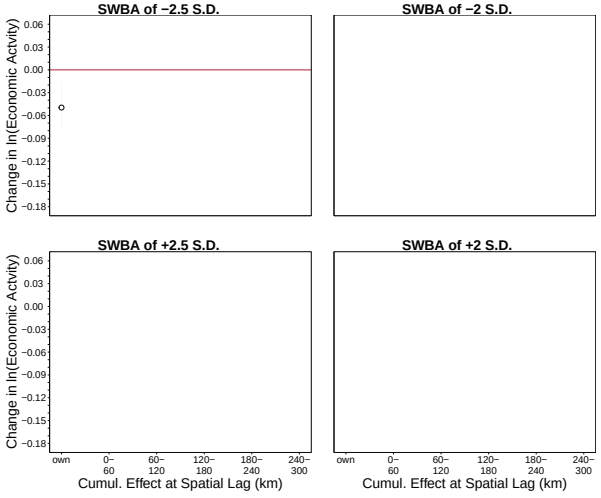


# Results: Spatial Structure of the Effect of Water Balance Anomalies on Economic Activity

Specification



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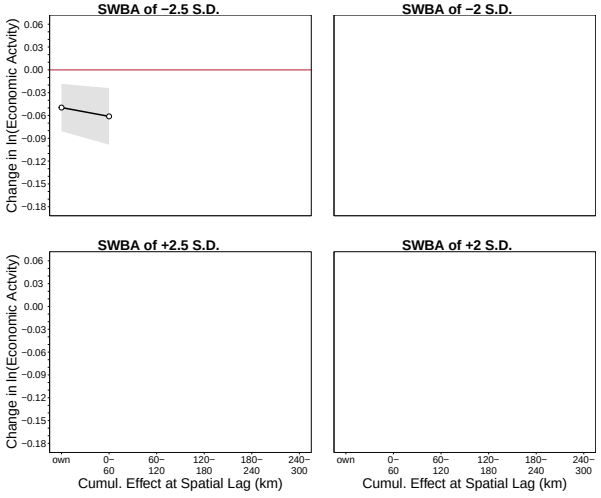

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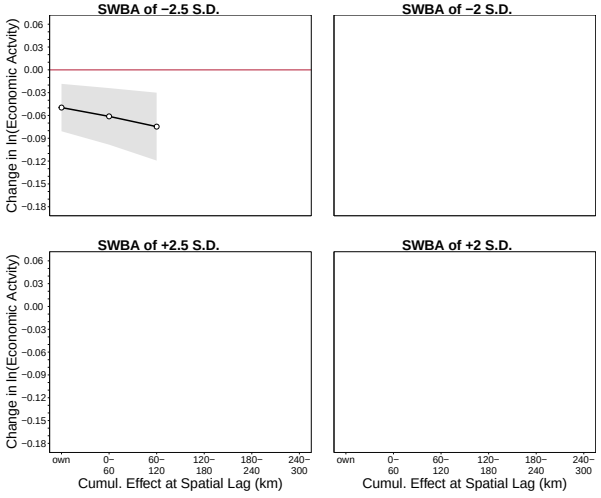

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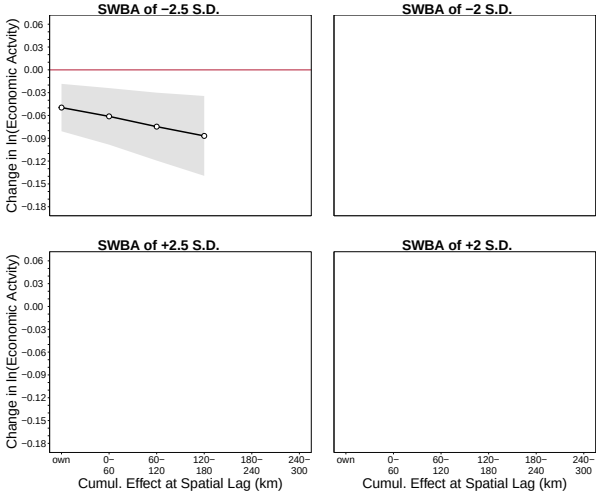

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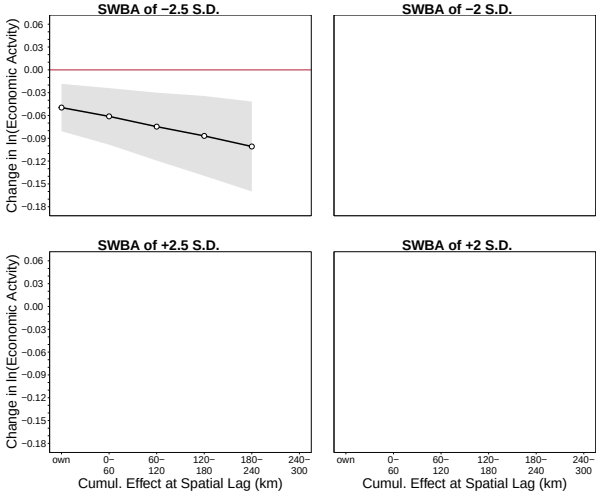

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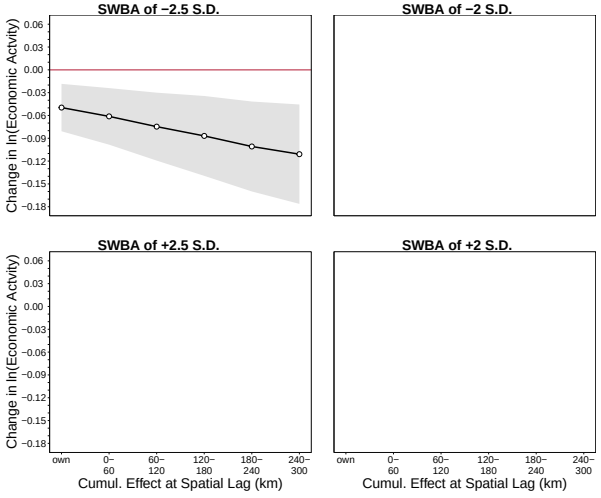

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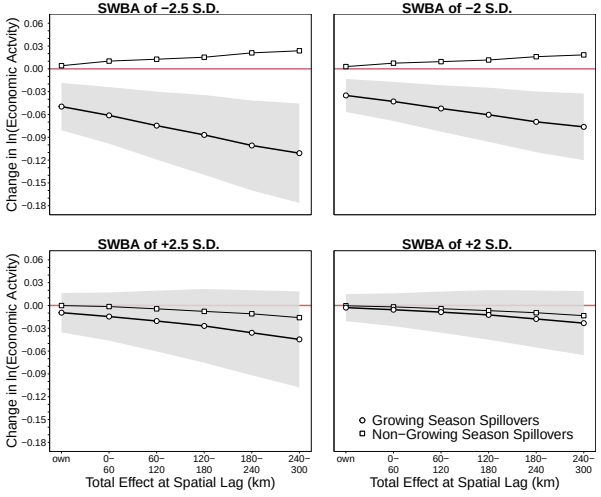

# Results: The Mitigating Effects of Irrigation 1

Specification

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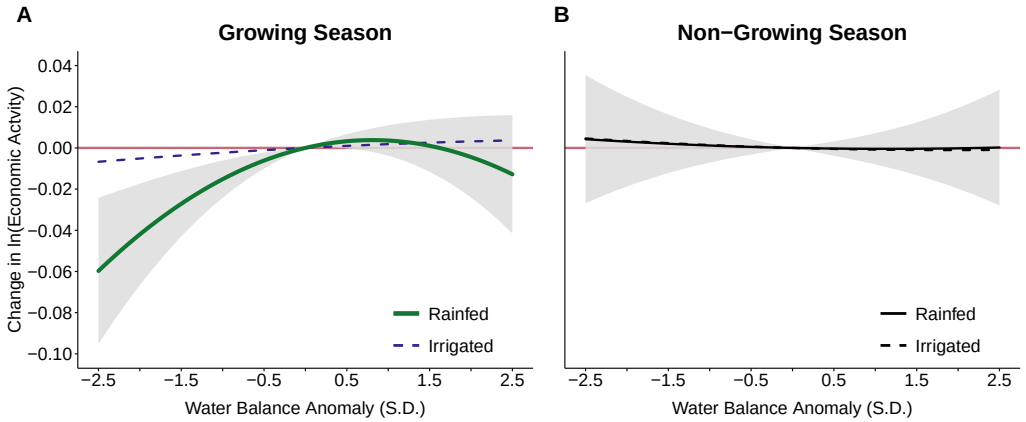


Figure: Agricultural-system-specific growing season and non-growing season water balance effects on growth in economic activity.

# Results: The Mitigating Effects of Irrigation 2

Specification

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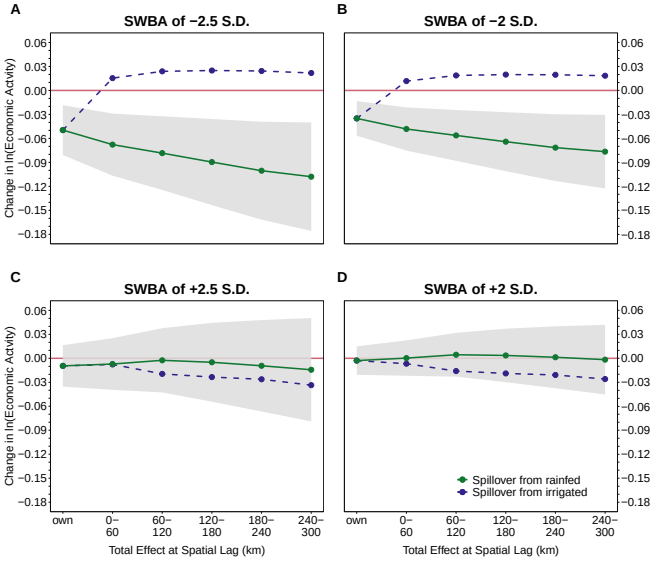
Specification



# Conclusion

Further evidence that water availability has a causal effect on economic activity:

**Agriculture is the main channel by which water scarcity affects the growth of economic activity.**

**2 new key findings:**

1. Agricultural water scarcities exhibit large negative spatial spillover effects
2. Irrigation mitigates the direct and spatial spillover effects of growing season water scarcity

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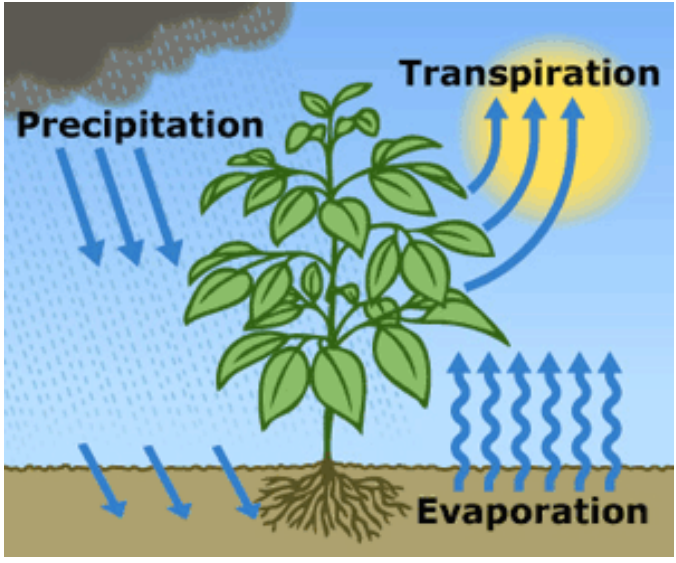
**Matter of concern:**

**Agricultural growing seasons are getting drier, and dry growing seasons have large negative impacts on economic activity.**

Future research should properly take hydrological conditions into account.

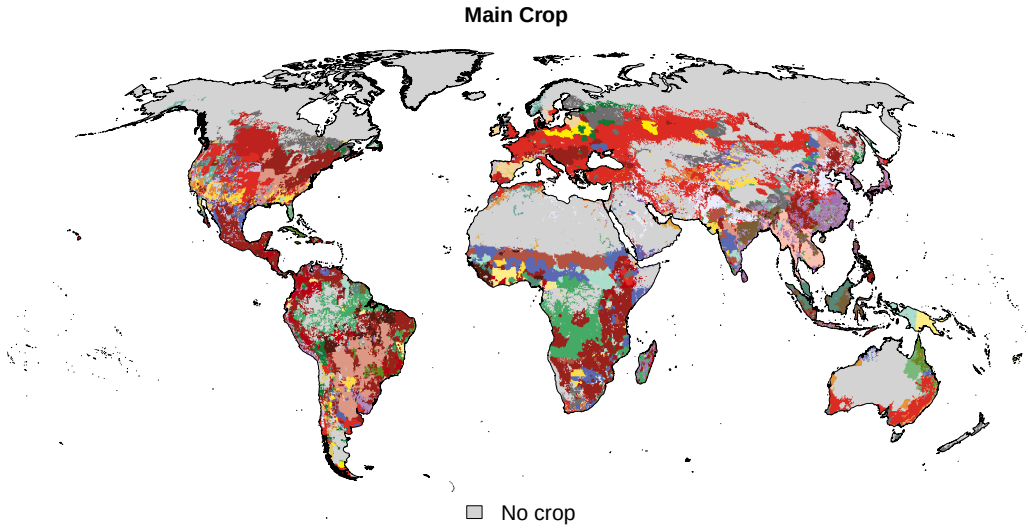
# Evapotranspiration

back



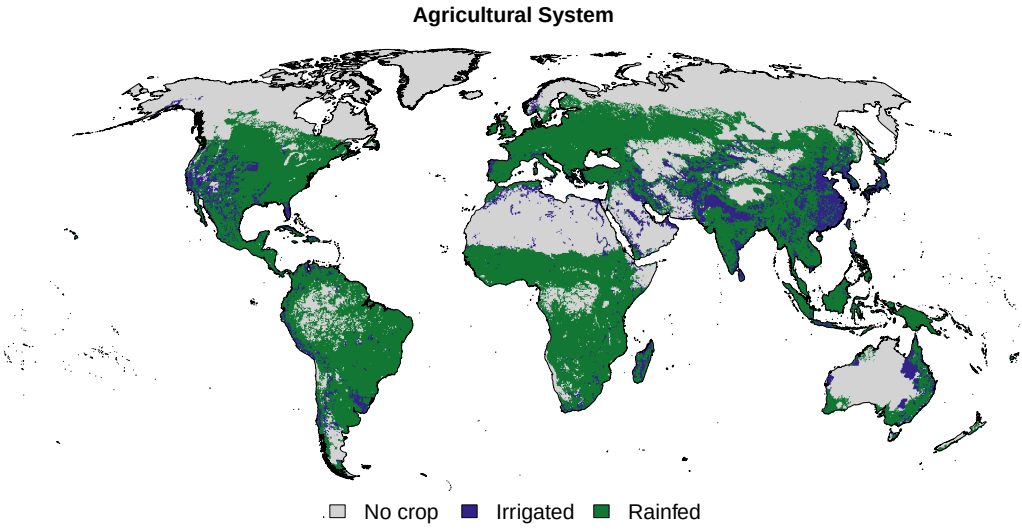
# Main Crop: Global Heterogeneity

back



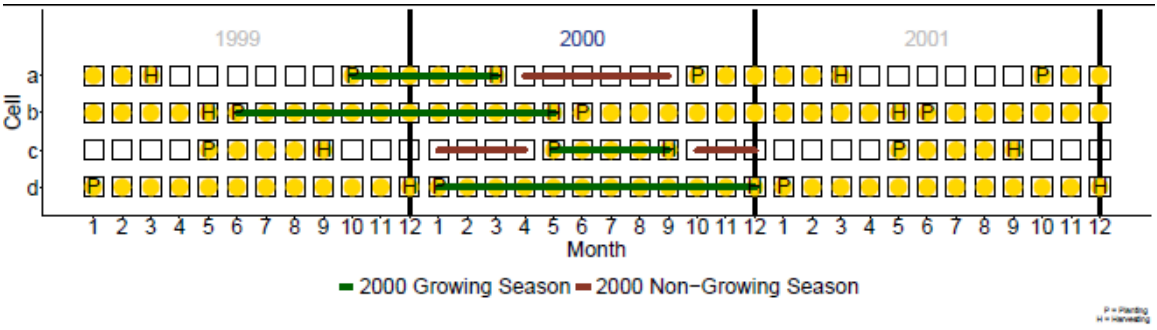
# Agricultural System: Rainfed (80%), Irrigated (20%)

back



# Growing Season & Non-Growing Season: Illustration

back



# Growing Season Climate (1981–2010)

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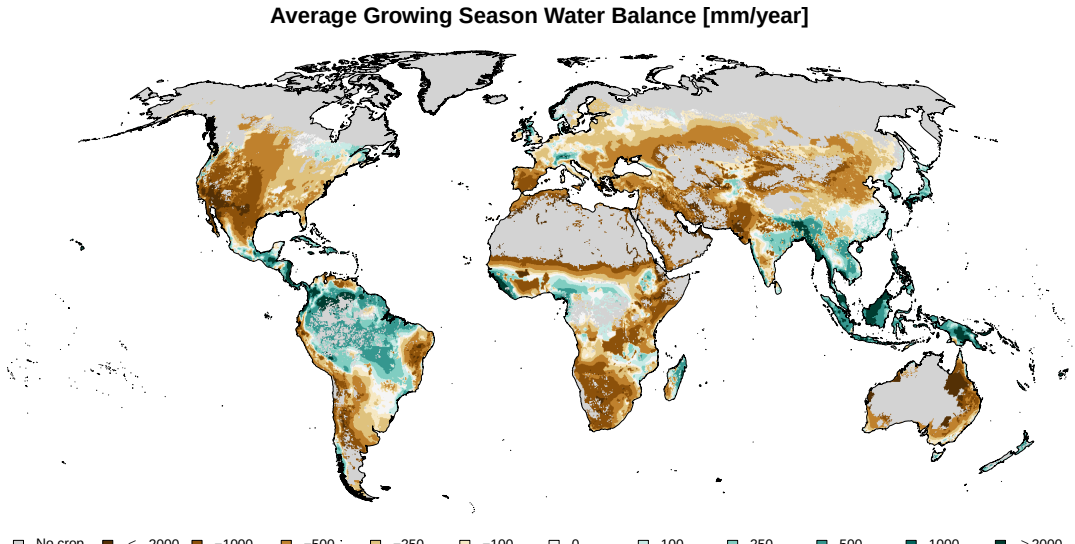

# Non-Growing Season Climate (1981–2010)

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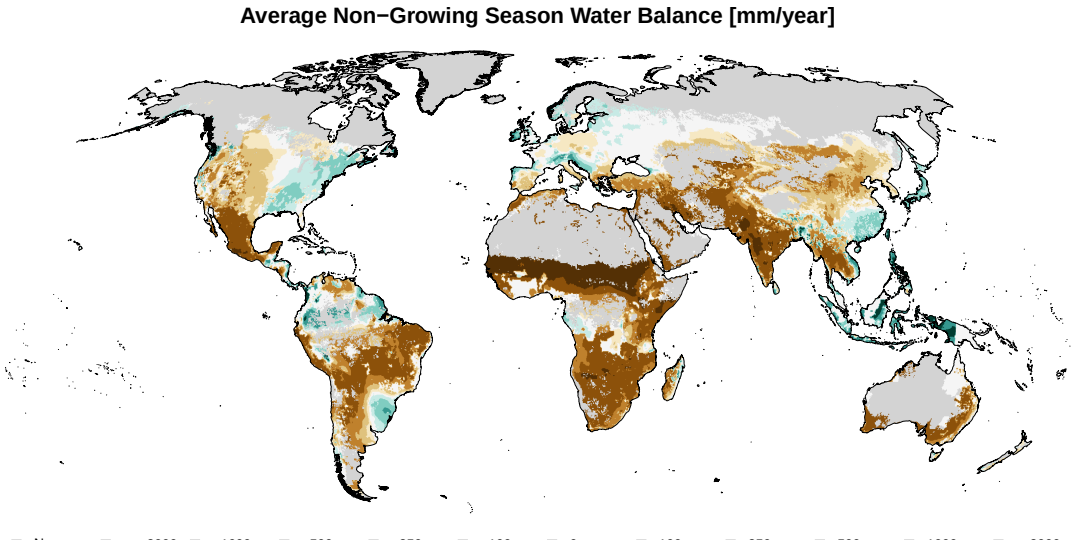
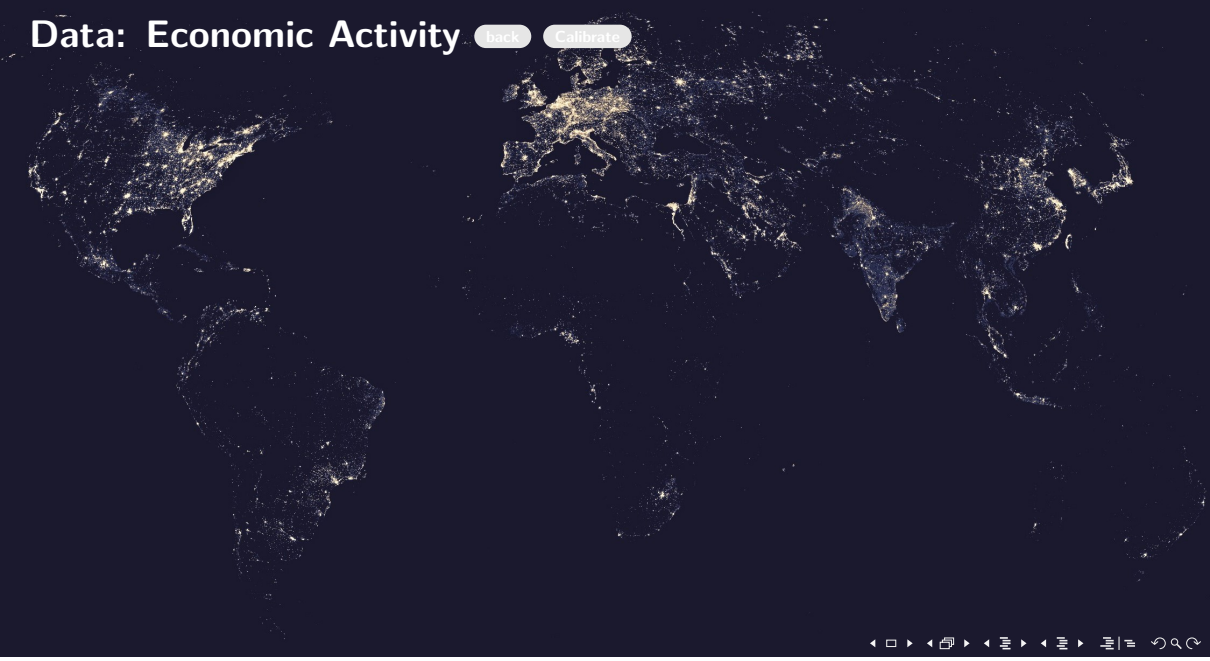


# Data: Economic Activity

back Calibrate



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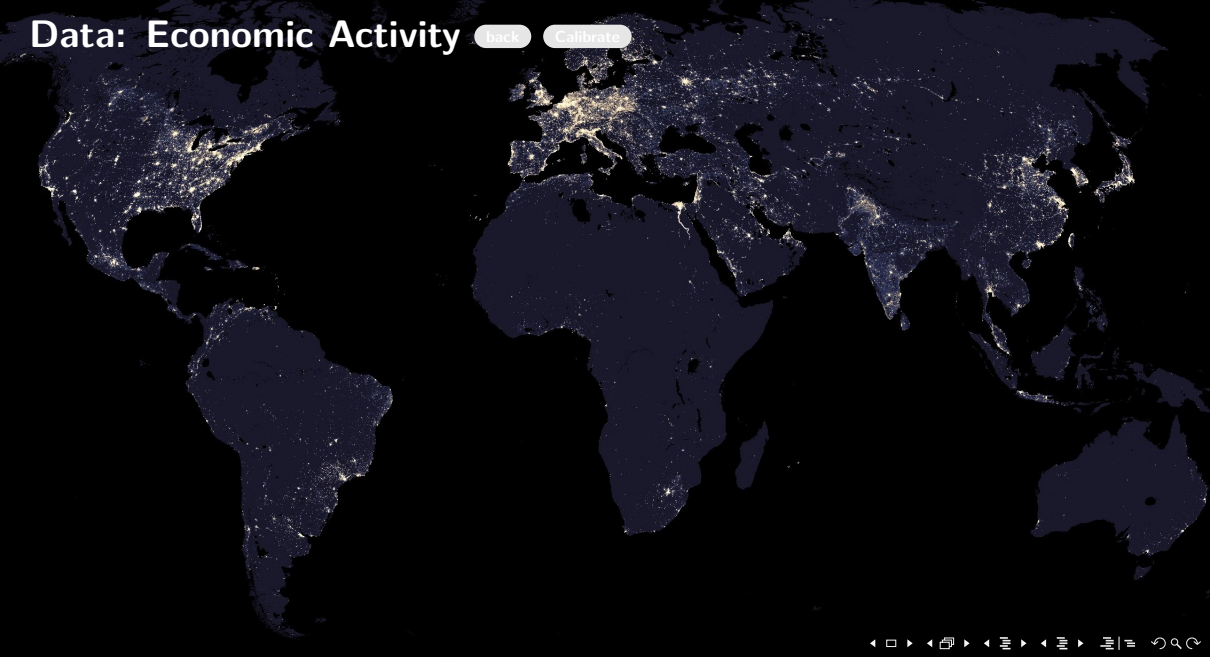

# Data: Calibration DMSP NTL

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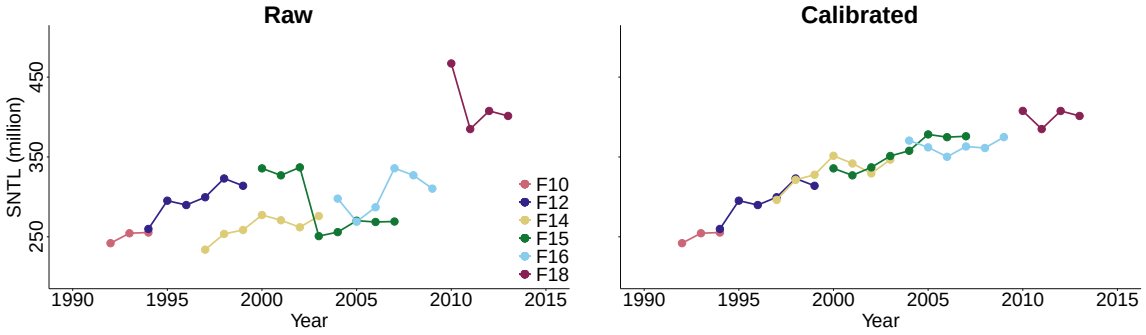
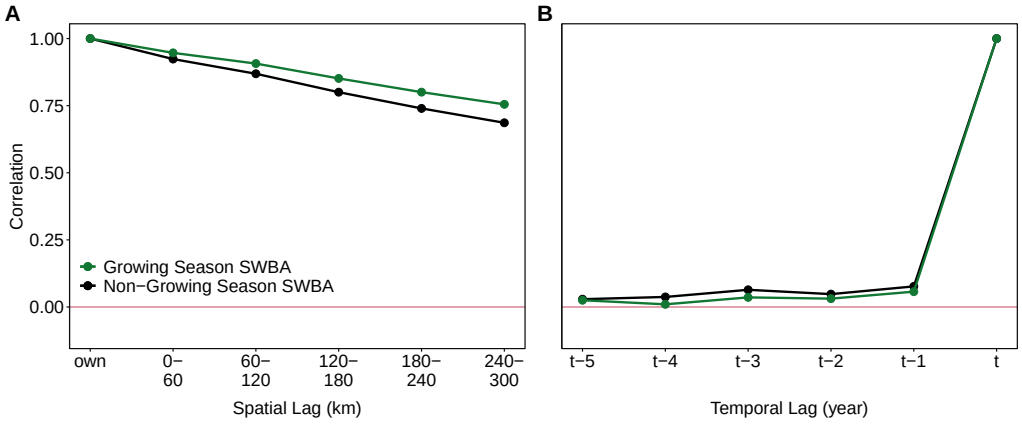



Figure: ***Uncalibrated and Calibrated Nighttime Lights*** The figure compares the evolution of the global sum of nighttime lights, SNTL, based on uncalibrated (left panel) and calibrated (right panel) NTL.

# Spatial and Temporal Correlation

back




- McGuirk and Burke (2020): individual direct and indirect effects are noisy, focus on overall effect over space

# Robustness: Alternative Functional Forms

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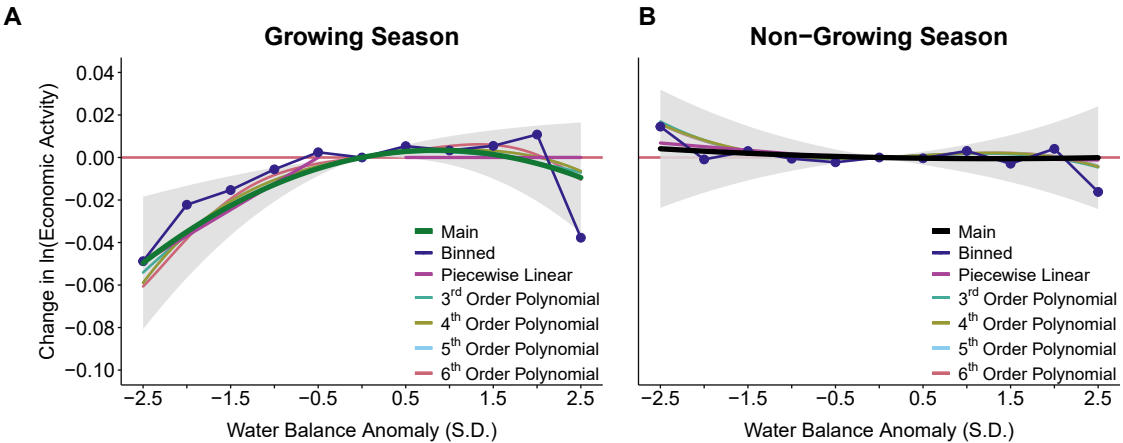
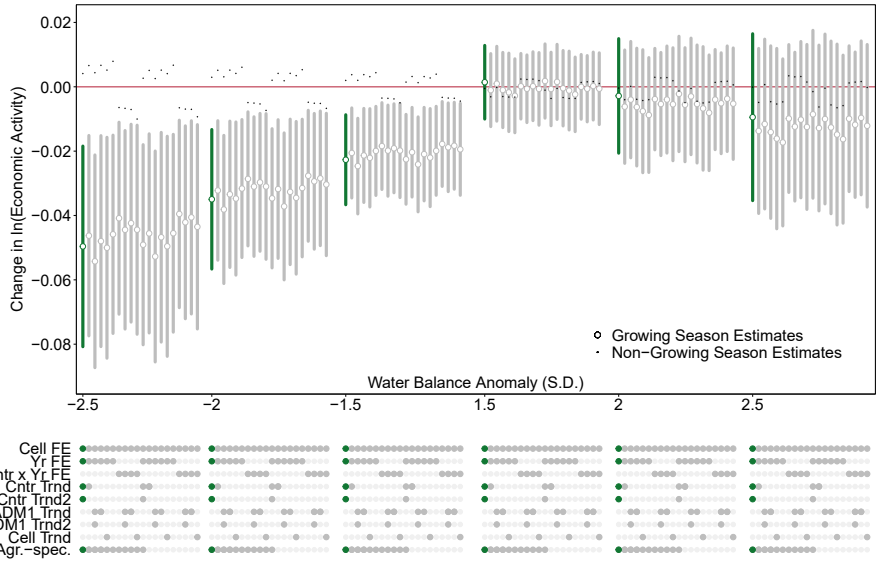



Figure: **Growing season** and **non-growing season** water balance effect on growth in economic activity.

# Robustness: Alternative FE and Trend Structures

back



# Robustness: Alternative Sources of Data

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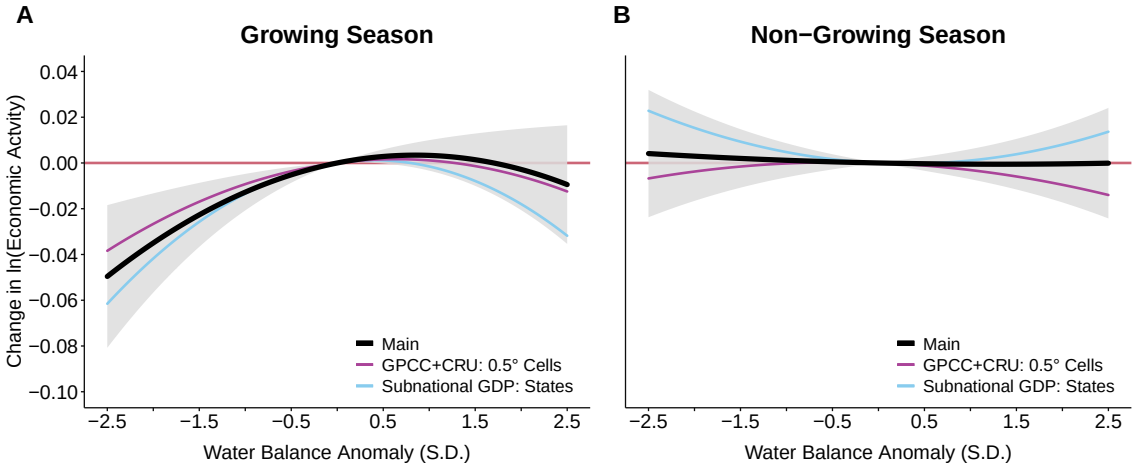


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# The Water Balance – Economic Activity Relationship: Spatial Structure

cor back

$$\Delta Y_{ict} = \underbrace{\sum_{l=0}^{2}\sum_{p=1}^{2}\left[\beta_{t-l}^{p,GS} SWBA\_GS_{ict-l}^{p} + \beta_{t-l}^{p,nGS} SWBA\_nGS_{ict-l}^{p}\right]}_{\textbf{direct exposure}}$$
$$+ \underbrace{\sum_{l=0}^{2}\sum_{p=1}^{2}\sum_{r=1}^{5}\left[\beta_{t-l}^{p,GS,60r} SWBA\_GS_{ict-l}^{p,60r} + \beta_{t-l}^{p,nGS,60r} SWBA\_nGS_{ict-l}^{p,60r}\right]}_{\textbf{indirect exposure}} \quad (2)$$
$$+ \alpha_i + \phi_{at} + \mu_{ac} \times \tau + \mu_{ac} \times \tau^2 + \epsilon_{ict},$$

- **Total GS effect** for model with 60 km spatial lag, i.e. $r = 1$:
  $\Omega_{60}^{GS} = \left(\sum_{p=1}^{2} \beta_t^{p,GS} \times SWBA\_GS^p\right) + \left(\sum_{p=1}^{2} \beta_t^{p,GS,60} \times SWBA\_GS^p\right)$

# The Mitigating Effects of Irrigation 1

back

$$\begin{aligned}\Delta Y_{ict} = &\sum_{l=0}^{2}\sum_{p=1}^{2} \beta_{t-l}^{p,GS} SWBA\_GS_{ict-l}^{p} \times \mathbf{Rf_i} + \beta_{t-l}^{p,nGS} SWBA\_nGS_{ict-l}^{p} \times \mathbf{Rf_i} \\ &+ \sum_{l=0}^{2}\sum_{p=1}^{2} \beta_{t-l}^{p,GS} SWBA\_GS_{ict-l}^{p} \times \mathbf{Irr_i} + \beta_{t-l}^{p,nGS} SWBA\_nGS_{ict-l}^{p} \times \mathbf{Irr_i} \\ &+ \alpha_i + \phi_{at} + \mu_{ac} \times \tau + \mu_{ac} \times \tau^2 + \epsilon_{ict},\end{aligned} \tag{3}$$

- $\mathbf{Rf_i}$ indicates that grid cell $i$ is **rainfed** and $\mathbf{Irr_i}$ indicates that grid cell $i$ is **irrigated**.

# The Mitigating Effects of Irrigation 2

back

$$
\begin{aligned}
\Delta Y_{ict} = & \underbrace{\sum_{l=0}^{2}\sum_{p=1}^{2}\left[\beta_{t-l}^{p,GS} SWBA_{ict-l}^{p,GS} + \beta_{t-l}^{p,nGS} SWBA_{ict-l}^{p,nGS}\right]}_{\textbf{own exposure}} \\
& + \underbrace{\sum_{l=0}^{2}\sum_{p=1}^{2}\sum_{r=1}^{5}\left[\beta_{t-l}^{p,GS,60r,\textbf{Rf}} SWBA_{ict-l}^{p,GS,60r,\textbf{Rf}} + \beta_{t-l}^{p,nGS,60r,\textbf{Rf}} SWBA_{ict-l}^{p,nGS,60r,\textbf{Rf}}\right]}_{\textbf{surrounding rainfed area exposure}} \\
& + \underbrace{\sum_{l=0}^{2}\sum_{p=1}^{2}\sum_{r=1}^{5}\left[\beta_{t-l}^{p,GS,60r,\textbf{Irr}} SWBA_{ict-l}^{p,GS,60r,\textbf{Irr}} + \beta_{t-l}^{p,nGS,60r,\textbf{Irr}} SWBA_{ict-l}^{p,nGS,60r,\textbf{Irr}}\right]}_{\textbf{surrounding irrigated area exposure}} \\
& + \alpha_i + \phi_{at} + \mu_{ac} \times \tau + \mu_{ac} \times \tau^2 + \epsilon_{ict},
\end{aligned}
\tag{4}
$$