Climate Change, Drought, and Agricultural Production in Brazil

Francisco Cavalcanti
PUC-Rio

Steven M. Helfand
University of California, Riverside

Ajax Moreira
IPEA

IAAE Inter-Conference Symposium, Montevideo, 2023

Introduction

Motivation:

- Climate change is one of the biggest challenges of our time
  - Broad agreement on rising temperature
  - But little agreement on rainfall patterns
- Changes in rainfall patterns can exacerbate droughts
  - Harm socio-economic development in regions dependent on agriculture
- Droughts are the second most frequent natural disaster worldwide
  - These natural events threaten approximately 70% of the world population, and this may worsen with climate change
  - Over 60% of population in low and low-middle income countries is rural; drought impact on poverty can be significant

Introduction

Motivation:

- Climate change is one of the biggest challenges of our time
  - Broad agreement on rising temperature
  - But little agreement on rainfall patterns
- Changes in rainfall patterns can exacerbate droughts
  - Harm socio-economic development in regions dependent on agriculture
- Droughts are the second most frequent natural disaster worldwide
  - These natural events threaten approximately 70% of the world population, and this may worsen with climate change
  - Over 60% of population in low and low-middle income countries is rural; drought impact on poverty can be significant

Introduction

Motivation:

- Climate change is one of the biggest challenges of our time
  - Broad agreement on rising temperature
  - But little agreement on rainfall patterns
- Changes in rainfall patterns can exacerbate droughts
  - Harm socio-economic development in regions dependent on agriculture
- Droughts are the second most frequent natural disaster worldwide
  - These natural events threaten approximately 70% of the world population, and this may worsen with climate change
  - Over 60% of population in low and low-middle income countries is rural; drought impact on poverty can be significant

Road map of the research project

Papers:

1. Study whether climate change is altering drought in Brazil
2. Study how different dimensions of drought impact agricultural production
3. Study how different dimensions of drought cause poverty
4. Study whether drought affects TFP in agriculture
5. Study whether drought affects poverty through the causal channel of TFP in agriculture

Our contribution and the focus of today's presentation

1. Is climate change affecting drought in Brazil?
   - 120 years of climate data at grid level
   - Analysis for all of Brazil and its regions over a long period of time
   - Incorporate potential evapotranspiration
2. How does drought impact agricultural production?
   - 46 years of annual data on 69 crops at municipal level (PAM)
   - Analyze distribution of impacts of drought
   - Forecast the impacts of drought throughout the 21st Century

Method

- **Drought variable construction**
  - Standardized Precipitation Evapotranspiration Index (Vicente-Serrano et al, 2010)
  - $SPEI12_{i,m} = \frac{(P_{i,m} - PE_{i,m}) - mean(P_i - PE_i)}{sd(P_i - PE_i)}$

    mean and sd if $year < 1980$
    $m =$ month, $i =$ grid
    $P_{i,m} = \sum_{m-12}^{m}$ precipitation,
    $PE_{i,m} = \sum_{m-12}^{m}$ potential evapotranspiration
- **Definitions**
  - Drought starts: two consecutive months of SPEI12 $<$ -1
  - Drought ends: SPEI-12 $>$ 0

Method

- **Drought variable construction**
  - Standardized Precipitation Evapotranspiration Index (Vicente-Serrano et al, 2010)
  - $$SPEI12_{i,m} = \frac{(P_{i,m} - PE_{i,m}) - mean(P_i - PE_i)}{sd(P_i - PE_i)}$$

    mean and sd if $year < 1980$
    $m =$ month, $i =$ grid
    $P_{i,m} = \sum_{m-12}^{m}$ precipitation,
    $PE_{i,m} = \sum_{m-12}^{m}$ potential evapotranspiration
- **Definitions**
  - Drought starts: two consecutive months of SPEI12 $<$ -1
  - Drought ends: SPEI-12 > 0

Method

- **Short-run drought**
  - *Quarter-1*: SPEI3 < -1
  - *Quarter-2*: SPEI3 < -1
  - *Quarter-3*: SPEI3 < -1
  - *Quarter-4*: SPEI3 < -1
  - *Semester-1*: SPEI6 < -1
  - *Semester-2*: SPEI6 < -1
  - *Annual-M*: Moderate drought (SPEI12 0 to -1)
  - *Annual-S*: Severe drought (SPEI12 -1 to -2)
  - *Annual-E*: Extreme drought (SPEI12 < -2)
- **Long-run drought (5yr)**
  - Drought Duration (DD): average number of consecutive months
  - Drought Frequency (DF): total number of events
  - Drought Severity (DS): absolute value of integral of SPEI12 below zero
  - Drought Extension (DE): share of grids in drought

Method

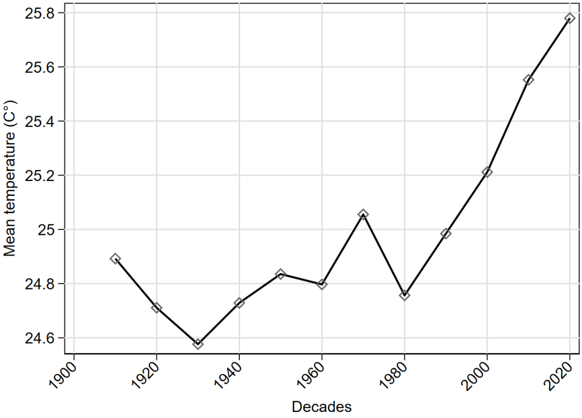
- **Short-run drought**
  - *Quarter-1*: SPEI3 < -1
  - *Quarter-2*: SPEI3 < -1
  - *Quarter-3*: SPEI3 < -1
  - *Quarter-4*: SPEI3 < -1
  - *Semester-1*: SPEI6 < -1
  - *Semester-2*: SPEI6 < -1
  - *Annual-M*: Moderate drought (SPEI12 0 to -1)
  - *Annual-S*: Severe drought (SPEI12 -1 to -2)
  - *Annual-E*: Extreme drought (SPEI12 < -2)
- **Long-run drought (5yr)**
  - Drought Duration (DD): average number of consecutive months
  - Drought Frequency (DF): total number of events
  - Drought Severity (DS): absolute value of integral of SPEI12 below zero
  - Drought Extension (DE): share of grids in drought

Data

- **University of East Anglia: CRU TS v. 4.05 (Climatic Research Unit gridded Time Series) (1901-2020)**
  - 7110 grids at 0.5°latitude and 0.5°longitude resolution (∼ 55x55 km)
  - Monthly precipitation, potential evapotranspiration, and average temperature

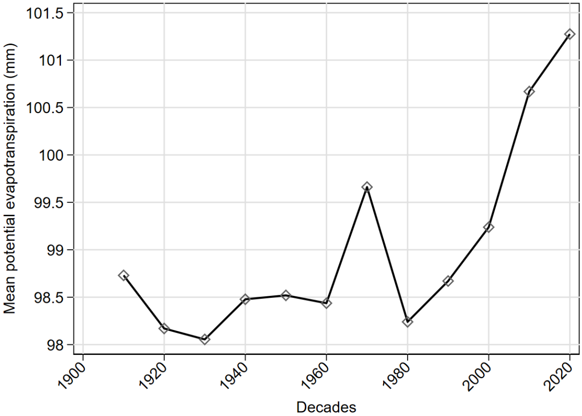
Back to begin

Figure 1: Average temperature in Brazil



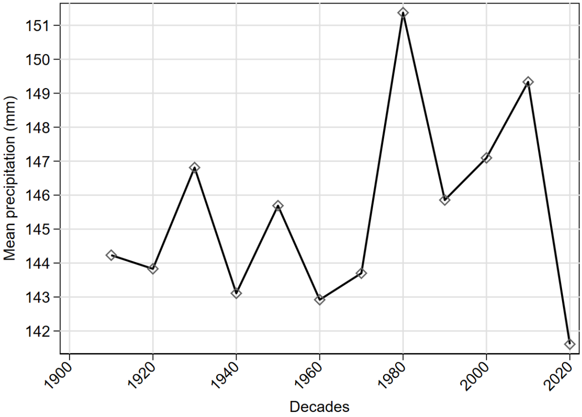
Back to begin

Figure 2: Average potential evapotranspiration in Brazil



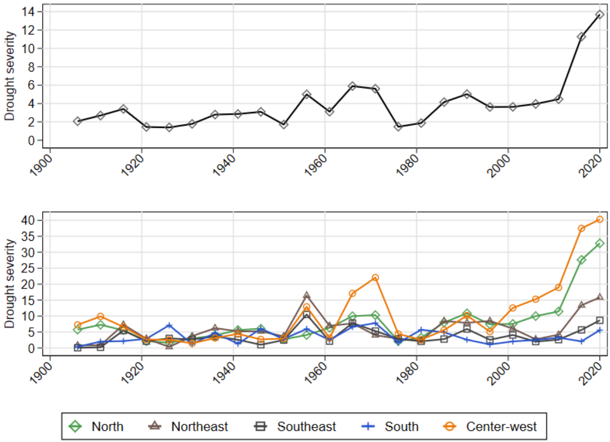
Back to begin

Figure 3: Average precipitation in Brazil



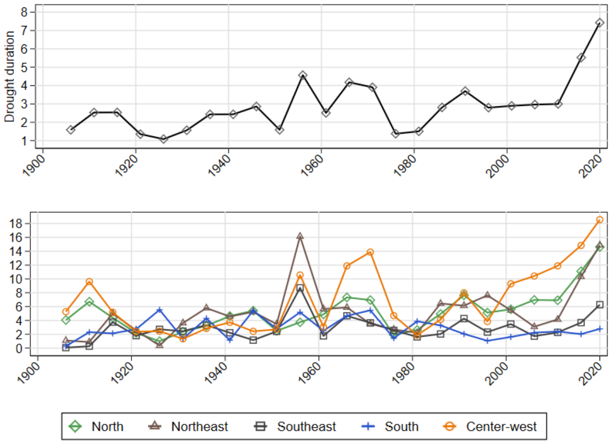
Back to begin

Figure 4: Drought severity in Brazil and by regions (integral of SPEI during droughts)



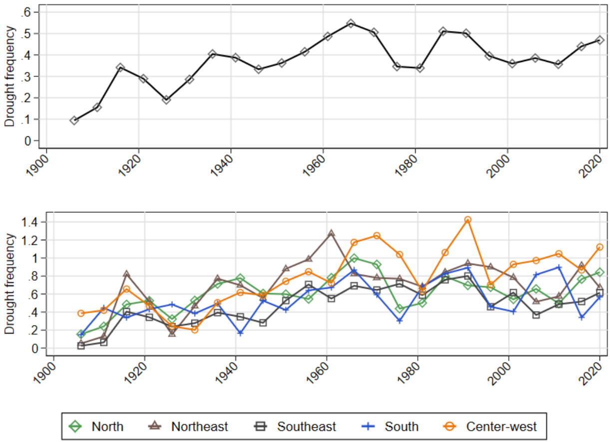
Back to begin

Figure 5: Drought duration in Brazil and by regions (months)



Back to begin

Figure 6: Drought frequency in Brazil and by regions (number of events)



2 How does drought impact agricultural production?

- Objectives
  1. How is production affected by drought?
     - Contemporaneous and lagged
     - SR vs. LR
  2. How do different dimensions of LR drought affect production?
     - Freq, Sev and interactions
     - Heterogeneity by type of product and biome
- Data
  - Municipal Agricultural Production (PAM) from the Brazilian Institute of Geography and Statistics (IBGE)
  - Panel dataset:
    - 69 crops by year (33 annual + 36 perennial)
    - 1974 to 2020
    - 3867 municipalities defined consistently over time (AMCs)

2 How does drought impact agricultural production?

- Objectives
  1. How is production affected by drought?
     - Contemporaneous and lagged
     - SR vs. LR
  2. How do different dimensions of LR drought affect production?
     - Freq, Sev and interactions
     - Heterogeneity by type of product and biome
- Data
  - Municipal Agricultural Production (PAM) from the Brazilian Institute of Geography and Statistics (IBGE)
  - Panel dataset:
    - 69 crops by year (33 annual + 36 perennial)
    - 1974 to 2020
    - 3867 municipalities defined consistently over time (AMCs)

Methodology

How to model (time-varying) local unobservables?

- Deterministic state trend model

$$log(Y_{m,t}) = \alpha_m + \beta D_{m,t} + \lambda(\alpha_s * t) + \delta(\alpha_s * t^2) + u_{m,t}$$

- Y: Fischer quantity index
- D: Drought measures
- m, t, and s: municipality, year, and state

Calculate the distribution of impacts of drought across biomes

- Calculate the distribution of impacts across AMC-years as the deviation of output from the trend

$$\log(Y_{m,t}) - \alpha_m^b - \lambda^b(\alpha_s * t) - \delta^b(\alpha_s * t^2) = \beta^b D_{m,t}$$

Methodology

How to model (time-varying) local unobservables?

- Deterministic state trend model

$$log(Y_{m,t}) = \alpha_m + \beta D_{m,t} + \lambda(\alpha_s * t) + \delta(\alpha_s * t^2) + u_{m,t}$$

- Y: Fischer quantity index
- D: Drought measures
- m, t, and s: municipality, year, and state

Calculate the distribution of impacts of drought across biomes

- Calculate the distribution of impacts across AMC-years as the deviation of output from the trend

$$\log(Y_{m,t}) - \alpha_m^b - \lambda^b(\alpha_s * t) - \delta^b(\alpha_s * t^2) = \beta^b D_{m,t}$$

Figure 7: Effect of drought on agricultural production

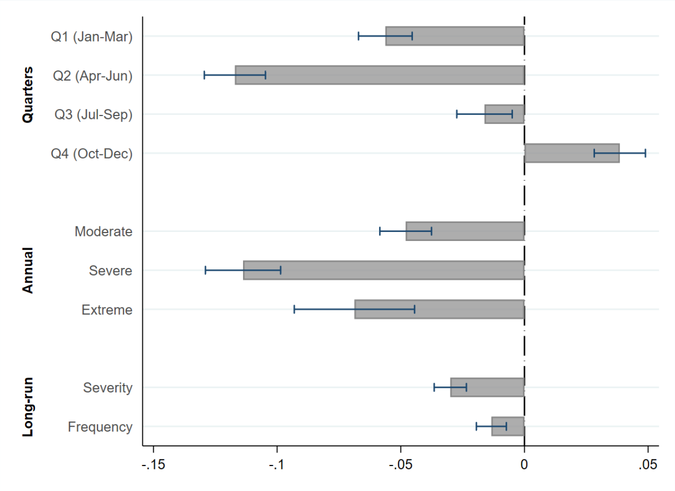


Figure 8: Heterogeneous effect of drought on agricultural production by crop type

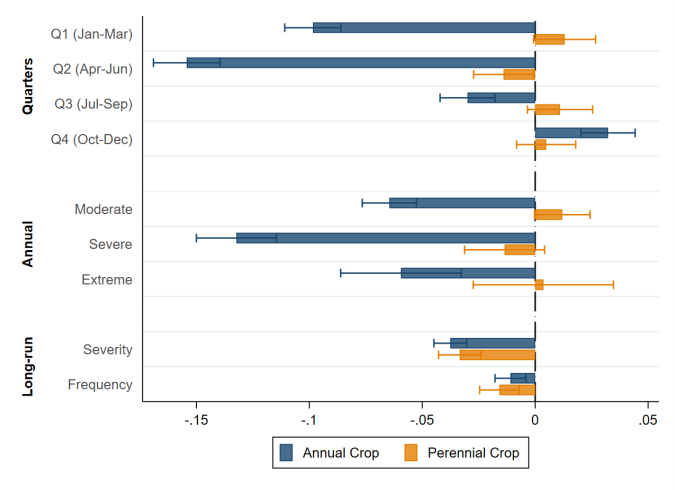


Figure 9: Heterogeneous effect of drought on agricultural production by biome

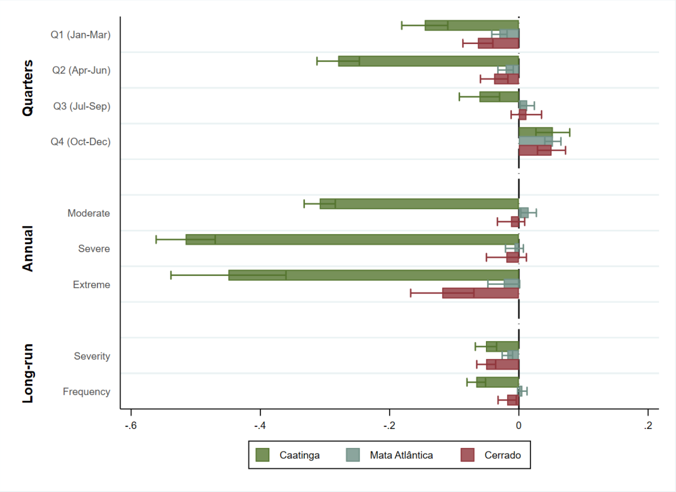


Figure 10: Heterogeneous distribution of impacts of drought by biome (percentiles)

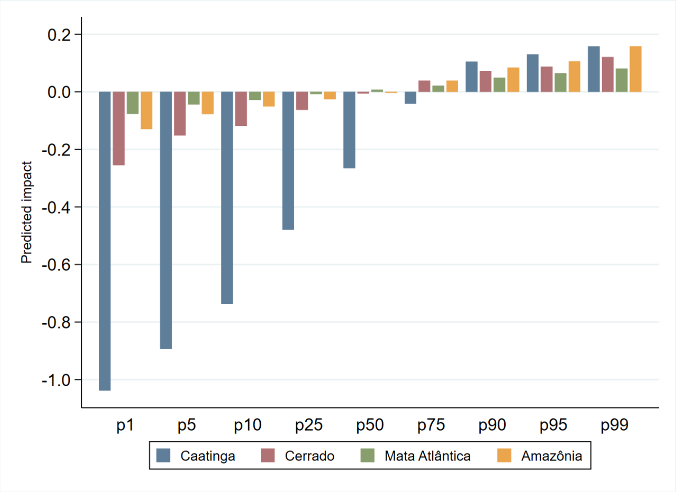


Figure 11: Heterogeneous distribution of impacts of drought by time period (percentiles)

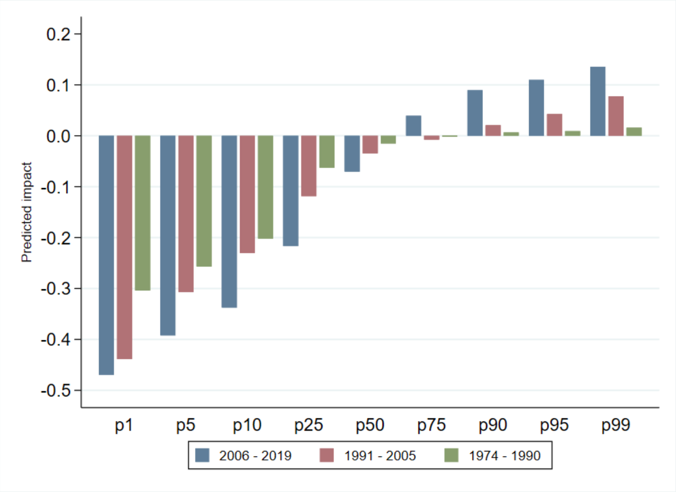
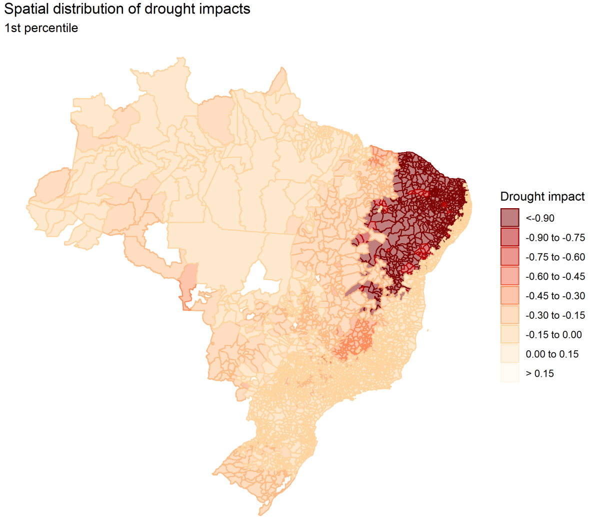


Figure 12: Spatial distribution of impacts: 1st percentile by municipality



Choosing CMIP6 Climate Models and SSP Scenarios

Procedure for choosing climate models:

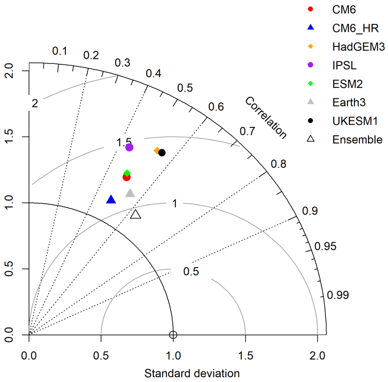
We will use a Taylor diagram to choose from several climate models. This diagram plots the standard deviation, correlation coefficient, and centered root-mean-square difference of a model's output against those of observations (1901-1980).

SSP scenarios:

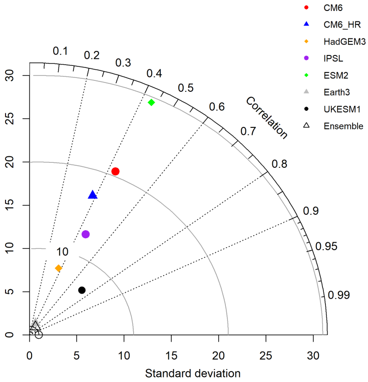
We will consider two Shared Socioeconomic Pathway (SSP) scenarios.

- **SSP126:** A sustainable development scenario with low challenges to mitigation and adaptation. GMST is projected to increase by 1.6°C by 2099.
- **SSP585:** A high greenhouse gas emissions scenario with very high challenges to mitigation and adaptation. GMST is projected to increase by 4.4°C by 2099.

Figure 13: Taylor diagram with CRU as reference

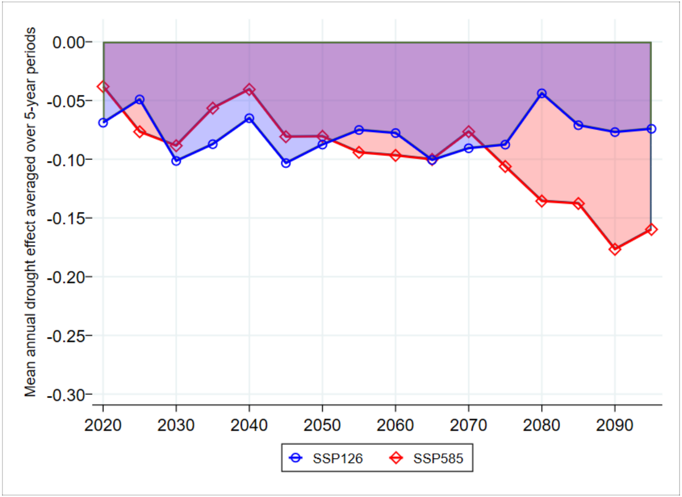


(a) Precipitation



(b) Potential Evapotranspiration

Figure 15: Impact of drought scenarios over time. Model: Ensemble



Next Steps

- Continue to explore the data to understand the impact of different types of drought
  - Heterogeneity is very important
- Drought is a rare event
  - Can't analyze means
  - Distribution of impacts is an important first step
- Use estimated coefficients to simulate distribution of impacts of drought on production in 21st century
- Study impacts of drought on poverty and total factor productivity

Thank you!

Thank you!