Impact of interannual climate variability on the agricultural sector in the Sahel region

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Outline of the study

Sahel region
Geographical region
Climatic indicators
Economic indicators

Methodology
Spectral decomposition
Statistical significance and hypothesis test

Main results
Interannual variability in the agricultural sector
Interannual variability in rainfall and temperature
Coupled climate-economic modes
The Sahel region

... under the influence of a semi-arid climate

Sahel represents a transitional zone between Sahara desert to the North and subtropical Savannah grasslands to the South.

Rainfall
- generally limited to boreal summer months
- maximum rainfall occurs in August

Precipitation variability
- key climatic factor for agriculture in semi-arid regions

Climate change entails increased risk in such regions.
The Sahel region

Strong seasonality in the rainbelt position
➢ different types of rainfall profiles

➢ notable contrasts across the Sahel region (Nicholson, 2013)

Low rainfall exposure
• Countries furthest north
• Exposed to a low level of rainfall during the rainy season.

Intermediate rainfall exposure
• Countries extending further south
• Parts of territory exposed to intermediate rainfall during the rainy season

High rainfall exposure
• Countries furthest south
• Significant part of territory exposed to high intensity rainfall during the rainy season
Climatic indicators

Annual rainfall records (mm/year)

- High-amplitude year-to-year variability superimposed on long-term trend
- Intense, occasionally multiannual droughts

Annual temperature records (°C)

- Warming trend of around 1°C over the whole record
Economic indicators

Gross domestic product (GDP)

- GDP (black) shows more or less persistent growth
- very little year-to-year variations around trend estimate (red)
- trend residuals capture less than 2%

Agriculture value added (AVA)

- AVA (black) much less regular and subject to substantial variability
- trend (red) differs from country to country
- trend residuals capture up to 20%
Economic indicators

- strong year-to-year variability in AVA
- potential links to climate variability on interannual time scales
- lack of agricultural technologies
  - lack of irrigation
  - technologies help stabilize agricultural production (Rockström et al., 2009)

### Share of AVA in GDP

<table>
<thead>
<tr>
<th>Country</th>
<th>Share</th>
</tr>
</thead>
<tbody>
<tr>
<td>Burkina Faso</td>
<td>32 %</td>
</tr>
<tr>
<td>Chad</td>
<td>51 %</td>
</tr>
<tr>
<td>Mauritania</td>
<td>18 %</td>
</tr>
<tr>
<td>Niger</td>
<td>37 %</td>
</tr>
<tr>
<td>Senegal</td>
<td>13 %</td>
</tr>
<tr>
<td>Sudan</td>
<td>32 %</td>
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</table>

Agriculture value added (AVA)
Methodology

... a very brief overview

- Spectral decomposition
- Statistical significance test
Spectral decomposition

Singular Spectrum Analysis (SSA)

... relies on the eigendecomposition of the covariance matrix

... is related to the Principal Component Analysis (PCA)

... considers spatial and temporal correlations (in contrast to PCA)

... enables spatio-temporal decomposition into trend, cyclical components and residuals

Detection of clusters of coupled oscillatory modes

Comprehensive review


Cluster analysis


Practical aspects

• website of the TCD group at UCLA https://dept.atmos.ucla.edu/tcd/resources
Monte Carlo SSA

Test statistical significance of cyclical components with a Monte Carlo-type technique:

1. fit an autoregressive (AR) process of order 1 to each time series
2. generate an ensemble of surrogate realizations from the AR(1) process
3. compare ensemble of surrogate covariance matrices with data covariance matrix to derive a null-hypothesis distribution for the data eigenvalues

Review of Monte Carlo SSA

Main results

- Interannual variability in the agricultural sector
- Interannual variability in rainfall and temperature
- Coupled climate-economic modes

... in the Sahel region
Interannual variability

... in the agricultural sector

Combined SSA analysis of AVA

- identify cross-country relationships in the Sahel region

Diverse picture of distinct significant modes (vertical lines) in each of the countries

Diversity in the SSA spectra is consistent with the strong diversity seen in the AVA time series

Sahel cannot really be considered as a single economic entity

Contrasts with a more synchronized behavior such as in Europe, cf. Sella et al. (2016)

Still, common cyclical modes can be found with a 2.4-year and 4.8-year period

These modes are not coupled to the GDP time series of the US and France, cf. our related paper
Interannual variability

... in the climatic indicators

Combined SSA analysis of rainfall, temperature and SOI index

- Impact of large-scale phenomena such as the El Niño–Southern Oscillation (ENSO) on the Sahel

Rainfall and temperature

- Few distinct oscillations
- Similar in period to those in AVA
- Few modes common to both temperature and rainfall dynamics

SOI index

- Two modes with 3.6 and 2.4-yr period
- Agree well in their period lengths with the well-known quasi-quadrennial and quasi-biennial oscillations present in many ENSO spectra
- Affect the Sahel’s rainfall and temperature fields

Shown are aggregated spectral properties, i.e. the sum over the countries individual spectra
Coupled climate-economic modes

Rainfall mode in Senegal

Combined SSA analysis of GDP, AVA, rainfall and temperature

- Identify country-specific behavior

AVA
- Coupled mode (red) captures 34% of the variance in the trend residuals (black)

Rainfall
- Coupled mode captures 24% of the variance

6 mm/year variation in rainfall corresponds to 170 million US$ variations in AVA
Coupled climate-economic modes

Rainfall mode in Niger

Combined SSA analysis of GDP, AVA, rainfall and temperature

1.5 mm/year variation in rainfall corresponds to 250 million US$ variations in AVA

Low rainfall exposure
- Niger further north of rainbelt core

Increased risk
- Higher sensitivity to small variations in rainbelt position
Coupled climate-economic modes

Temperature mode in Sudan

Increase of 0.4°C in temperature is associated with a decrease of 570 million US$ in AVA and 880 million US$ in GDP

Increase in temperature has a negative effect on the whole economy

Agricultural sector and the GDP is strongly affected
Conclusions

The Sahel's climatic and economic system

- Strong locality and diversity

Related publications


Coupled climate-economic modes

- variety of coupled climate-economic modes on interannual time scales
- differences in the countries' exposure to rainfall during the boreal summer months
- coupled climate-economic modes strongly differ from country to country in their characteristics

Impact on agricultural sector

- important share of the agricultural sector on the economy (around 30%)
- low development of modern agricultural practices such as irrigation
- enhanced sensitivity to climate signals in the economy