Satellite imagery reveals large-scale land restoration measures improved resilience to drought in Ethiopia's degraded watersheds

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1.1 Motivation

- The livelihoods of rural populations in developing economies are threatened by anthropogenic land degradation.
- Development agencies have invested heavily in sustainable land management (SLM) projects to battle land degradation and to improve livelihood resilience to severe weather conditions.
- Rigorous impact evaluation has been lagged behind the widespread implementation of SLM projects, due to data limitations.

1.2 Research Question

- Conventional impact evaluations relying on household surveys are not suitable for these projects.
  - Programs often start before a proper baseline survey has been conducted.
  - Program effects often materialize over many years and conducting many surveys to capture dynamic program impacts are prohibitively expensive.
  - Difficult to include sufficient number of observations hit by natural disasters to examine resilience outcomes.
- **Our study combines satellite imagery products and quasi-experimental impact evaluation methods to investigate the impacts of Ethiopia's Sustainable Land Management Project (SLMP).**

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1.3 Description of Ethiopia's SLMP

- Target areas: watersheds in Ethiopia's highlands
- Three phases
  - SLMP1 (2009-2013): 45 watersheds, USD 37.79 million
  - SLMP2 (2014-2019): 135 watersheds, USD 107.61 million
  - SLMP3 (Resilient Landscapes and Livelihoods Project) (2019-2024): 152 watersheds, USD 100 million
- Key components
  - Integrated watershed and land management: irrigation, afforestation, pasture management etc.
  - Capacity building
  - Land administration

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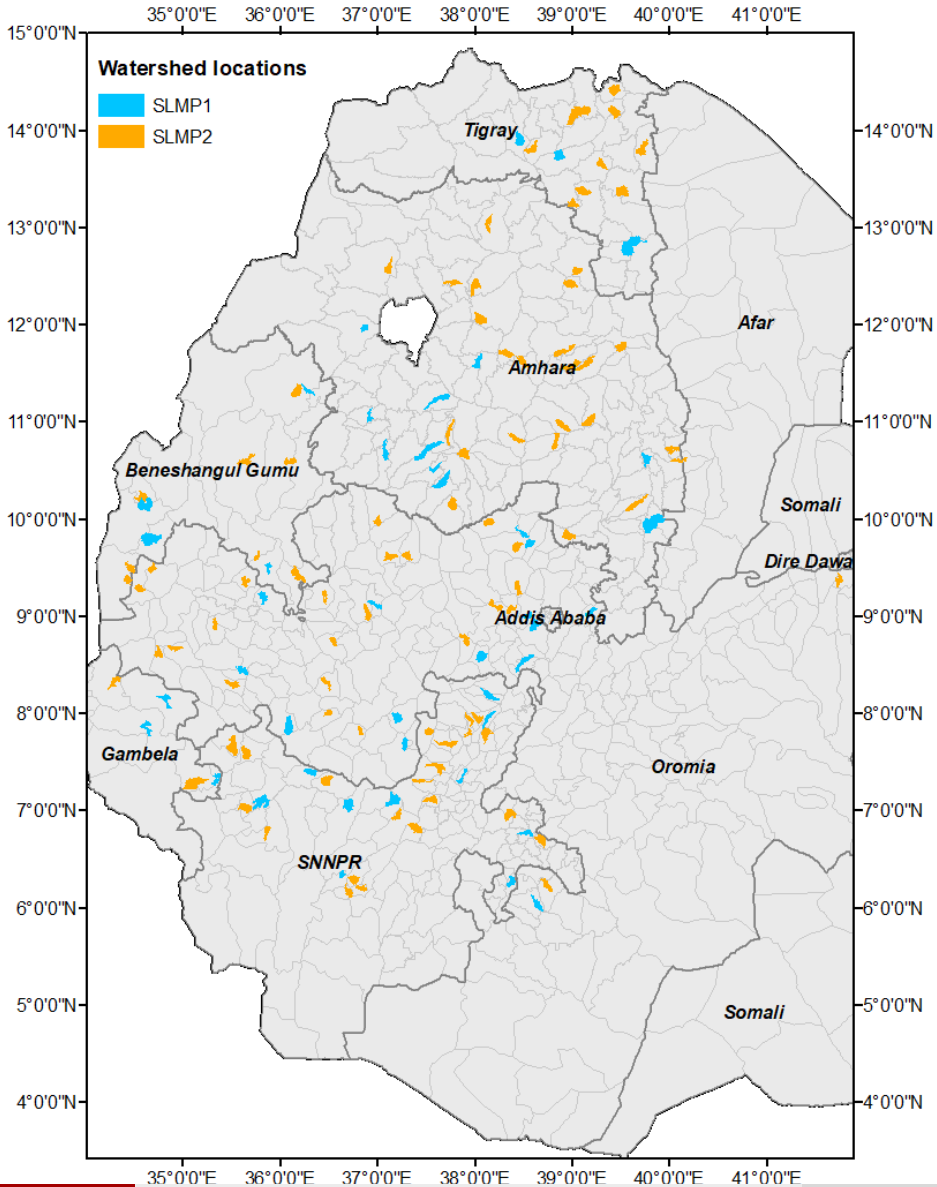
Map of SLMP1 and SLMP2 locations



1.4 Key innovations

- Use of SIF (Solar-induced Chlorophyll Fluorescence) and EVI (Enhanced Vegetation Index) as land productivity measures
  - Two complementary but different satellite imagery products
- SIF-GPP (SIF-based gross primary production) provides a directly quantifiable measure of land productivity.
  - Allows for the interpretation of findings in terms of both statistical and **economic significance**.
- We investigate SLMP's impacts on **resilience to drought**.
  - An imperative but under-studied research question

Outline

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2. Data

- Geospatial data with public access - a cost-effective impact evaluation
- Analysis unit: pixel-year (focus on the main crop season: June-September)
- Outcomes: SIF-GPP and EVI (measures of land productivity)
- Key control variables
  - Rainfall and temperature
  - Elevation and soil quality
  - AEZs (Agro-ecological zones)
  - % area covered by crop and by rangeland

Outline

3. Identification strategy: DID + pipeline design

- Use SLMP2 locations as the control group to estimate program effects of SLMP1.
  - SLMP1 and SLMP2 were selected following similar criteria.
- Difference-in-difference method (DID) using data from 2002-2015
  - Pre-intervention period: 2002-2010 (date back many years before the intervention)
  - Intervention period: 2011-2015 (restricted by the pipeline design as the effective start year of SLMP2 is 2016)
- Event study to test for parallel trends and to show dynamics of program effects

Outline

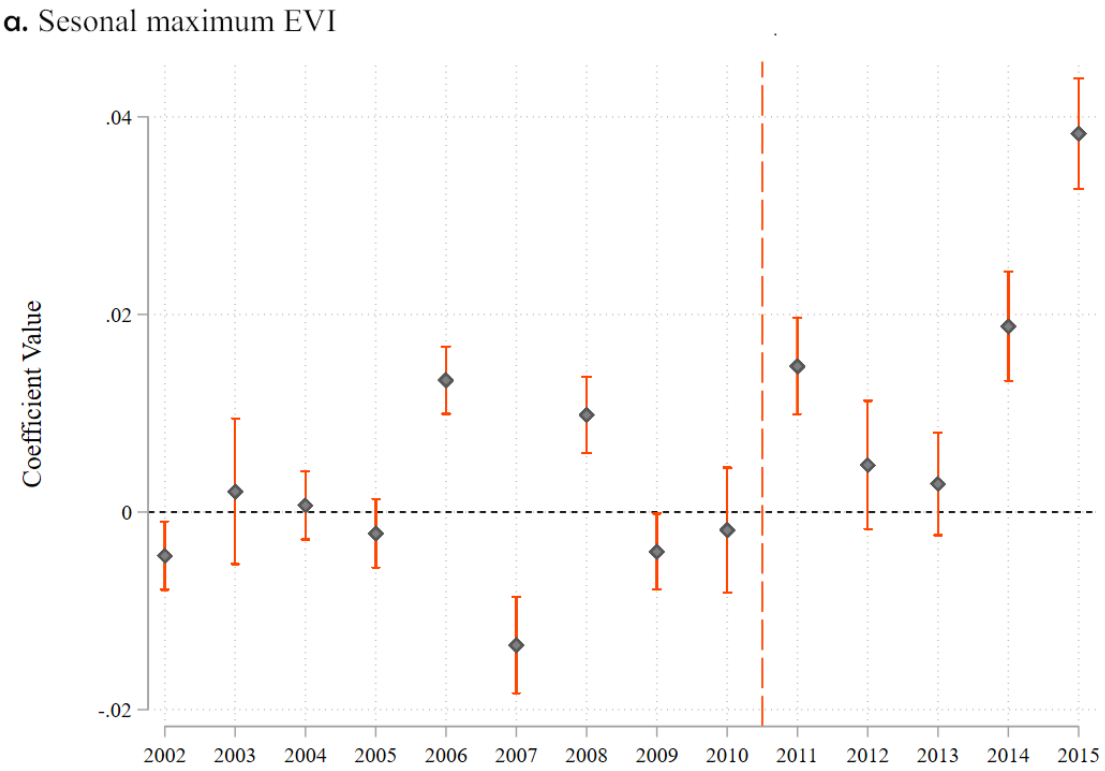
4.1 Event study: model

$$y_{idt} = \sum_{n=-9}^{n=4} \vartheta_n 1(n = t - 2011) T_{idt} + x_{idt}\beta + \delta_i + \gamma_{dt} + \epsilon_{idt}, \quad (1)$$

- y_{idt} is EVI or SIF-GPP at pixel i in AEZ d in the main crop season of year t (t=2002, ..., 2015).
- $1(n = t - 2011)$ indicates that year t falls into the event interval n.
- T_{idt} indicates SLMP1 locations.
- x_{idt} is a set of control variables including rainfall, temperature, and their interactions with key terrain and soil-quality variables, such as elevation and the soil's water-holding capacity.
- δ_i is pixel fixed effects.
- γ_{dt} is AEZ-year fixed effects.
- ϑ_n (n=-9,...,4) indicate the difference in outcome variables between treatment and control groups in event year n.

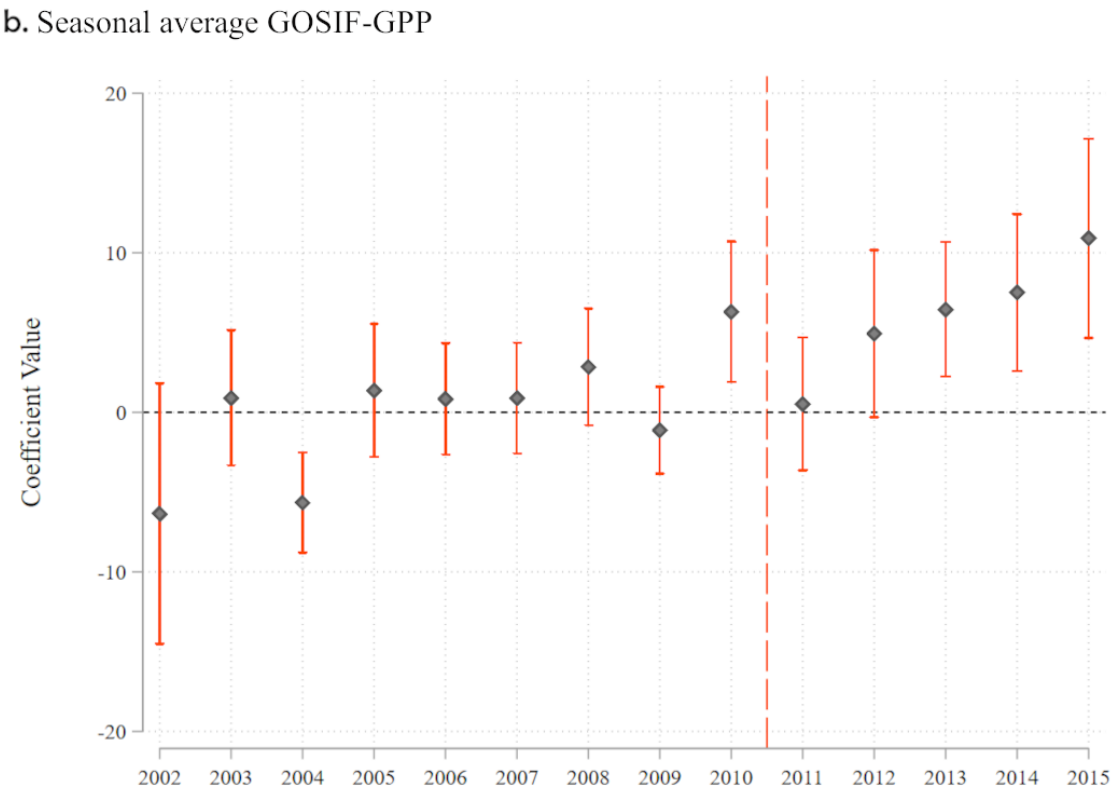
4.2 Event study: EVI

- Difference in EVI between the treatment (SLMP1) and the control (SLMP2) locations by year (after controlling for fixed effects and confounding factors)



4.3 Event study: SIF-GPP

- Difference in SIF-GPP between the treatment (SLMP1) and the control (SLMP2) locations by year (after controlling for fixed effects and confounding factors)



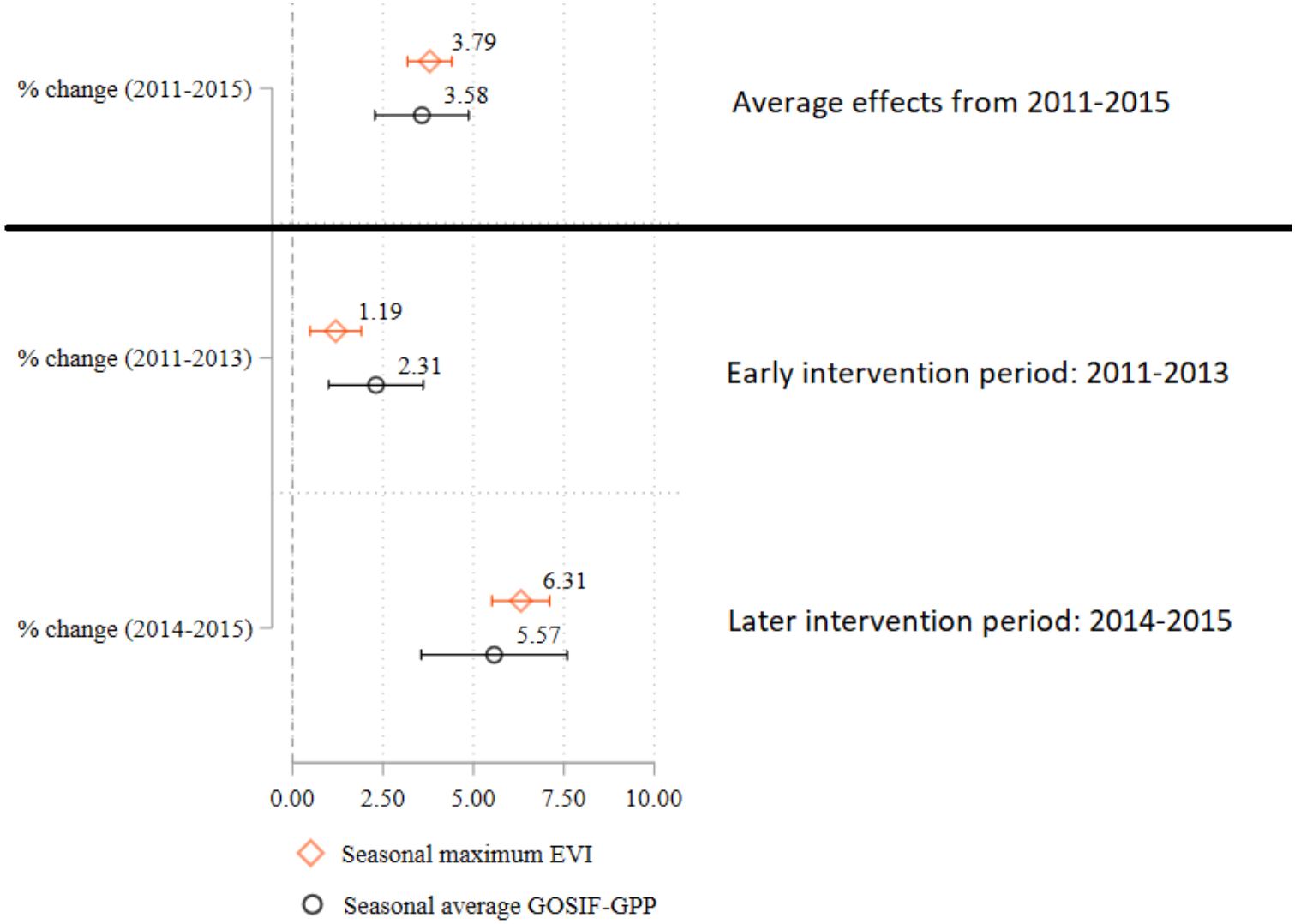
Outline

5.1 Average program effects on productivity: Model

$$y_{idt} = \theta T_{idt} \cdot 1[Post] + x_{idt}\beta + \delta_i + \gamma_{dt} + \epsilon_{idt}, \quad (2)$$

- y_{idt} is EVI or SIF-GPP at pixel i in AEZ d in year t.
- T_{idt} indicates SLMP1 locations.
- $1[Post]$ indicates the post-intervention period ($t \geq$2011)
- x_{idt} is a set of control variables including rainfall, temperature, and their interactions with key terrain and soil-quality variables, such as elevation and the soil's water-holding capacity.
- δ_i is pixel fixed effects.
- γ_{dt} is AEZ-year fixed effects.
- θ estimates the average effects of SLMP1 during the intervention period.

5.2 Average program effects on productivity: Results

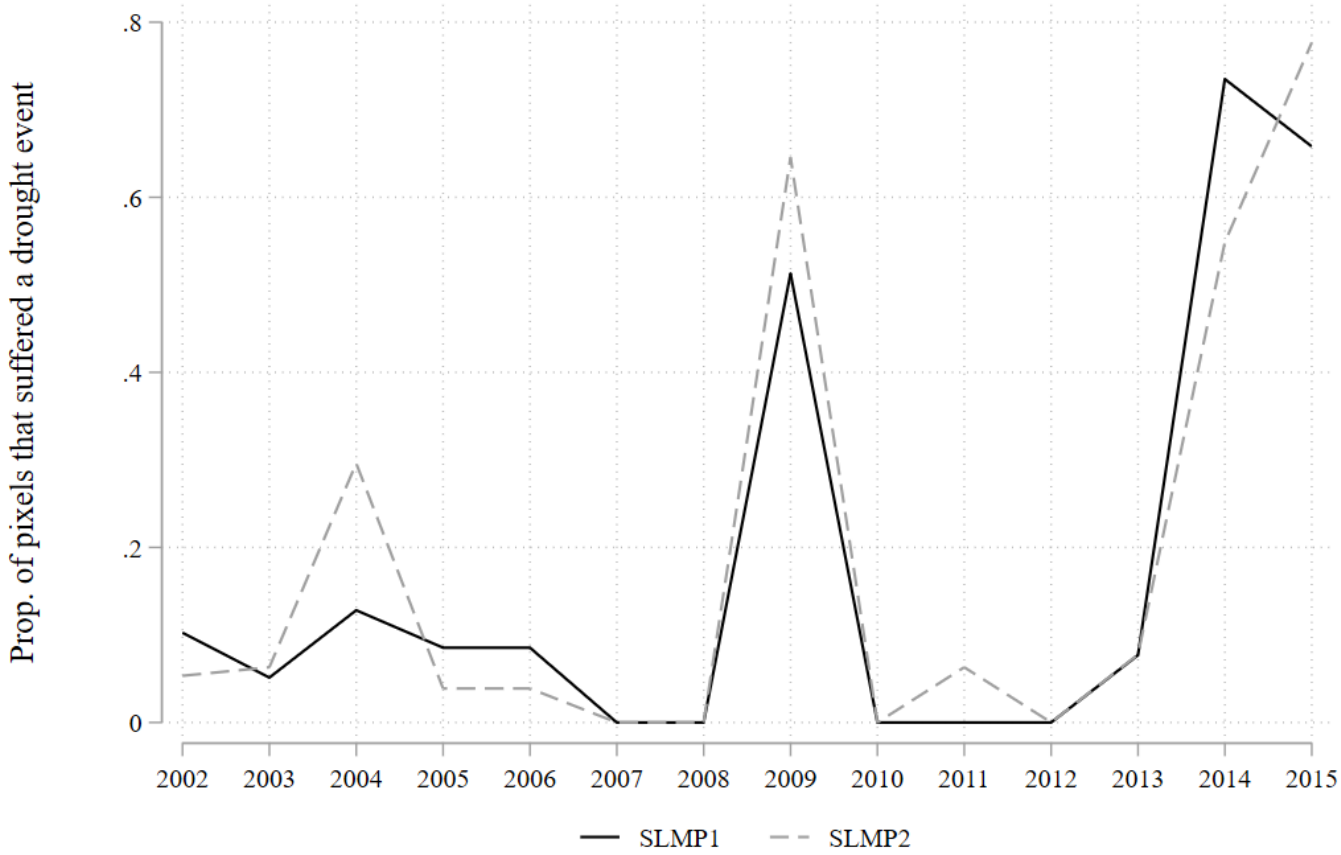


Outline

6.1 Drought indicator

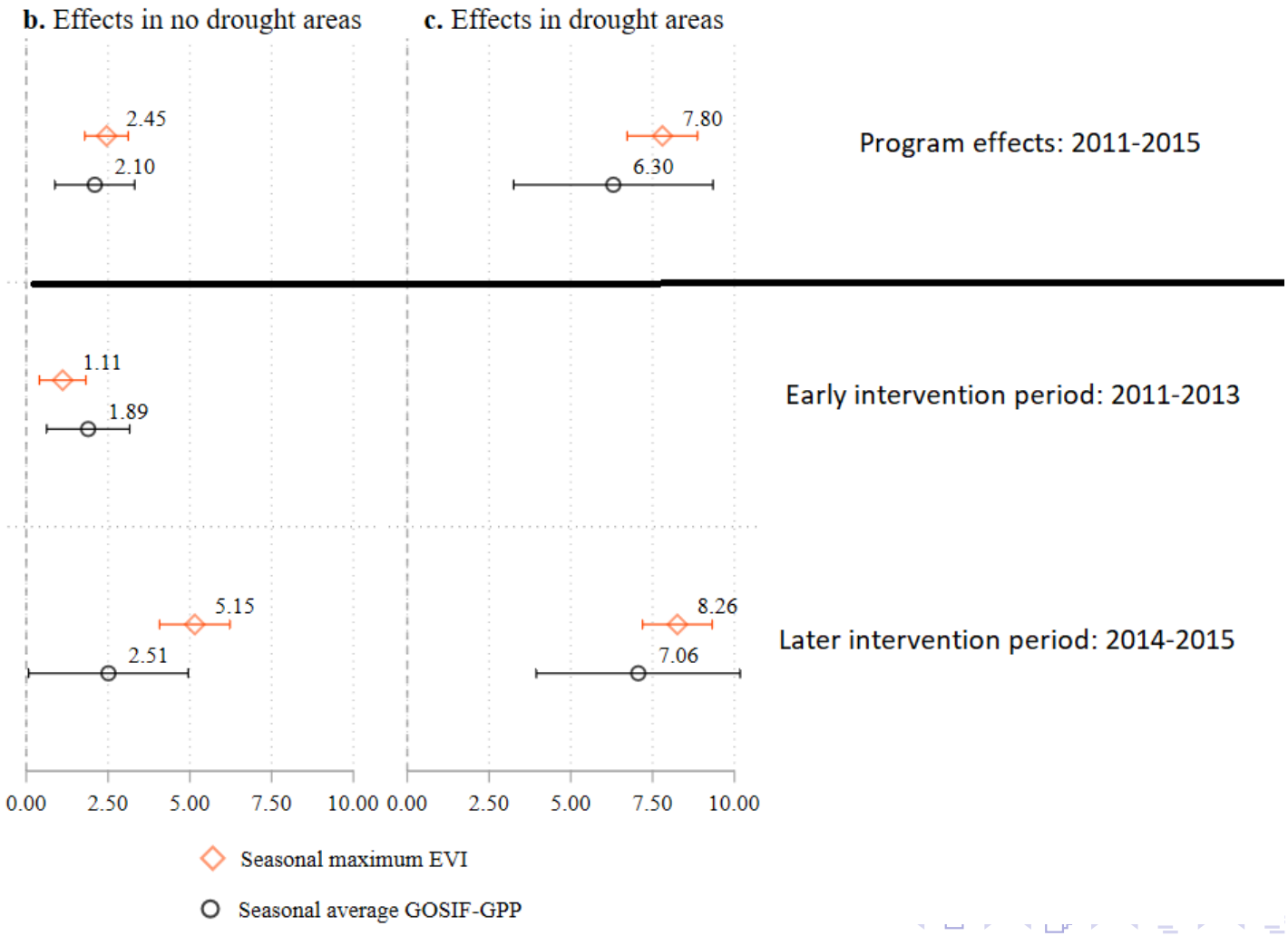
Drought: large negative deviations from normal rainfall: z-score $<$ -1.5

Figure: Proportion of pixels under drought, 2002-2015



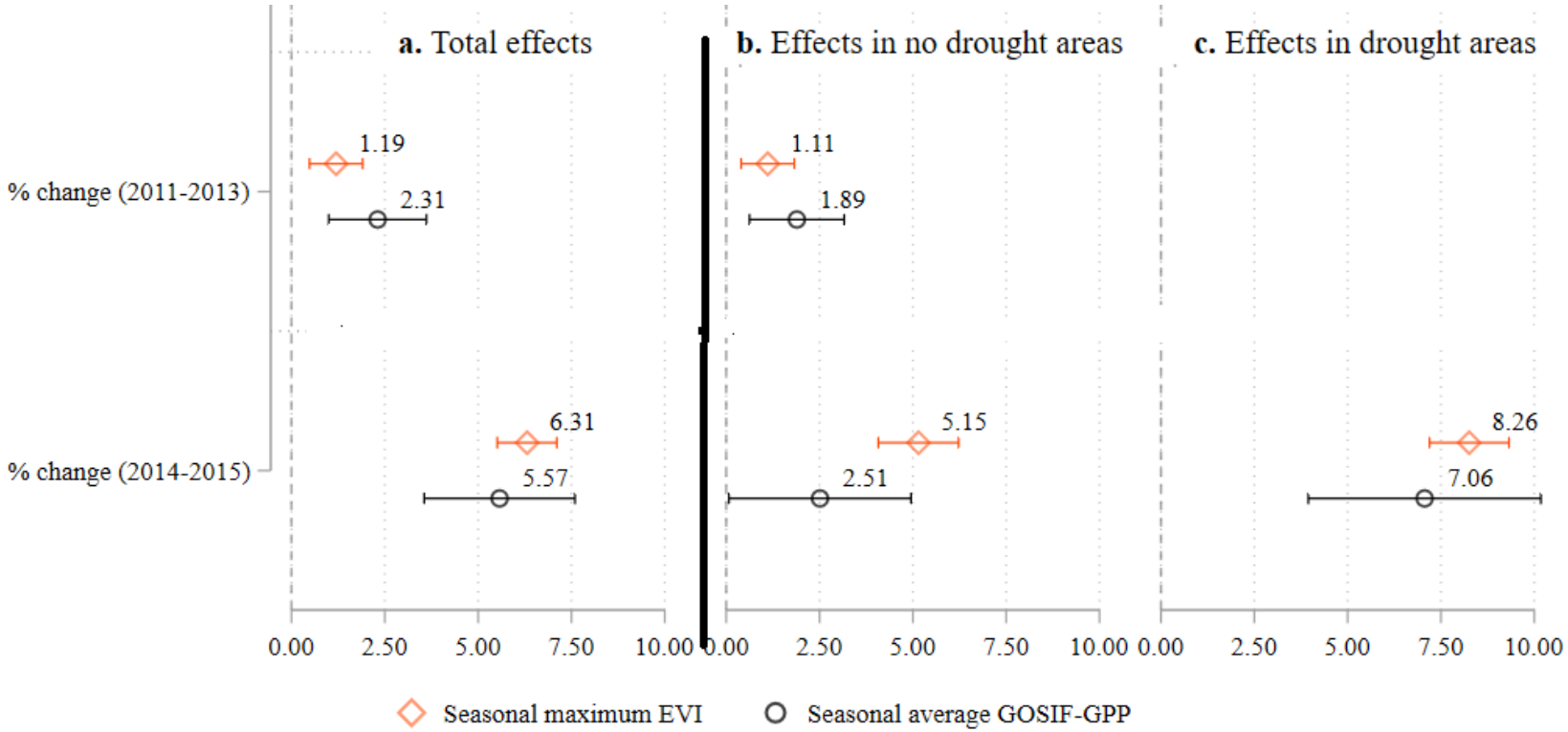
6.2 Drought-buffering effects

Figure: Program effects on productivity: with and without drought



6.3 Drought-buffering effects versus dynamic effects

Large effects in later intervention period is mostly driven by the drought-buffering effects.



Outline

7 Key findings and contributions

- Program effects (averaged over 5 intervention years):
  - 6.3% increase in land productivity in drought-affected areas
  - 2.1% increase in land productivity in no-drought areas
- Contributions:
  - Provides the first empirical evidence on large effects on resilience to droughts of sustainable land management projects.
  - Shows the potential of combining remote sensing technologies with impact evaluation models to assess ecosystem restoration programs.