Measuring the Impact of Land Titling on Investment via Satellite

CEGA Research Retreat

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BIG PIXEL
INITIATIVE AT UC SAN DIEGO

What we are doing here?

A CEGA-Inspired Project!

- Panel at Geospatial Analysis for International Development:
  - The truth isn't necessarily on the ground
  - We're still figuring out what's possible (and not yet possible)
  - How to use different degrees of freedom?
- Can we use RCTs on the ground to test the possibilities/limits of Remote Sensing for impact evaluation?

Two Reasons to Stay for the Rest

Substantive:
Does formalization of landholdings lead to greater on-farm investment?

- Yes: Modest Impacts
- Meh: SSA, Heterogeneity

We have some (preliminary) evidence towards yes in a few different ways.

Methodological:
Can remote sensing help us conduct longer-run, ex-post evaluations?

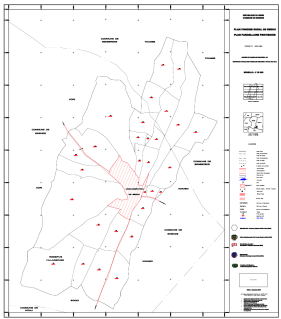
- Night Lights, Built-up Area, Yields
- Us: Drivers of LUC @ farm scale

Cool tools to learn more from the information that already exists.

What are we Actually Doing?

World Bank project (Plans Fonciers Ruraux) to formalize landholdings across Benin

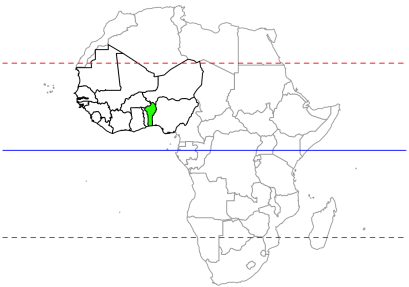
- National scale program
- 2009-2011 (mostly)
- Randomized at village level
- Village-level: conflict resolution, plot demarcation, title issuance
- $N_{village}$ = 300 and n_{plot} = 70,000
- HH survey from 2011 (WB)



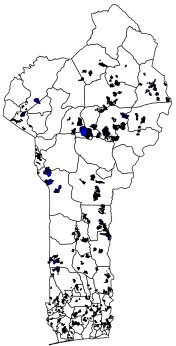
Look for fingerprints of impact in remotely-sensed vegetation indices. Do we see what the conventional impact evaluation saw?

Quick PFR Summary

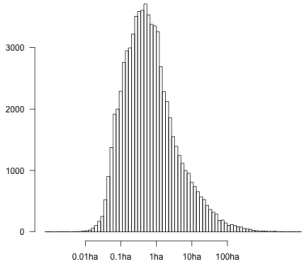
Benin



PFR Villages



Plot Size Distribution



Why is this a Good Project to Use? (1)

	Obs.	Control		ITT	
		Mean	Std. dev.	Coeff.	s.e.
Parcel has clear borders[†]	6,094	0.061		0.270***	(0.02)
Panel A: Tenure security					
Fear of land loss during fallow[†]	6,094	0.116		0.007	(0.01)
Land conflict[a†]	6,094	0.052		-0.009	(0.01)
Perceived land rights					
- *A HH member will inherit land*	3,582	0.829		-0.007	(0.02)
- *The HH head can lend/rent-out/give the parcel*	3,582	0.731		0.017	(0.02)
- *The HH head can pledge land*	3,582	0.719		0.000	(0.02)
- *The HH head can sell land*	3,582	0.554		0.040*	(0.02)
Panel B: Investment and land transfers					
Investment in tree planting[a†]	6,094	0.040		0.017**	(0.01)
Started fallowing parcel[a†]	6,094	0.010		0.004	(0.00)
Parcel is rented in/out[†]	6,094	0.147		-0.014	(0.01)
- *rented in*	6,094	0.082		0.002	(0.01)
- *rented out*	6,094	0.065		-0.016*	(0.01)
Panel C: Agricultural activities[b]					
Total land size (ha)	2,972	6.236	13.827	0.320	(0.54)
Participation in agriculture[†]	2,972	0.902		0.006	(0.01)
Share of land size cultivated	2,675	0.538	0.323	-0.001	(0.01)
Panel D: Agricultural production[c]					
Type of crop cultivated					
Cereals[†]	6,094	0.505		0.001	(0.02)
Pulses[†]	6,094	0.150		0.003	(0.01)
Roots and tubers[†]	6,094	0.245		-0.005	(0.02)
Vegetables[†]	6,094	0.052		-0.004	(0.01)
Cash crops[d†]					
- *annual*	6,094	0.037		0.001	(0.01)
- *perennial*	6,094	0.067		0.026**	(0.01)
Inputs					
- *farm labor supply (person-days/ha)*	3,994	202.854	261.071	1.690	(9.88)
- *fertilizer/high-yield seeds*[†]	3,994	0.272		0.018	(0.02)
Output					
- *total output (Log USD)*	3,677	6.135	1.358	-0.043	(0.06)
- *yield (Log USD of total output/ha)*	3,677	6.379	1.064	0.023	(0.05)

A few percent increase in tree planting and cultivation of perennial (e.g. trees) and annual cash crops.

Why is this a Good Project to Use? (2)

While demarcation activities do lead to an increase in long-run investments, they do not generate an initial increase in agricultural output, farm yields (measured as the log of the value harvested per hectare), or the use of productivity-enhancing inputs such as labor, fertilizer, or improved seeds. Given that it takes more than one year for these long-term investments to bear fruit, it is unsurprising that demarcation does not generate productivity gains at this early stage in implementation.[32]

[32] The gestation period for cashew and oil palm trees, for example, is at least four to five years.

The More Nuanced Truth

- Obvious Pros: An RCT with a few small significant effects over a short time period, and a lot of other null findings.
- Less Obvious Pros: No geographic control information, and no baseline! So RCT is irrelevant.
  - Geospatial synthetic control opportunity
  - Pretty independent cross-validation

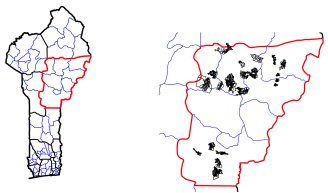
Potential to open up a lot of other un-evaluated interventions for observational analysis.

Goals

1. What effects do we measure remotely?
    - Production time scale is slow compared to stagger and evaluation
    - Learning curves may exist, weather definitely exists
    - Even immediate changes might take a few seasons to be "visible"
2. Test-drive geospatial synthetic controls:
    - Generate a synthetic control for every treatment observation
    - Create random draw of plots/pixels from all non-treated areas
    - Derive weights for comparisons to generate a control that matches the treatment observation's pre-intervention levels and trends

How the Sausage is Made (Methods)

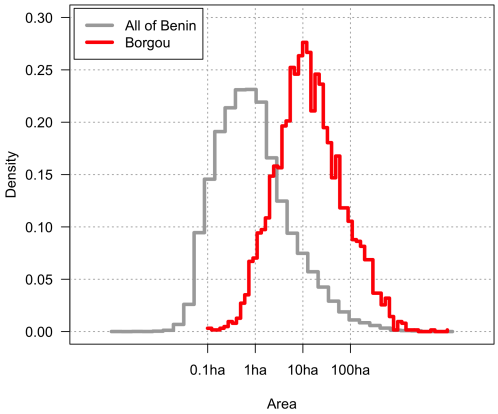
Test Region: Borgou Department



Borgou Plot Stats:

- 3132 treated plots
- PFR rolled out from late 2009 to early 2011
- 1.5 % female titleholders

Borgou Plots are Larger:



Outcomes?

Many types of investment (pathways) we'd like to measure:

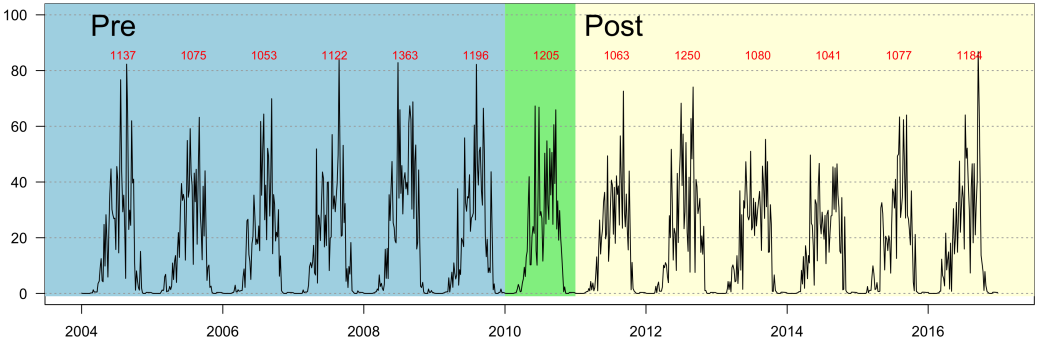
- Fertilizer, HYV use
- Irrigation / water management
- Diversification, high-value crops
- Fallowing, rotation practices

These map non-uniquely to what we can measure @ scale of 1-30m:

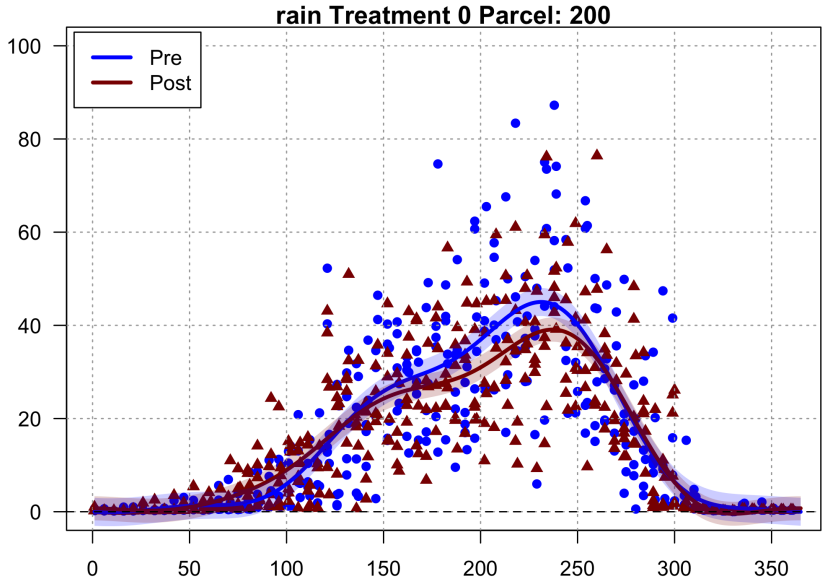
- Productivity (for same crop)
- Seasonal production cycle
- Relationship with precipitation
- Fallowing, rotation practices

Here we focus on perennial and counter-seasonal production.

Seasonality



Decrease in Rainfall



Outcomes

All on a Seasonal Basis:

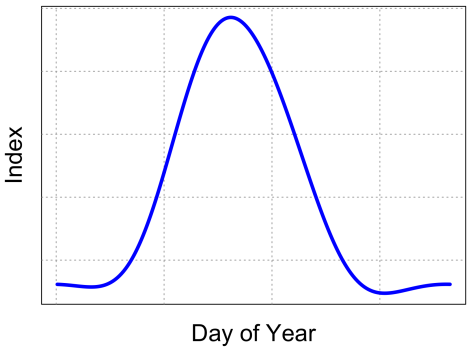
- Predicted (fit) Max VI value
- Day of Max Predicted VI value [1:365]
- Is Max Predicted VI in dry season? (binary)
- Average VI, end of main season
- Average VI, dry season (1)
- Average VI, dry season (2)

Data Sources:

- Landsat 7 8-day TOA Corrected Composites in GEE
  - Extract time series for all treated plots (average) and control points (pixels)
  - Generate NDVI, EVI, SAVI, LSWI, GCVI
  - Get dry season metrics
  - Fit seasonal pattern in pre- and post- treatment period
- CHIRPS (5-day) precip (seasonality)

Fitting Annual Cycles

Stack annual values:



Fit arbitrary sinusoid:

$$y = I_0 + A_1 sin\left(\frac{2\pi J}{365}\right) + A_2 cos\left(\frac{2\pi J}{365}\right) + B_1 sin\left(\frac{4\pi J}{365}\right) + B_2 cos\left(\frac{4\pi J}{365}\right) + C_1 sin\left(\frac{6\pi J}{365}\right) + C_2 cos\left(\frac{6\pi J}{365}\right) + D_1 sin\left(\frac{8\pi J}{365}\right) + D_2 cos\left(\frac{8\pi J}{365}\right)$$

Control Strategy

- No control plots
- No control villages
- Basically observational data
- What would a good control look like?

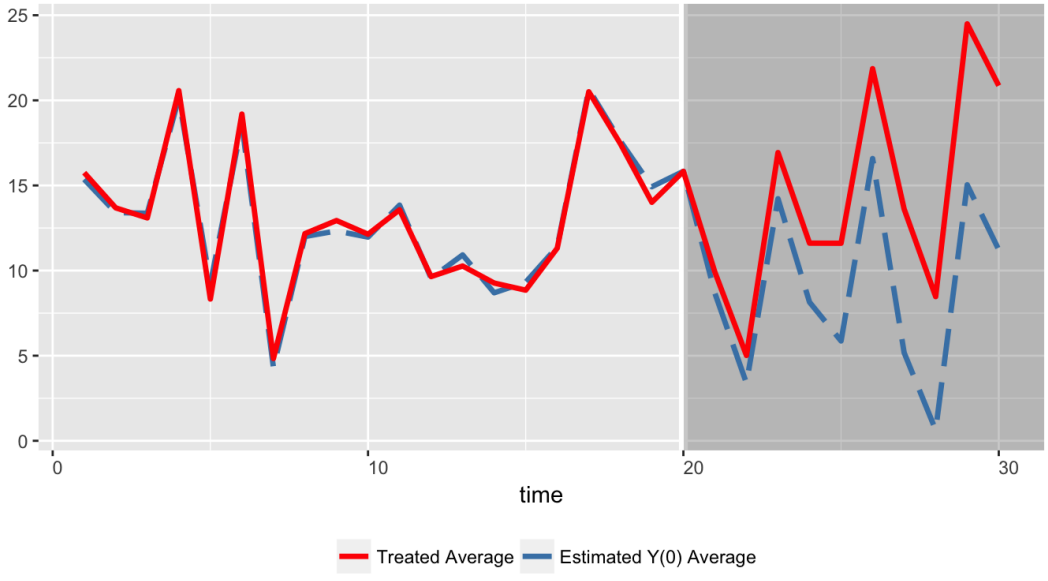
Control Strategy

- Would match a treated unit exactly before treatment
- Synthetic control method **Abadie Diamond and Hainmueller 2010**
- Interactive Fixed Effect method **Bai 2009**
- Generalized synthetic control method **Xu 2017**

Estimation

- Estimate latent factors and factor loadings from control group via IFE
- Find the factor loadings that best predict the treated units in the pre-treatment period
- Impute counterfactuals in post-treatment period based on latent factors and these factor loadings
- An estimator $A\hat{T}T_t$ is $(1/N_{tr}) \sum_{i \in \tau} [Y_{it}(1) - \hat{Y}_{it}(0)]$ for $t > T_0$

Estimation-Example

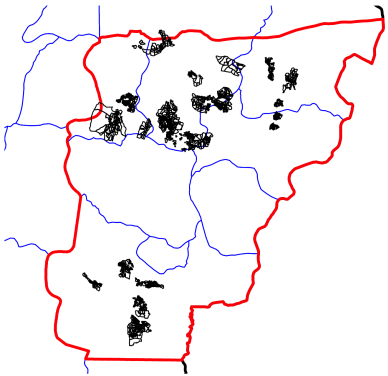


Estimation

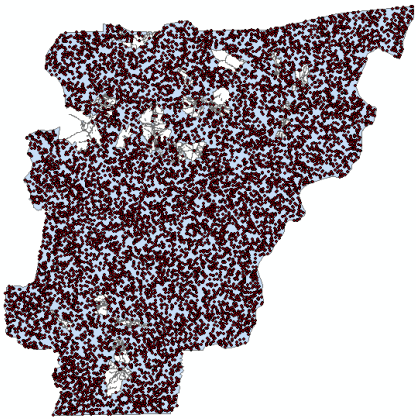
- Treated units are plots (average of pixel values in plot)
- Control units are points from Borgou outside of the treated plots
- Synthetic control is (basically) a weighted average of the untreated points that match a treated plot best

Data

Treated Plots



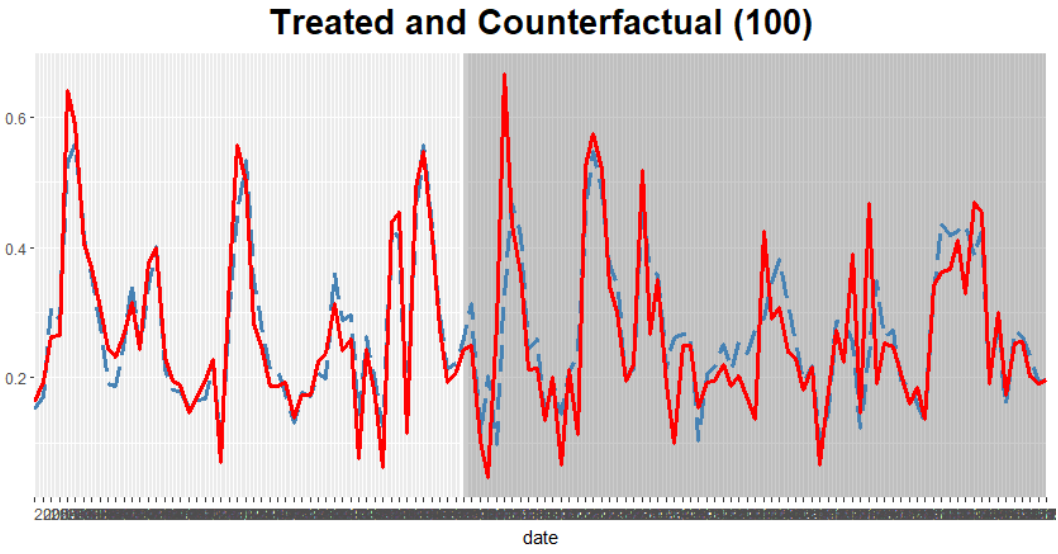
Untreated Points



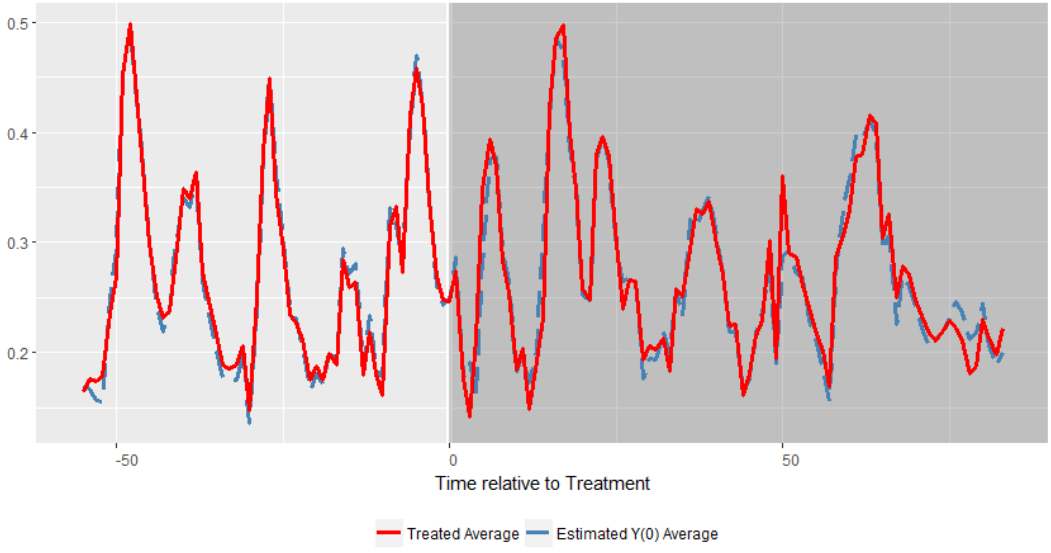
Data

- Begin with 15132 observations, about 250 time periods
- Drop time periods with >50% missingness
- Drop observations with >10% missingness
- Result: 1545 treated, 4881 control, 126 dates from 2005-2017
- Output 3090 observations. Half treated, half imputed control

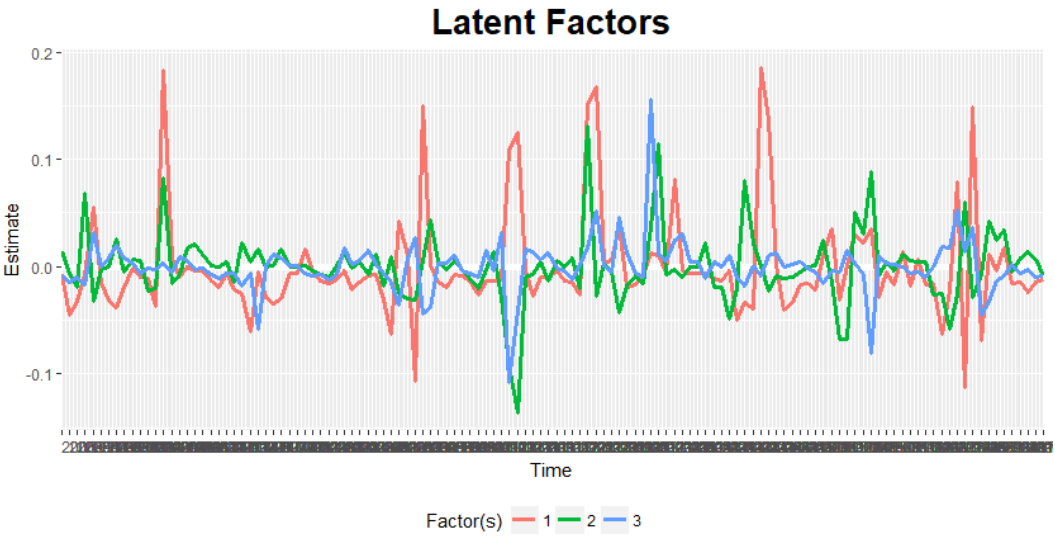
Estimation-One of our examples



Estimation-Whole sample



Factors



Estimation

Difference-in-Differences:

$$y_{it} = \beta T_{it} + s_i + \theta_t + \epsilon_{it}$$

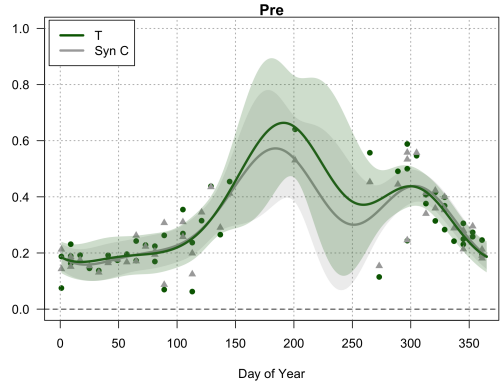
- y_{it}: DVs, I_0 and 1st, 2nd, 3rd Harmonics
- i: plot (either PFR or synthetic control)
- t: pre- or post- PFR
- s_i: plot FE
- θ_t: pre- post- FE

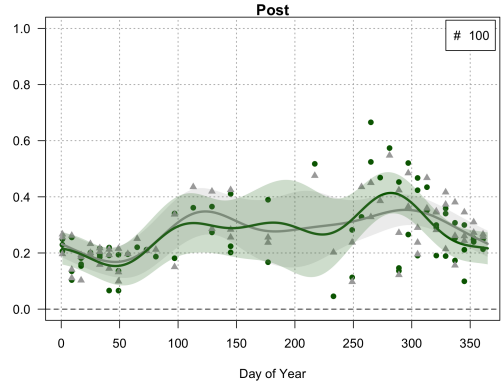
Standard Errors

- They are incorrect at the moment–don't pass-through uncertainty from synthetic control method
- Also don't account for spatial autocorrelation or village clustering

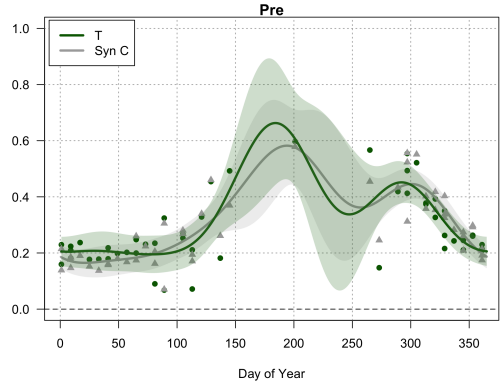
Results

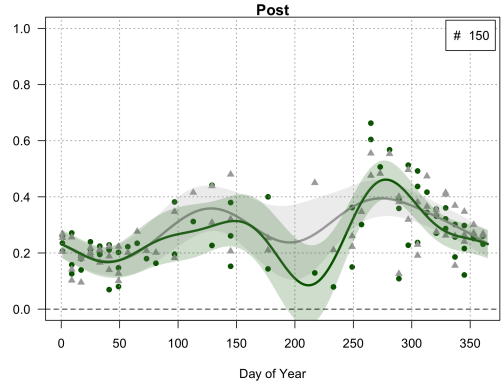
Output of matching and harmonic fitting





And a few more for results





Hypothesis Tests

Table: Preliminary Results

	Dependent variable:					
	NDVI					
	(Max)	(Day of max)	(max in dry season?)	(end of main)	(dry season)	(first 4 months)
post:treatment	−0.095***	41.126***	−0.001	0.001	0.003***	0.012***
	(0.003)	(1.403)	(0.005)	(0.001)	(0.001)	(0.001)
Constant	0.536***	213.664***	0.034***	0.326***	0.223***	0.184***
	(0.001)	(0.702)	(0.003)	(0.001)	(0.0003)	(0.0003)
Observations	6,180	6,180	6,180	6,180	6,180	6,180
R^2	0.144	0.122	0.00001	0.0002	0.002	0.056
Adjusted R^2	0.144	0.122	−0.0002	0.0001	0.002	0.056
Residual Std. Error (df = 6178)	0.101	47.764	0.180	0.036	0.023	0.021
F Statistic (df = 1; 6178)	1,037.128***	859.060***	0.060	1.470	13.942***	368.897***

Note: *p<0.1; **p<0.05; ***p<0.01

Comparison to WB Survey Data

- Lower max NDVI (Perennials?)
- Day of max NDVI is later (Land improvements?)
- No change in whether the date of max NDVI is in the dry season
- No change in NDVI at end of main season
- Higher dry season NDVI (Improvements/perennials)
- Higher NDVI in first four months of the year (Improvements/perennials)

Conclusions

Substantive Results Summary

- Some support for the theory that land titling leads to long-term improvements to land
- This appears as more growing in the dry and off seasons, and/or increase in perennial crops.

Feasibility and Expansion

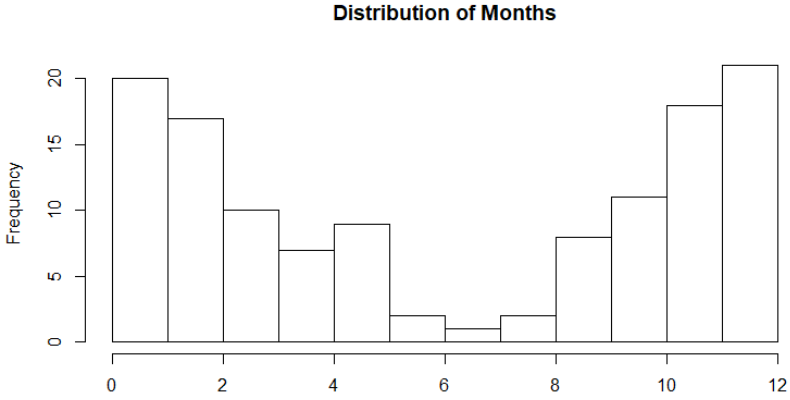
- Feasibility
  - Limits of data extraction from Google Earth Engine
  - Memory and computational intensity of synthetic control method
- Next Steps
  - Different indices in the same region
  - Do different indices work better in different regions?
  - Are the control points farmland?

Bigger Questions

- Further applications of geospatial synthetic control method?

Remaining Methods Questions

- The fit isn't perfect in pre-treatment periods (do we need more data?)
- Missing observations during the rainy season–how does this affect the matching process



Remaining Methods Questions

- What is the right way to measure shift in production?
- If productivity had increased or a shift to perennials had occurred, how would we observe it?

References

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Synthetic Control Methods for Comparative Case Studies: Estimating the Effect of California's Tobacco Control Program
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Thank you!

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