Personalizing Sustainable Agriculture with Causal Machine Learning

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Agriculture: Modern Challenges

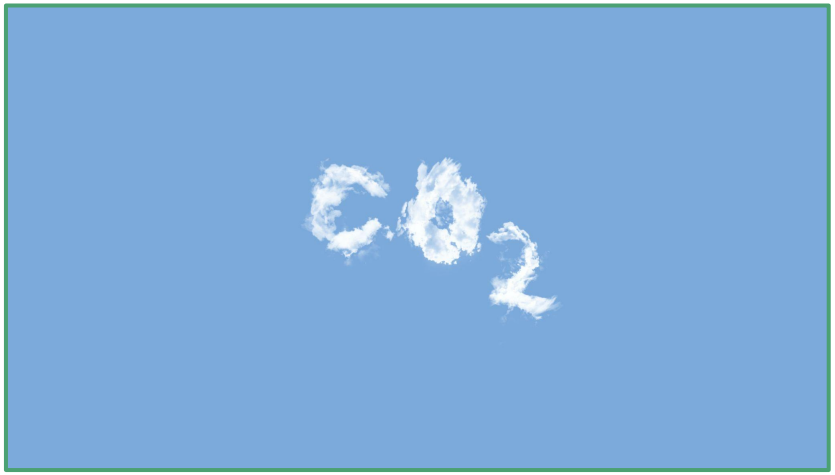
Ever-increasing demand for agricultural products

Climate change, Environmental degradation

“Sustainable Intensification”

Agriculture: Modern Potential

Crops naturally capture CO_2 from the atmosphere and store it in soil



Maximizing soil carbon sequestration can enlarge the global carbon sink

Carbon Farming

A diverse world

Differences in climate, soil, land use

Different environmental responses to interventions carried out by farmers

Effect Heterogeneity

Diverse policy measures (EU)

The new common agricultural policy: 2023-27

The new common agricultural policy will be key to securing the future of agriculture and forestry, as well as achieving the objectives of the European Green Deal.

On 2 December, 2021, the agreement on reform of the common agricultural policy (CAP) was formally adopted. The new legislation, which is due to begin in 2023, paves the way for a fairer, greener and more performance-based CAP.

It will seek to ensure a sustainable future for European farmers, provide more targeted support to smaller farms, and allow greater flexibility for EU countries to adapt measures to local conditions.

Targeted support

Flexibility to adapt measures to local conditions

Geospatial “personalization”

What we need?

“Sustainably Intense”
Agricultural Planning

Farming context

Farming context

Causal Machine Learning

Personalized advice on sustainable, most impactful policy measures

Ecosystem Services
GHG emissions
Soil Organic Carbon (SOC)

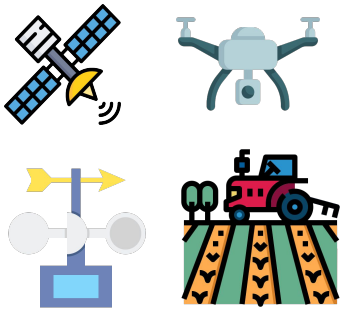
Crop rotation
No tillage
Eco-friendly practices

What data do we have for this problem?

Data

Earth Observation data are constantly improving in terms of quality and volume

Coupled with other geospatial data sources they provide useful agro-environmental info



Soil
Climate
Practices
Reanalysis Data
Farmer Declarations

Conditional Average Treatment Effects (CATEs)

What is the impact of a treatment for a unit with particular characteristics?

Eco-Friendly Practice  Field  Agro-environmental info 

$$\theta(x) = \mathbb{E}[Y(1) - Y(0)|X = x]$$

Potential SOC when practice is applied

Potential SOC when practice is not applied

Outcome Y: Soil Organic Carbon Content (field-level)
Treatment T: Eco-friendly practice (field-level)
Characteristics X: Crop, soil, climate info (field-level)*

Double ML (Chernozukov et. al, 2016)

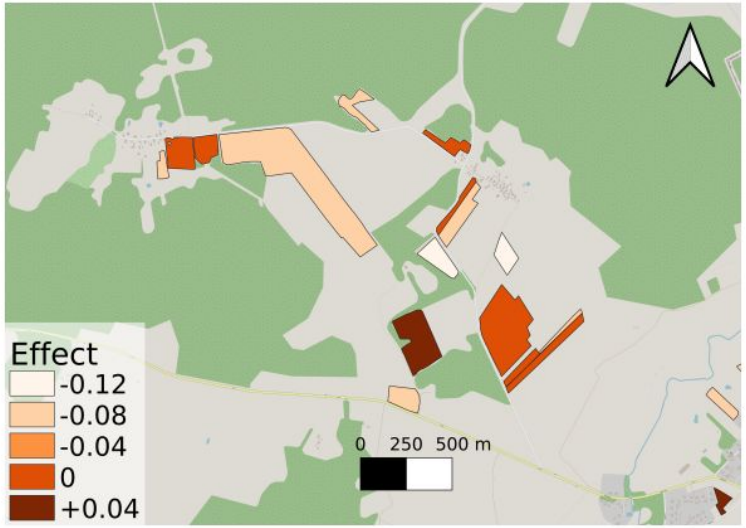
- Flexible framework for CATE estimation
- Robust for spatial data [1]

$$Y = \theta(X) \cdot T + g(X) + \varepsilon$$
$$T = f(X) + \eta$$
$$\hat{\theta} = \arg\min_{\theta \in \Theta} \mathbb{E}\left[(\tilde{Y} - \theta(X) \cdot \tilde{T})^2\right]$$

[1] *Approaches to spatial confounding in geostatistics*, Gilbert et al., 2022

Preliminary Results

(Lithuania, 2017-2021)



Color coded CATE point estimates for selected fields

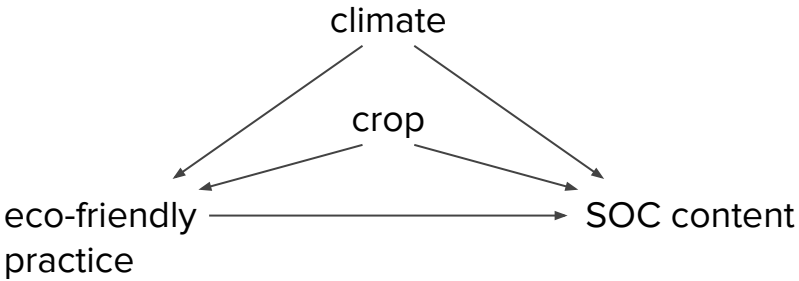
Conditional Average Treatment Effects			
Crops	PP	SP	WW
Point Estimate	0.06	-0.08	-0.09
Standard Error	0.14	0.17	0.28
Z-score	0.41	-0.44	-0.32
P-value	0.69	0.66	0.75
95% CI (Lower)	-0.22	-0.42	-0.63
95% CI (Higher)	0.34	0.26	0.45

CATE point estimates and associated uncertainty

PP = Perennial Pastures, SP = Simple Pastures, WW = Winter Wheat

The impact of eco-friendly practices on SOC content (WIP)

Limitations & Future Work

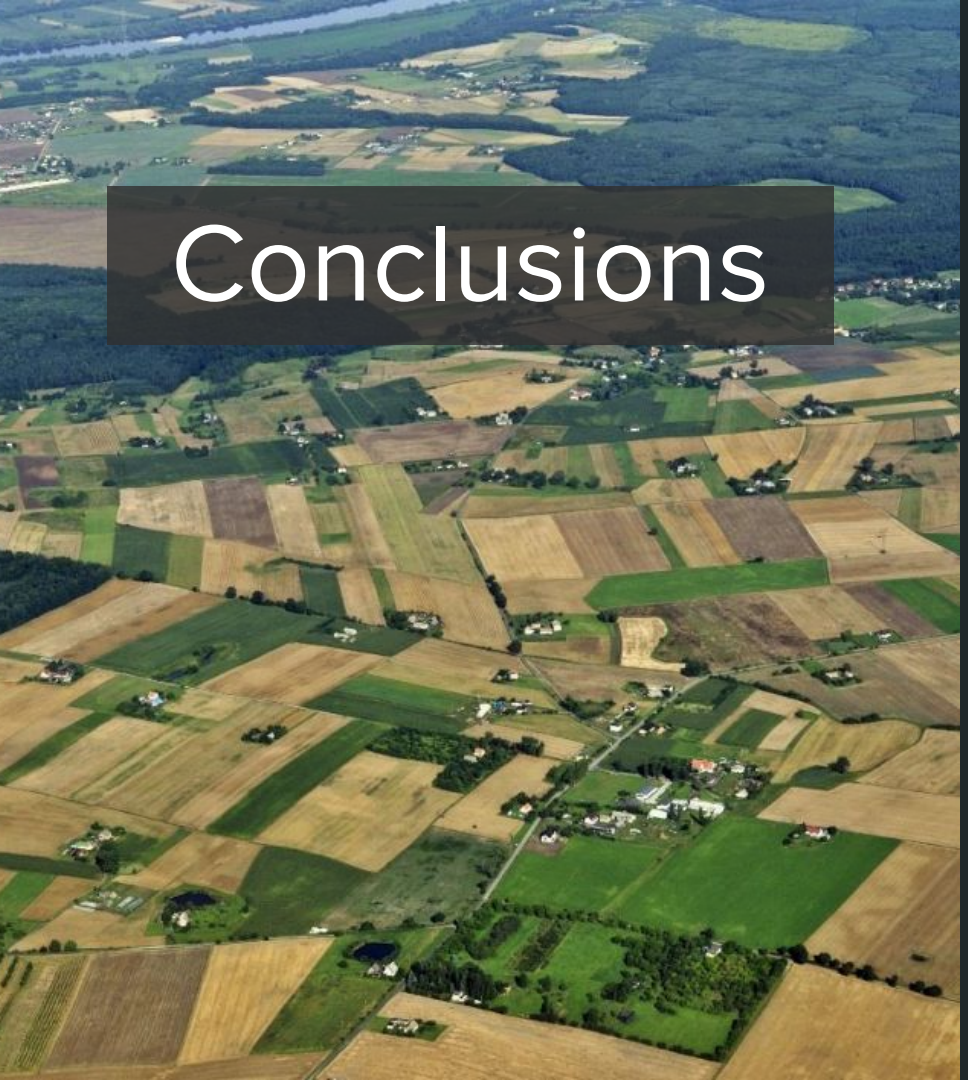


The causal graph assumed thus far is simplistic, bias in estimates exists

Slowly changing soil properties require the expansion of the time window considered

Did farmers self-select into the treatment? Interference or unobserved confounding?

Robustness checks and sensitivity analyses should be performed for validating results



Conclusions

Proposing causal machine learning for efficiently uplifting green metrics and personalizing sustainable agriculture

Ever-increasing volume and variety of Earth Observation data enables extraction of actionable insights on large scales

But: be wary of limitations - how to better control sources of bias?

Thank you!

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