Synthetic Control Method for Carbon Tax Effectiveness Evaluation in British Columbia

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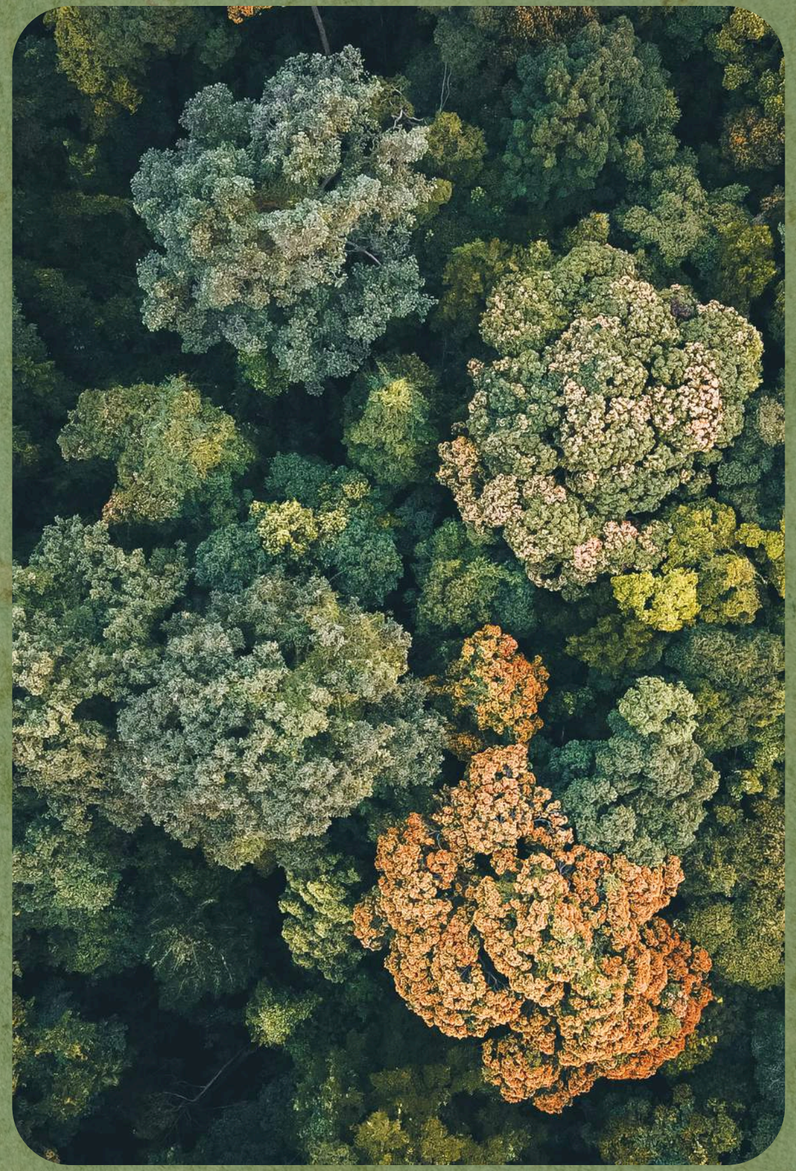


Introduction

Carbon Tax

Place a price on GHG emissions to reduce emissions

British Columbia

- British Columbia implemented carbon tax in **2008** and it was the first state to implement it in North America
- The tax covers nearly 80% of GHG emissions
- In 2008: 10 CAD per ton of emission
  In 2024: 80 CAD per ton of emissions

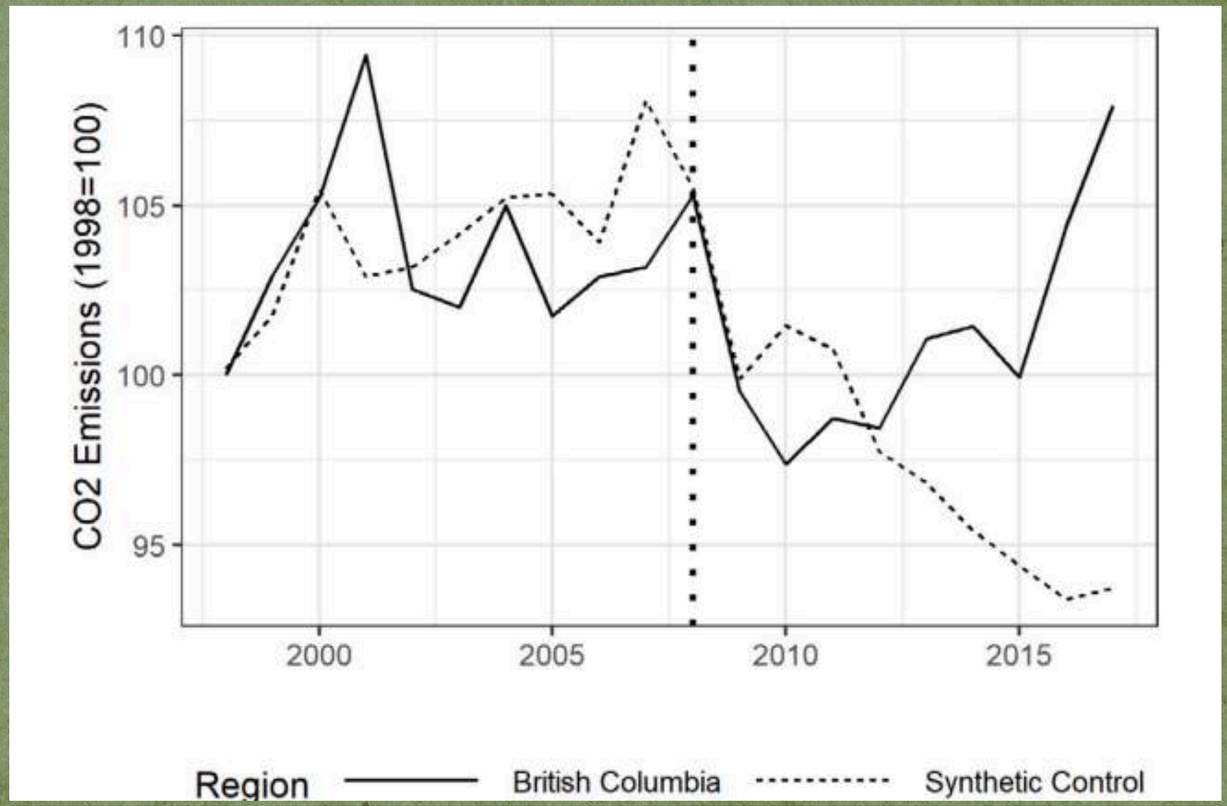
Previous Study

Arcila & Baker (2022) and Pretis (2022) examined the effect of carbon tax on CO2 emissions using the **synthetic control method**

Main Findings

Arcila & Baker (2022): CO2 emissions and fossil fuel consumption have risen in BC

Pretis (2022): Carbon tax has not led to large statistically significant CO2 emissions reduction in BC



ATT = **4.0**

Research Gap & Aim of our study

Some arbitrary decisions

- How covariates are selected
- Time points for pre-treatment

Permutation test with a small samples

- Permutation test used in Pretis (2022) not very informative due to low power (p-value = 1)

To explore the effect of carbon tax on CO_2 emissions in British Columbia, using the synthetic control with some improved methods

Methodology

Cross-Validation

Determine which covariates to include in the synthetic control by their predictive power using cross validation (Abadie 2021)

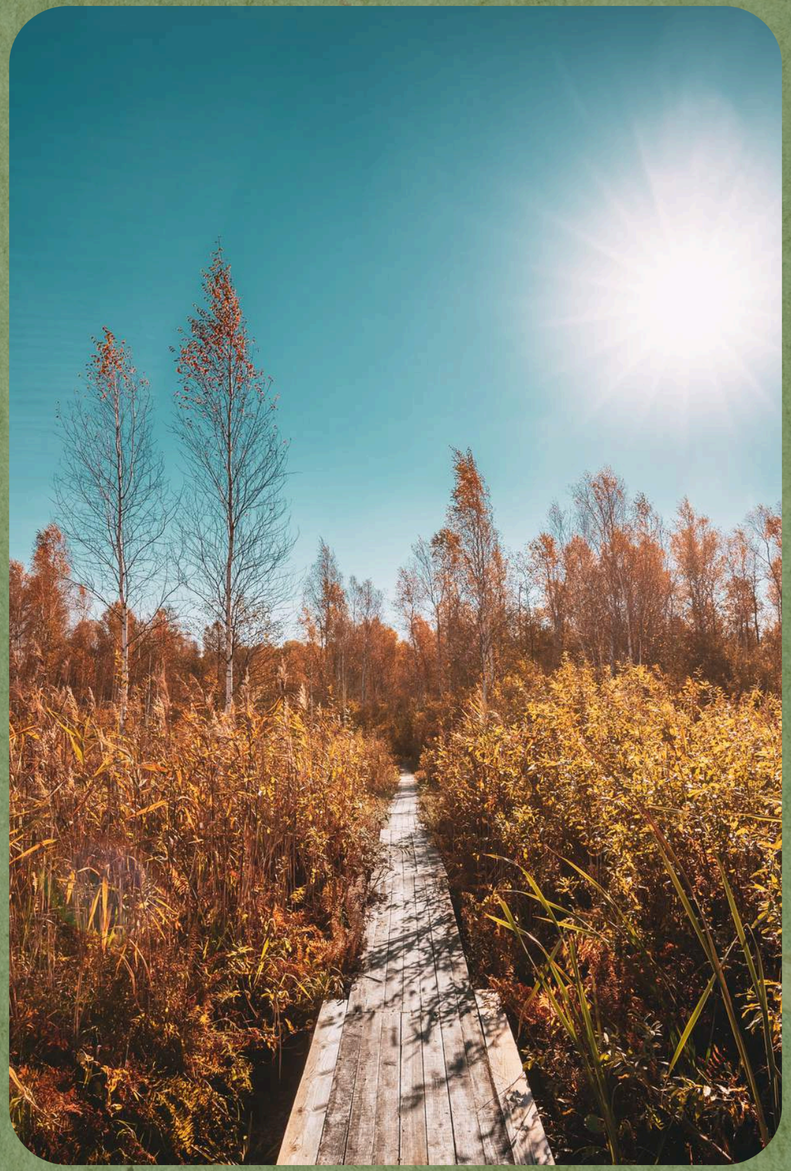
T-test

Examine significance of ATT using t-test on k-fold cross-validation performances (Chernozhukov 2018)

Generalized SCM

Compare t-test results with generalized synthetic control methods (Xu 2017)

Results



1. Predictor selection via cross-validation

Outcome: Annual emission index (1998:2017)
Treatment: Carbon tax (2008)

Predictors (Arcila 2021)

- Emission index (2000)
- Emission index (2004)
- Emission index (2008)
- Average GDP growth (1998:2008)
- Average unemployment rate (1998:2008)
- Log population (2008)
- % employment in energy industry (2008)

Lagged outcomes

Economic covariates

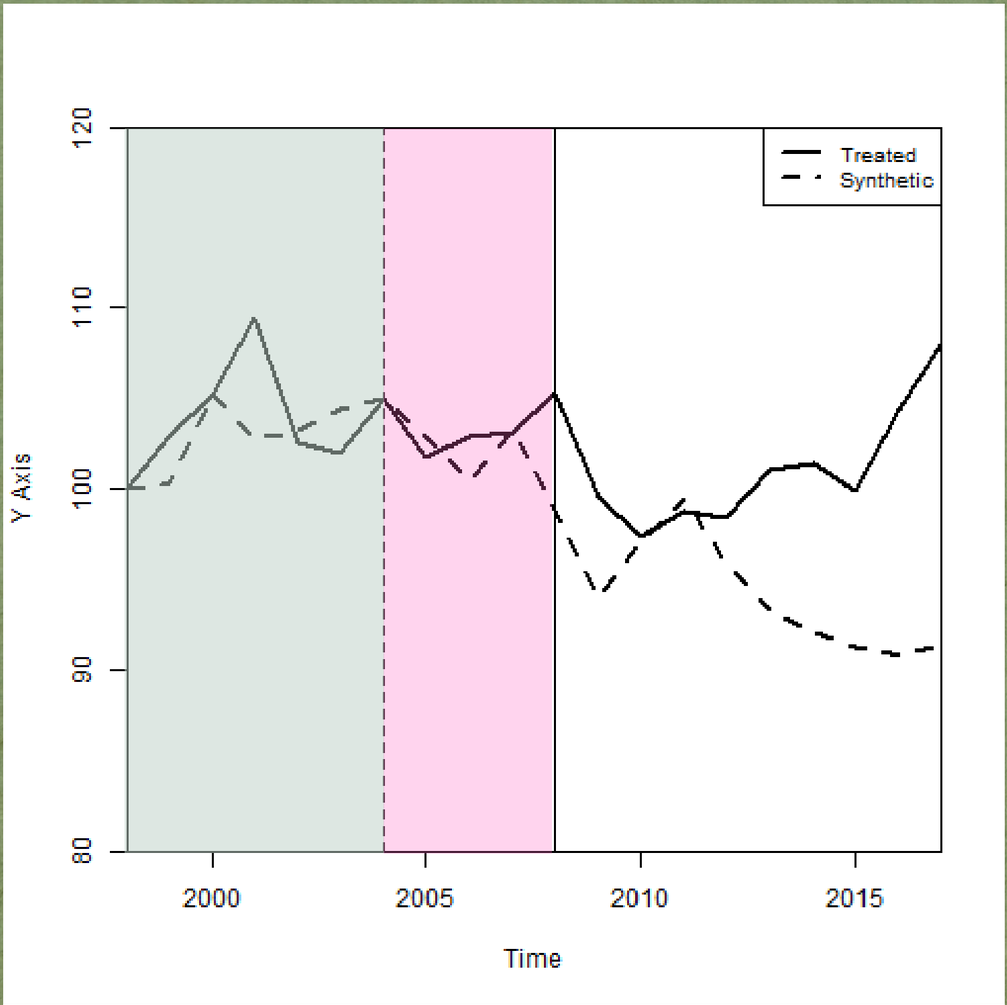
Other covariates

Modified predictors (ours)

2008 → 2007: ATT increases from 4.56 to **6.23**

1. Predictor selection via cross-validation

Training period | Validation period



Lagged outcome types

- **all**: 1999:2003
- **first_mid_last**: 1999, 2001, 2003
- **last**: 2003
- **mean**: average across 1998:2003

Additional covariate types

- **none**: no additional covariates
- **econ**: economic covariates
- **all**: economic + other covariates

1. Predictor selection via cross-validation

Training RMSPE	*Additional covariate type*		
Outcome type	none	econ	all
all	0.01	0.02	0.02
first_mid_last	0.47	0.08	0.53
last	3.75	2.67	2.55
mean	3.24	2.64	2.08

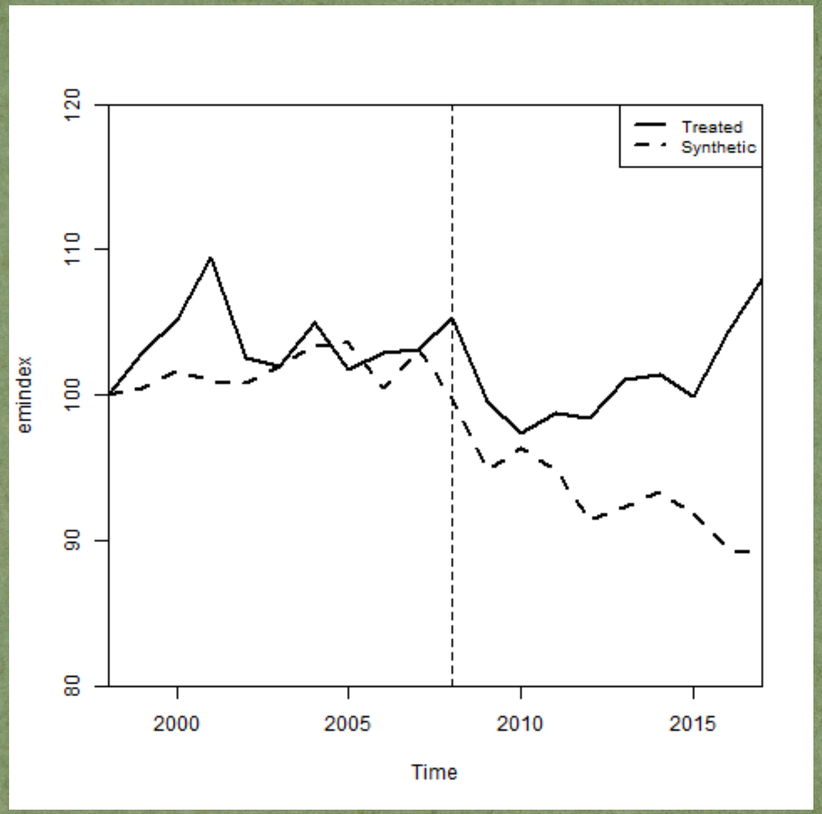
More lagged outcomes tend to overfit the synthetic control (low training but high validation RMSPE, Kaul 2022)

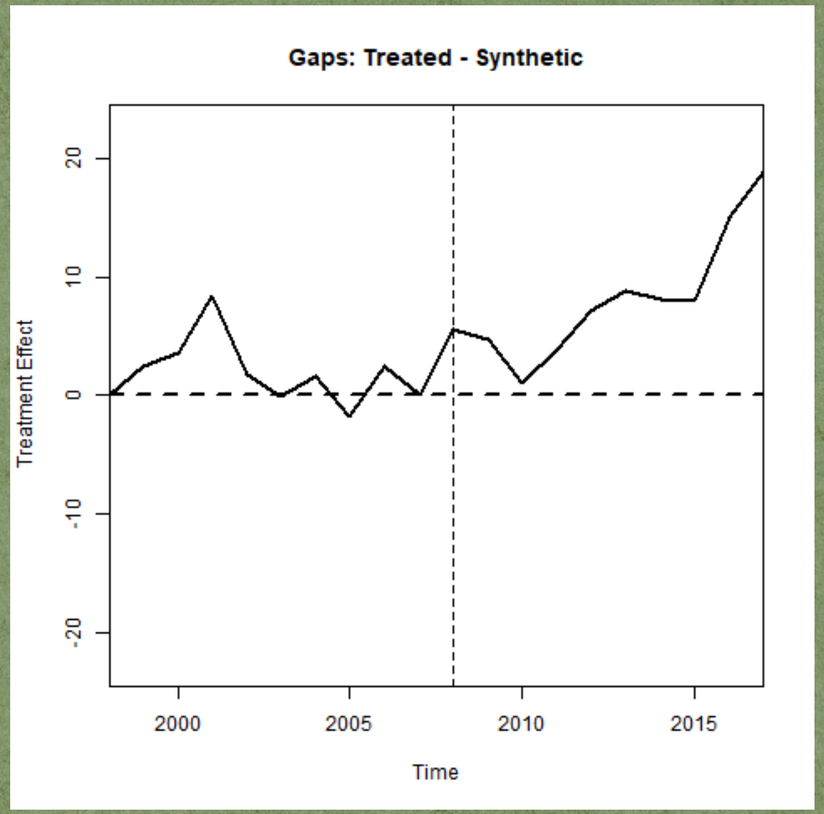
Validation RMSPE	*Additional covariate type*		
Outcome type	none	econ	all
all	3.50	3.49	3.48
first_mid_last	3.26	3.74	1.84
last	1.60	1.94	2.69
mean	3.98	3.33	4.41

More additional covriates tend to overfit the synthetic control (low training but high validation RMSPE)

Last lagged outcome + no additional covariate has the lowest validation RMSPE (1.60)

1. Predictor selection via cross-validation

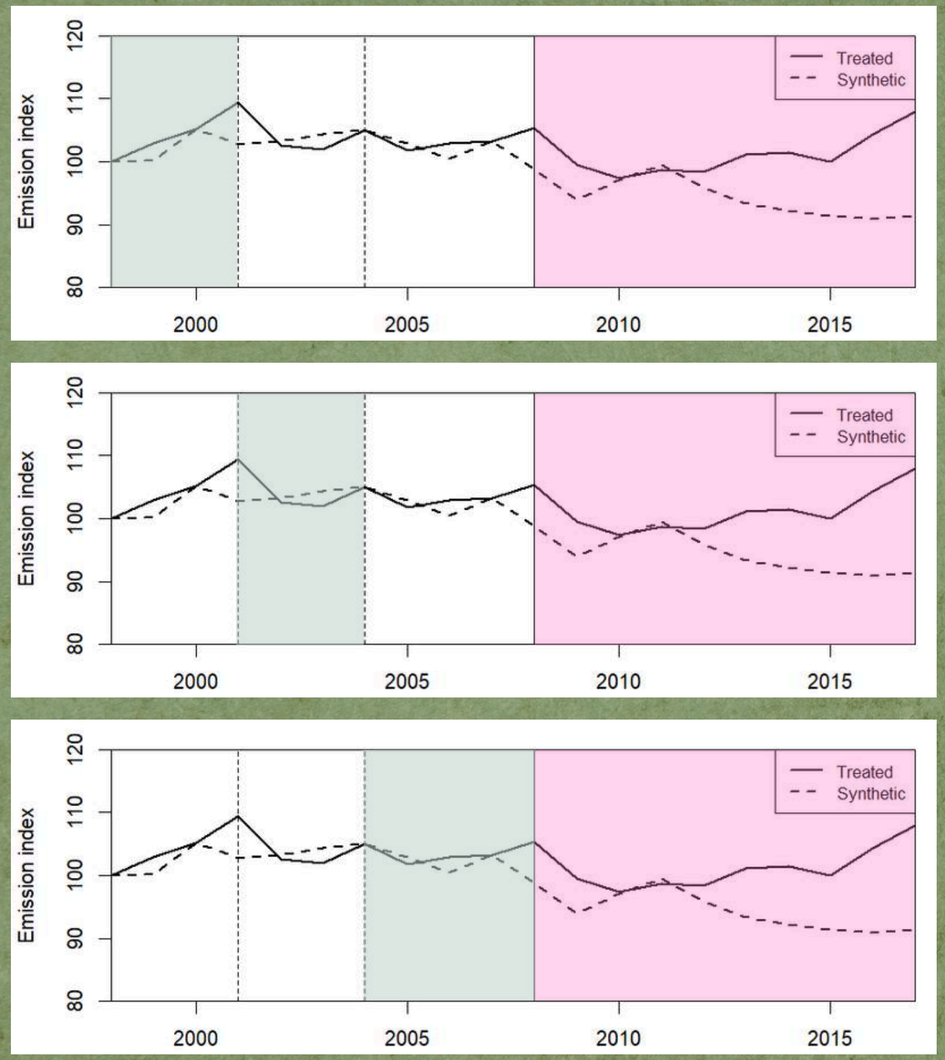




ATT = 6.28

(vs 6.23 with original predictors)

2. Effect inference with t-test



ATT

5.84

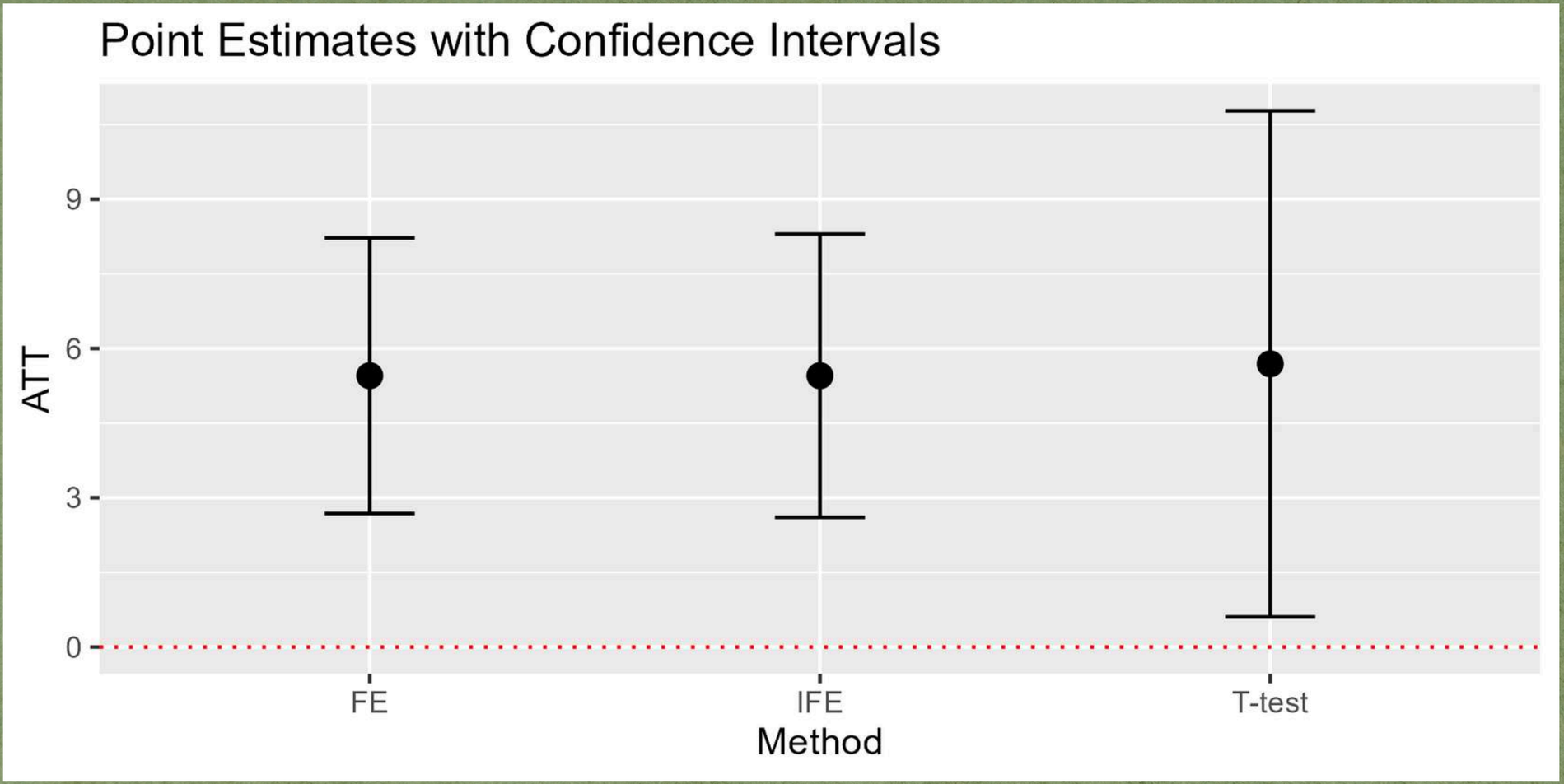
3.66

7.56

5.69

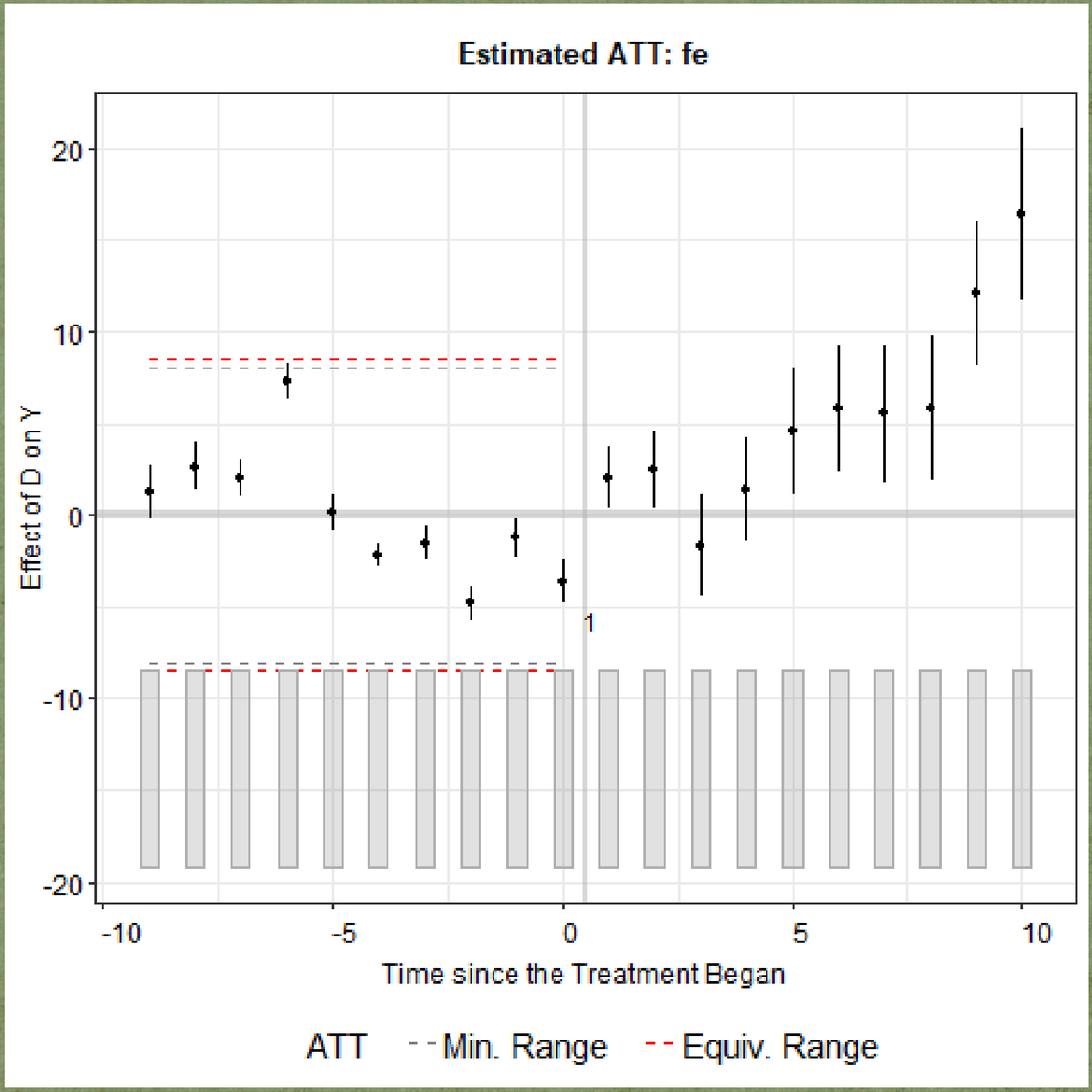
p-value = 0.037

3. Compare result with generalized SCM



t-test ATT estimate is consistent
with fixed effect & interactive fixed effect estimates

3. Compare result with generalized SCM



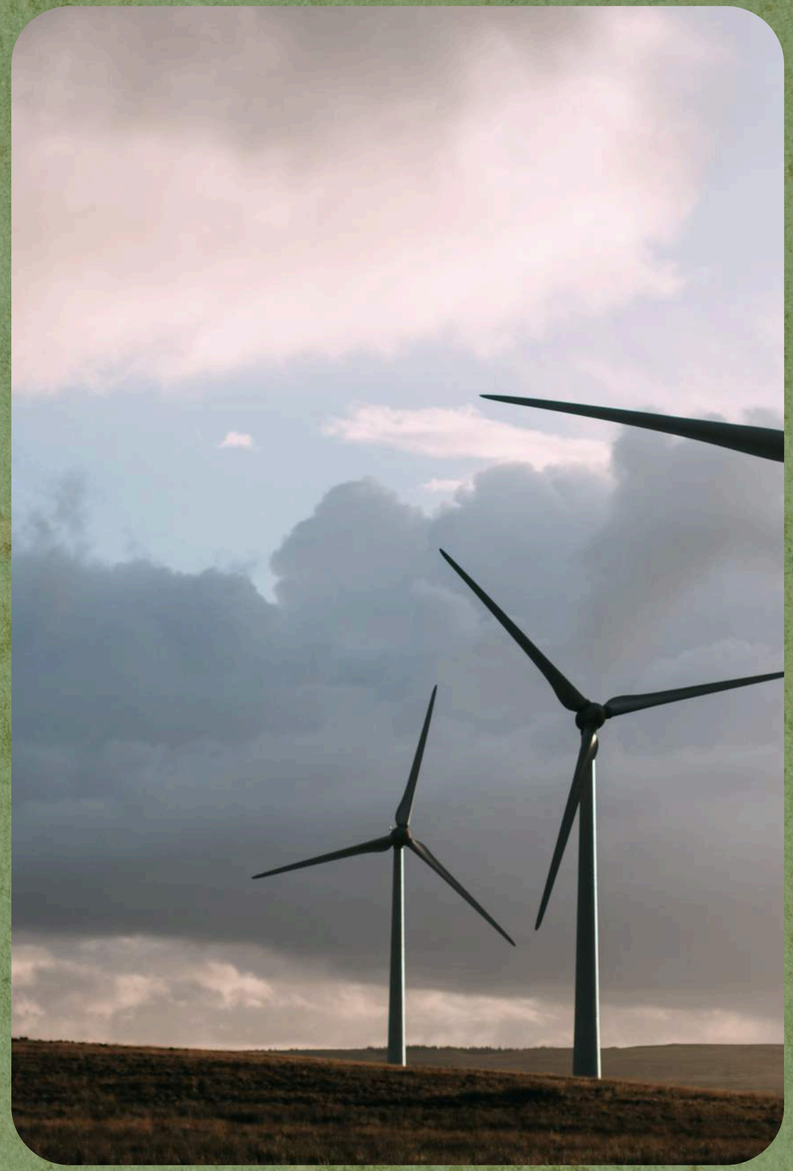
While there are some **parallel trend violations** from ATT of placebo treatments, they are **not large enough** to negate the significant positive ATT of the actual treatment

Conclusions

- **Synthetic control with last lagged outcome** (emission index at 2007) & **no additional covariates** have the best predictive power (lowest validation RMSPE)

- t-test with 3-fold cross-validation shows a **statistifically significant ATT of 5.69** (indexed on 1998 emissions) from carbon tax on CO_2 emission in BC

- This result is **consistent with treatement effects from generalized SCM methods** (fixed effects & interactive fixed effects)



Future Studies

Repeat study with **more pre-treatment periods**

Explore & validate **other covariates**

2 stage optimization of synthetic control
to minimize both training & validation RMSPE
(Klößner 2015)

Reconcile results of the 2 studies on statistical significance of the effect of carbon tax

References

Abadie, A. (2021). Using Synthetic Controls: Feasibility, Data Requirements, and Methodological Aspects. In Journal of Economic Literature (Vol. 59, Issue 2, pp. 391–425). American Economic Association. https://doi.org/10.1257/jel.20191450

Arcila, A., & Baker, J. D. (2022). Evaluating carbon tax policy: A methodological reassessment of a natural experiment. In Energy Economics (Vol. 111, p. 106053). Elsevier BV. https://doi.org/10.1016/j.eneco.2022.106053

Chernozhukov, V., Wuthrich, K., & Zhu, Y. (2018). A t-test for synthetic controls (Version 8). arXiv. https://doi.org/10.48550/ARXIV.1812.10820

Kaul, A., Klößner, S., Pfeifer, G., & Schieler, M. (2021). Standard Synthetic Control Methods: The Case of Using All Preintervention Outcomes Together With Covariates. In Journal of Business & Economic Statistics (Vol. 40, Issue 3, pp. 1362–1376). Informa UK Limited. https://doi.org/10.1080/07350015.2021.1930012

Klößner, S., Kaul, A., Pfeifer, G., & Schieler, M. (2018). Comparative politics and the synthetic control method revisited: a note on Abadie et al. (2015). In Swiss Journal of Economics and Statistics (Vol. 154, Issue 1). Springer Science and Business Media LLC. https://doi.org/10.1186/s41937-017-0004-9

Pretis, F. (2022). Does a Carbon Tax Reduce CO2 Emissions? Evidence from British Columbia. In Environmental and Resource Economics (Vol. 83, Issue 1, pp. 115–144). Springer Science and Business Media LLC. https://doi.org/10.1007/s10640-022-00679-w

Xu, Y. (2017). Generalized Synthetic Control Method: Causal Inference with Interactive Fixed Effects Models. In Political Analysis (Vol. 25, Issue 1, pp. 57–76). Cambridge University Press (CUP). https://doi.org/10.1017/pan.2016.2

Thank you