# Analyse contrefactuelle de l'application d'une taxe carbone en Grande Bretagne sur le secteur électrique

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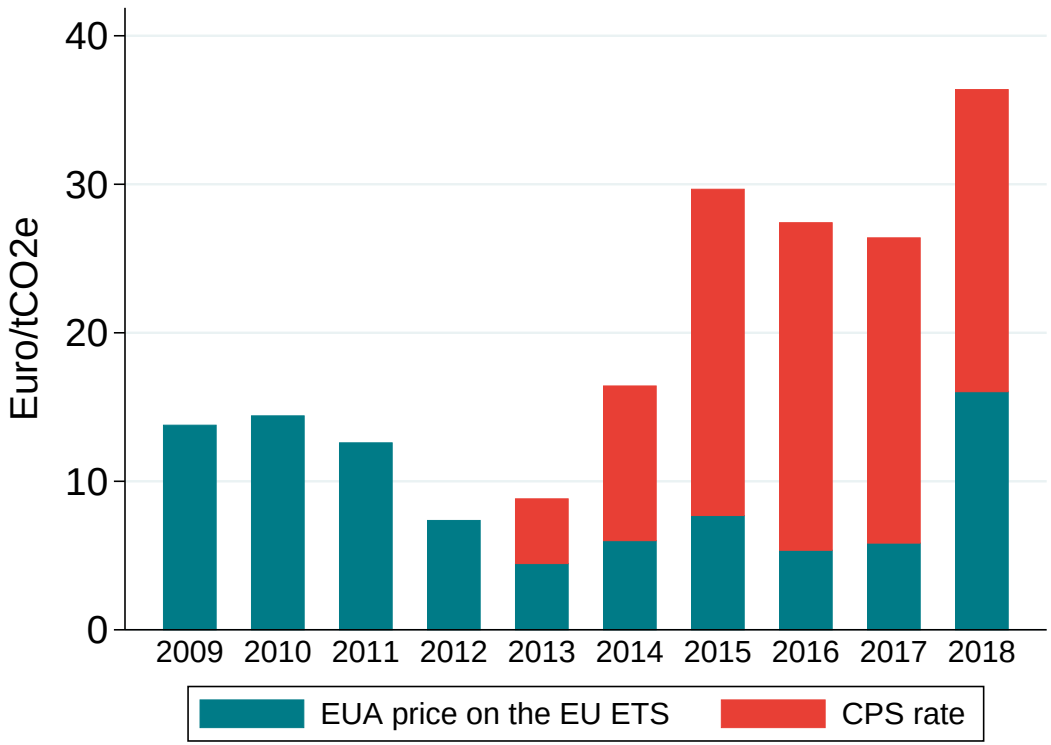
# Motivation

- **Recent development of carbon markets and taxes** across the world in an attempt to curb global GHG emissions
- Typically cover the **electricity and heat production sector**, which represent 25% of worldwide emissions (IPCC 2014)
- **But few ex-post evaluations** isolating causal impact of carbon pricing on abatement in the power sector
  - in the EU [Ellerman and McGuinness, 2008]; [Martin et al., 2016]; [Abrell et al., 2019]

# The UK Carbon Price Support

- **Context**:
  - Low prices on the European carbon market
  - UK facing binding Carbon Budget targets
- **April 2013**: Carbon Price Support implemented in the *GB power sector* CPS rates in pound/tCO2e CPS rates by input fuel



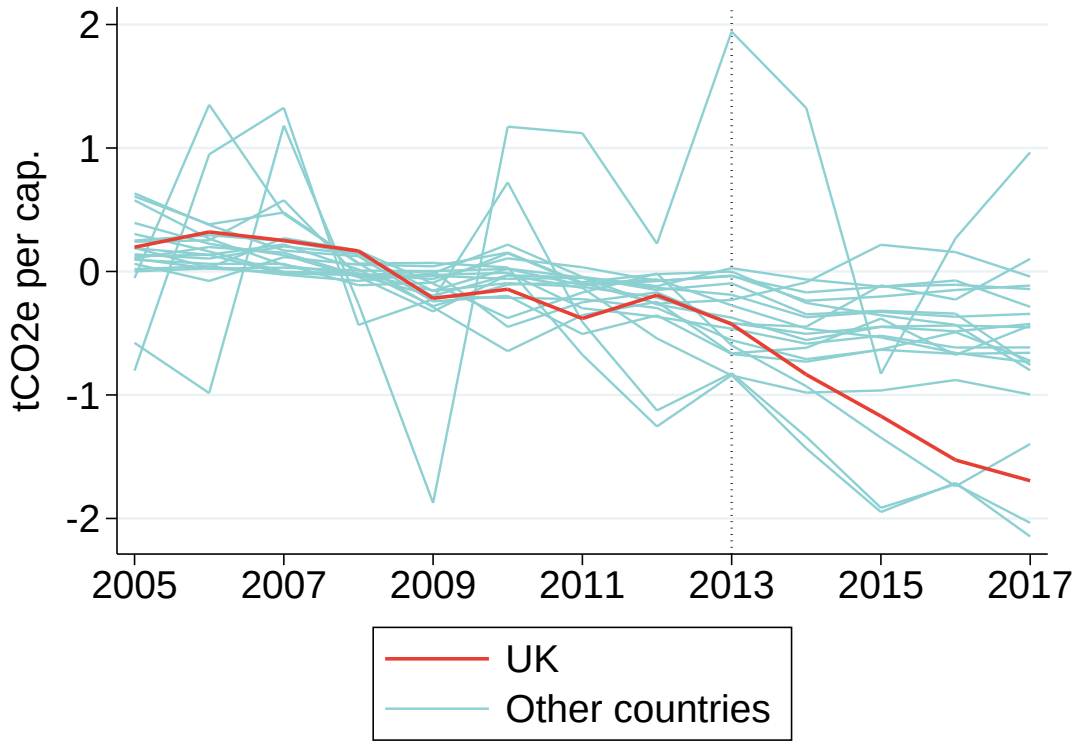
# This paper

- **What is the impact of the UK Carbon Price Support on CO2e abatement**? $\rightarrow$ Synthetic Control Method (SCM) (Abadie et al 2003)
- **What are the mechanisms at play?**

# A strong decrease in emissions from UK power installations

- Main outcome=per capita emissions in the UK power sector

Figure: Demeaned per capita emissions, UK and other countries




- Non-power installations | Absolute power emissions | Outliers visible

# What happened?

- 3 main possible channels:
  1. $\downarrow$ in domestic demand ?
  2. $\uparrow$ in net imports ?
  3. $\downarrow$ in the emission intensity of domestic production ?

# What happened?

- 3 main possible channels:
  1. $\downarrow$ in domestic demand ? **A little** Graph
  2. $\uparrow$ in net imports ? **Not really** Graph
  3. $\downarrow$ in the emission intensity of domestic production ? **YES** Graph

# Estimation strategy: Synthetic Control method

- **Synthetic control method (SCM)** = Build a counterfactual UK power sector using a weighted combination of other European countries [Abadie and Gardeazabal, 2003]
- **Assumptions**:
  1. Outcome can be modelled as a linear factor model → more flexible than diff-in-diff
  2. $T_0$ large enough
- **Requirements**:
  1. Countries in the synthetic UK are not affected by the CPS and haven't implemented similar policies
  2. A weighting vector exists that minimizes distance between treated and synthetic units' pre-treatment characteristics and outcomes
  3. Common support assumption
- Get the right country weights with a nested optimization programme

Details Theory SCM

# SCM in practice

- **Data**
  - **Country-level balanced panel** of 21 European countries spanning 2005-2017, combining:
    1. **Emission data** from $\approx$ 5,000 power plants covered by the EU ETS (EUTL and Sandbag)
    2. **Country-level power sector characteristics** (Various sources) Details

# SCM in practice

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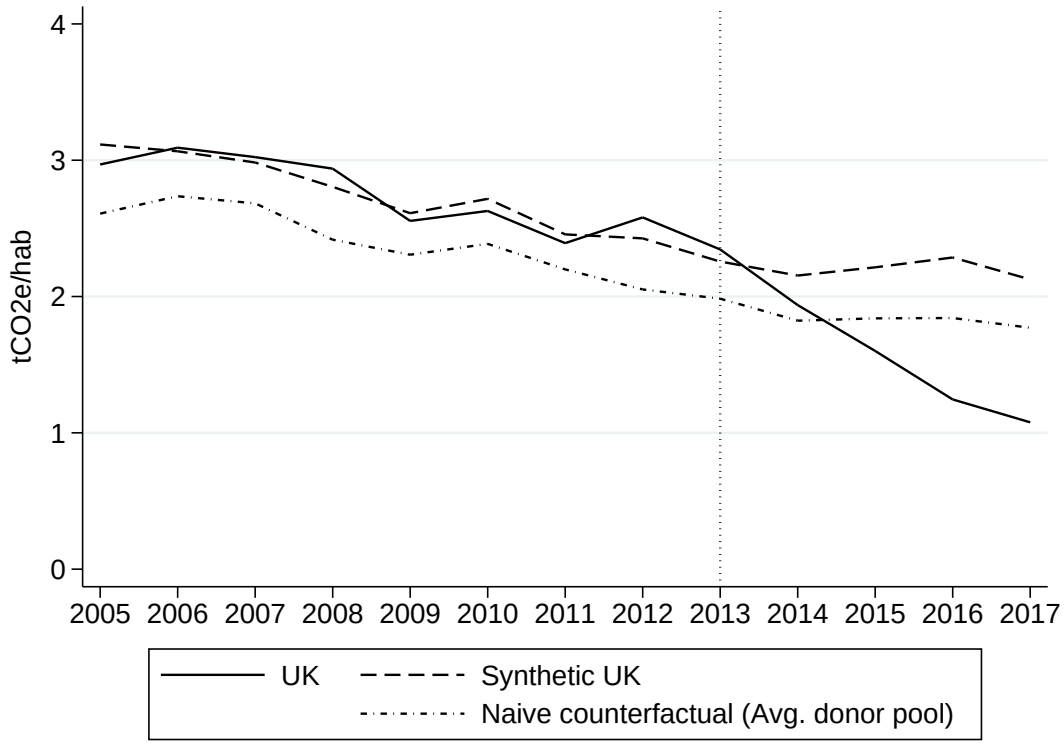
    1. **Emission data** from $\approx$ 5,000 power plants covered by the EU ETS (EUTL and Sandbag)
    2. **Country-level power sector characteristics** (Various sources) Details
- **Donor pool**: restricted to 15 countries
- **Predictors**: 4 variables predicting power sector emissions + 2 lags of the outcome
  - **Coal-to-gas price ratio** affecting fuel switching potential and its squared
  - Dummy for large **lignite** reserves
  - **Per capita residual load**= Demand to be covered by combustible fuels
  - 2009 Amount of emissions coming from installations **expected to shut down** due to an EU air quality regulation (LCP directive)

# SCM main estimate of abatement

Figure: Per capita $CO_2e$ emissions in the power sector, UK and synthetic UK




- Total cumulated abatement of **185 millions of $tCO_2e$** over 2013-2017 (2017: - **49%** in the UK vs synthetic UK)
- Synthetic UK = Ireland (51.3%), Slovakia (25.7%), the Netherlands (11.1%), Finland(6.3% ) and Czech Republic (5.5%)

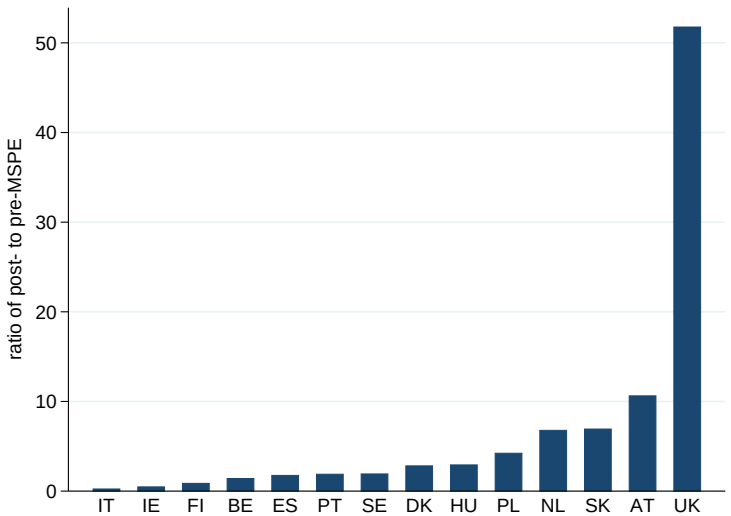
Predictors'weights

# Inference: permutation test

- Run placebo study where SCM is applied to every potential control country

Figure: Permutation test


(a) Permutation test w/o outliers




(b) Ratio of post to pre-MSPE

$\rightarrow$ Probability of $1/14 = 7.14\%$ to observe an effect as large as the one observed for the UK under a random permutation of the intervention

In-time placebo

# Potential confounders

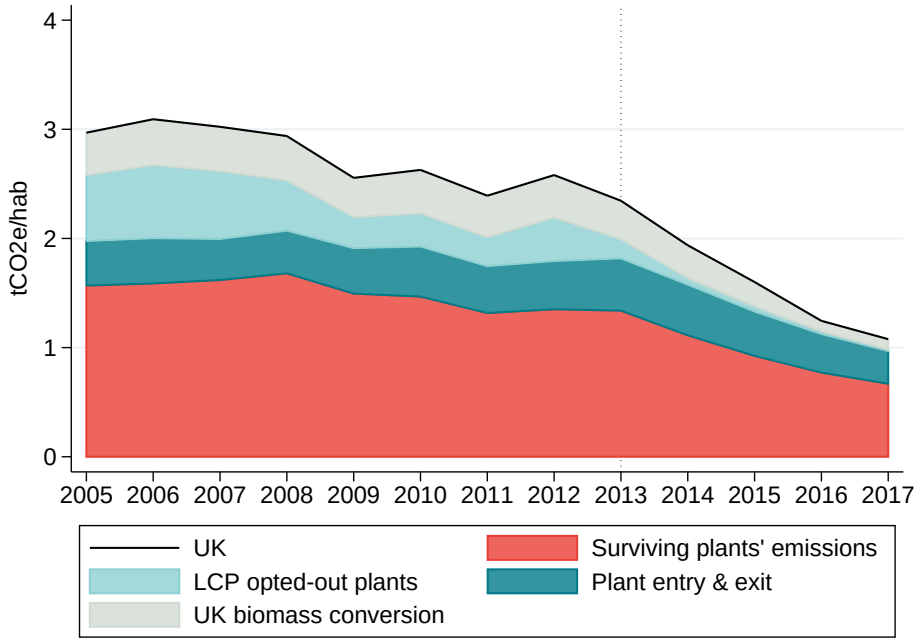
1. **EU-level air quality regulation** (LCP directive) inducing plant closure between 2012 and 2015 (although) account for this risk in the set of predictors Details
2. **UK policy** to encourage coal-fired plants' conversion to biomass

$\rightarrow$ lower bound of the impact without those plants' emissions Details

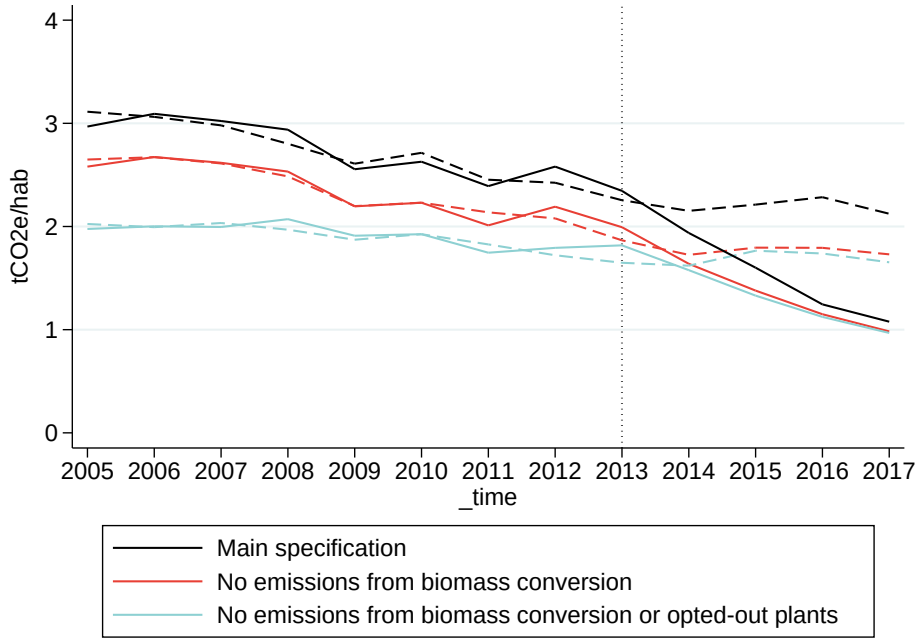
# Lower bound estimate

- Re-run SCM on country-level emission data w/o emissions from LCP-opted out plants and plants converted to biomass
- Abatement decreases to **106 $\mathbf{MtCO_2e}$** over the 2013-2017 period (116$MtCO_2e$ when keeping emissions from opted-out plants)

(a) UK emissions decomposed




(b) SCM w/o emissions from biomass and LCP opt-outs



# Robustness checks

Test the sensitivity of the method to:

1. The **risk of spillovers** via increased electricity exports to UK or waterbed effect → **OK** Slide
   - assessing upper bound for net imports spillovers: Slide
   - assessing upper bound for the impact of the waterbed effect Slide
2. **Anticipation** of the policy: → **some anticipation from LCP opted-out plants** Slide
3. The **donor pool** and **predictors** → **OK**
   - including Greece and Germany: Slide
   - using alternative predictors Slide

# Conclusion

- The UK Carbon Price Support is associated with an **abatement by 41 to 49% in 2017**
  - $\rightarrow$ CPS contributed to abate 45% to 79% of the abatement necessary to achieve 2nd carbon budget targets
  - tax-induced abatement cost $\approx$ €15/t$CO_2$e
- **Channels**
  - $\downarrow$ **of emission intensity** of domestic power production
  - $\approx$ **50/50** changes at the **intensive vs extensive margin** (plants' exit/non-entry)
- **Policy implications**:
  - A carbon tax in the power sector can lead to rapid decarbonisation
  - Important: limited interconnection limits negative spillovers to other countries/carbon leakage

# Conclusion

Thank you!

# References I



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New EU ETS Phase 4 rules temporarily puncture waterbed.
*Nature Climate Change*, 8:262–264.

# The UK Carbon Price Floor in practice

Table: Level of CPS rate for each period in pound per ton of CO2e (Source: [Ares and Delebarre, 2016])

| Period | CPS rate in £/tCO$_2$e |
|---|---|
| **April 2013/March 2014** | 4.96 |
| **April 2014/March 2015** | 9.55 |
| **April 2015/March 2016** | 18.08 |
| **April 2016/March 2017** | 18 |
| **April 2017/March 2018** | 18 |
| **April 2018/March 2019** | 18 |

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# The UK Carbon Price Floor in practice

Table: Level of CPS rate by input fuel for each period, in pence per fuel-specific unit

| Period | Natural Gas (p[1] per kWh) | Petroleum gas[2] (p per kg) | Coal[3] (p per GJ on GCV[4]) | Fuel oil[5] (p per litre) | Gas oil[6] (p per litre) |
|---|---|---|---|---|---|
| **2013/2014** | 0.091 | 1.146 | 44.264 | 1.568 | 1.365 |
| **2014/2015** | 0.175 | 2.822 | 81.906 | 3.011 | 2.642 |
| **2015/2016** | 0.334 | 5.307 | 156.86 | 5.730 | 4.990 |
| **2016/2017** | 0.331 | 5.28 | 154.79 | 5.711 | 4.916 |
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(Source: HM Revenue and Customs 2014, 2016 and 2017 and Envantage website: `https://www.envantage.co.uk/carbon-management/climate-change-levy-agreement/climate-change-levy-rates.html`)

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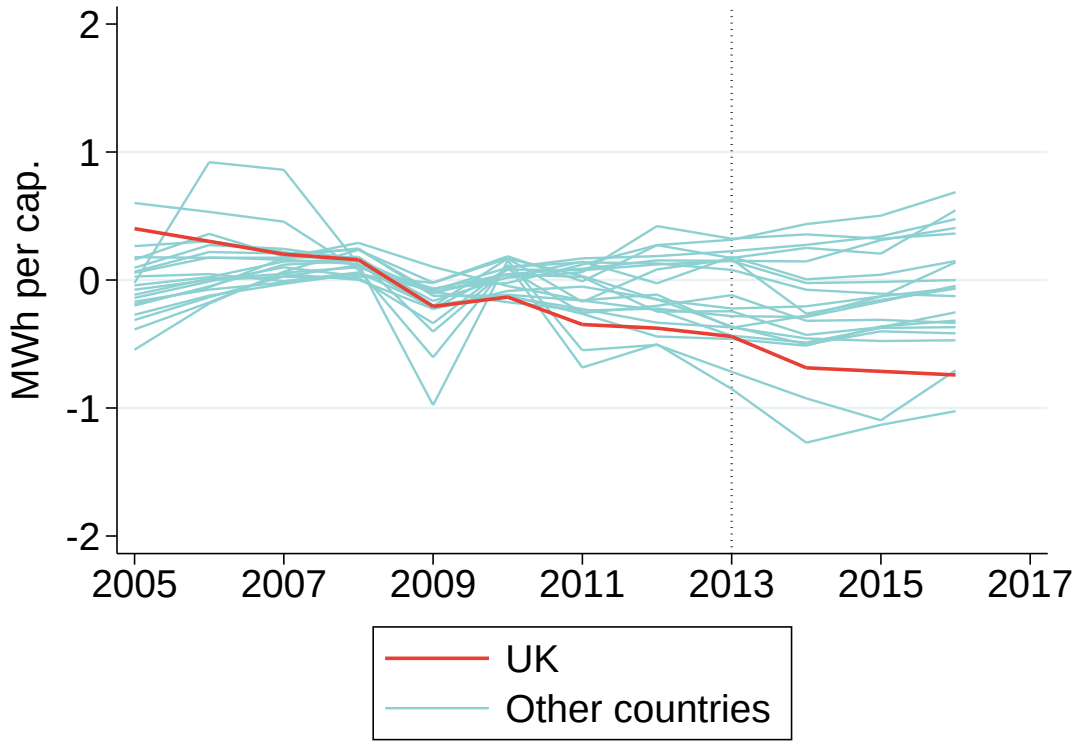
# The demand channel

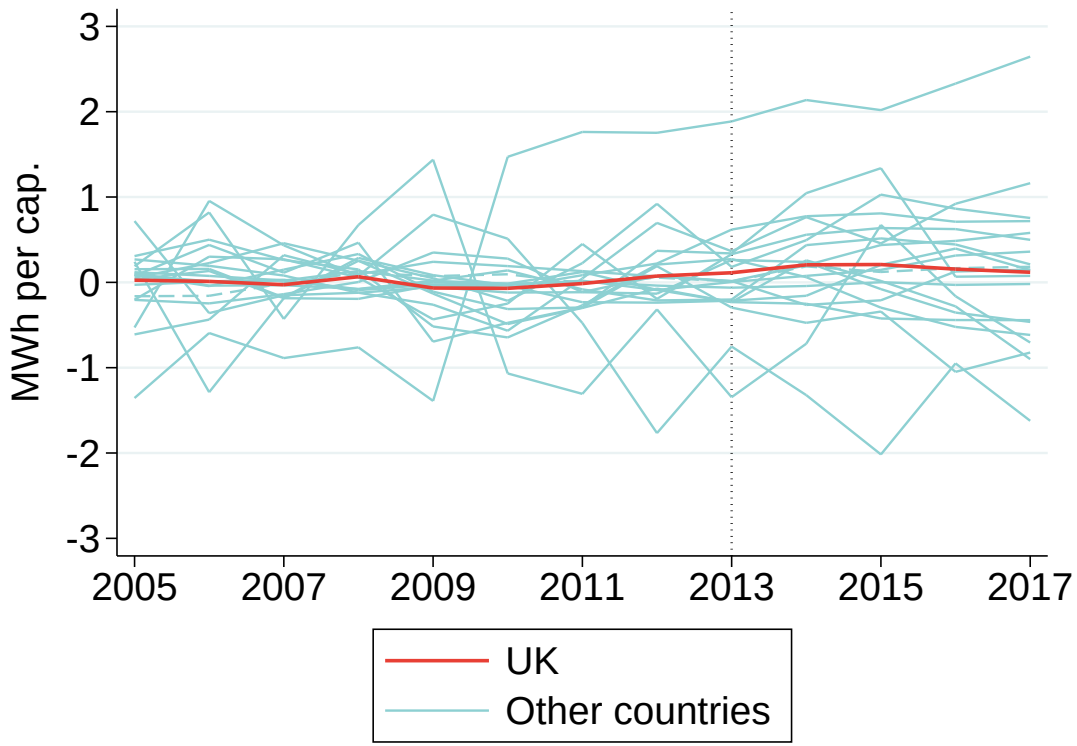
Figure: Demeaned per capita net power consumption, UK and other countries




→ A continuous decrease rather than a break in trend Back

# The trade channel

Figure: Demeaned per capita net imports, UK and other countries




$\rightarrow$ Physical constraints on electricity trading $\rightarrow$ UK share very low and stable over time compared to other countries Back

# The emission intensity channel

Figure: Demeaned CO2 intensity of gross power production


→ Likely the most important driver of de-carbonisation, driven by change in fuel mix Back Graph

# No evidence of a decrease in emissions for non-power installations

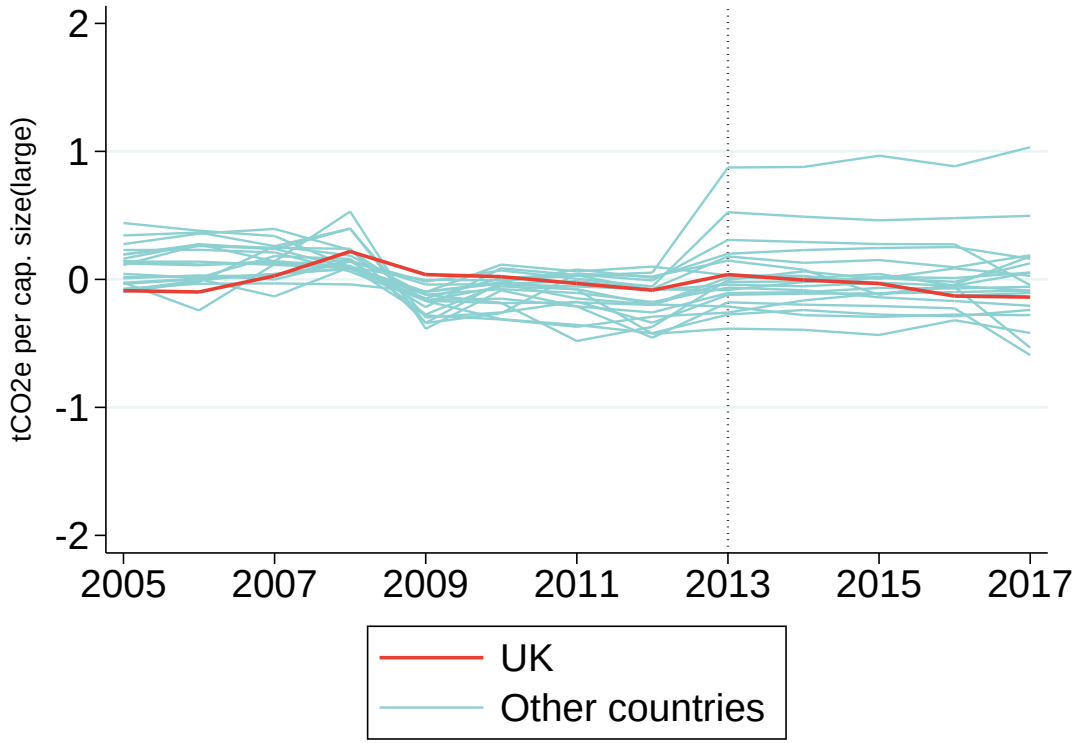



Figure: Deviation from the 2005-2012 mean for aggregate per capita $CO_2e$ emissions of non-power installations covered by the EU ETS, 2005-2017

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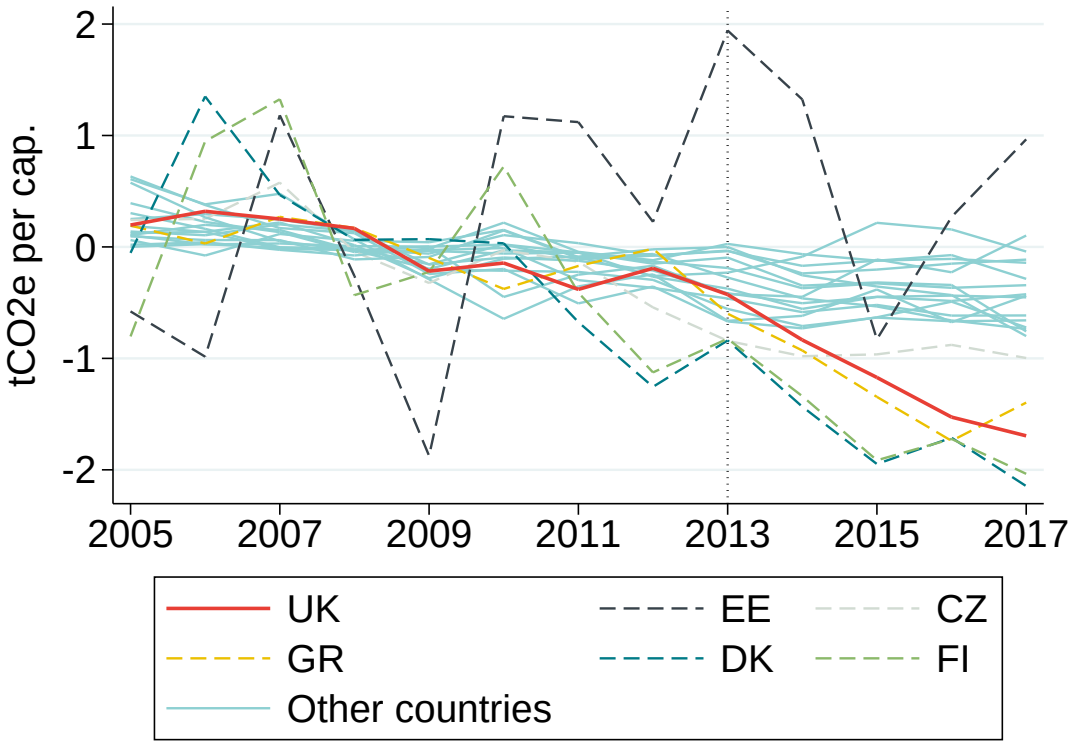
# Data sources

- **Emission data**: European Union Transaction Log for emission data of all installations covered by the EU ETS, data from the European Commission, Sandbag and Florence School of Regulation to identify power installations
- **Country-level power sector characteristics**
  - production, net imports, final consumption, number of degree days: Eurostat
  - coal and gas fuel prices: Eurostat coal trade data, Eurostat gas wholesale prices for large business consumers, and IEA energy price statistics
  - lignite resources: Industry association Euracoal
  - status regarding EU air quality regulation: Large Combustion Plant Directive database from the EEA
- Back

# A strong decrease in emissions from UK power installations

Figure: Demeaned per capita emissions, UK and other countries

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# A strong decrease in emissions from UK power installations

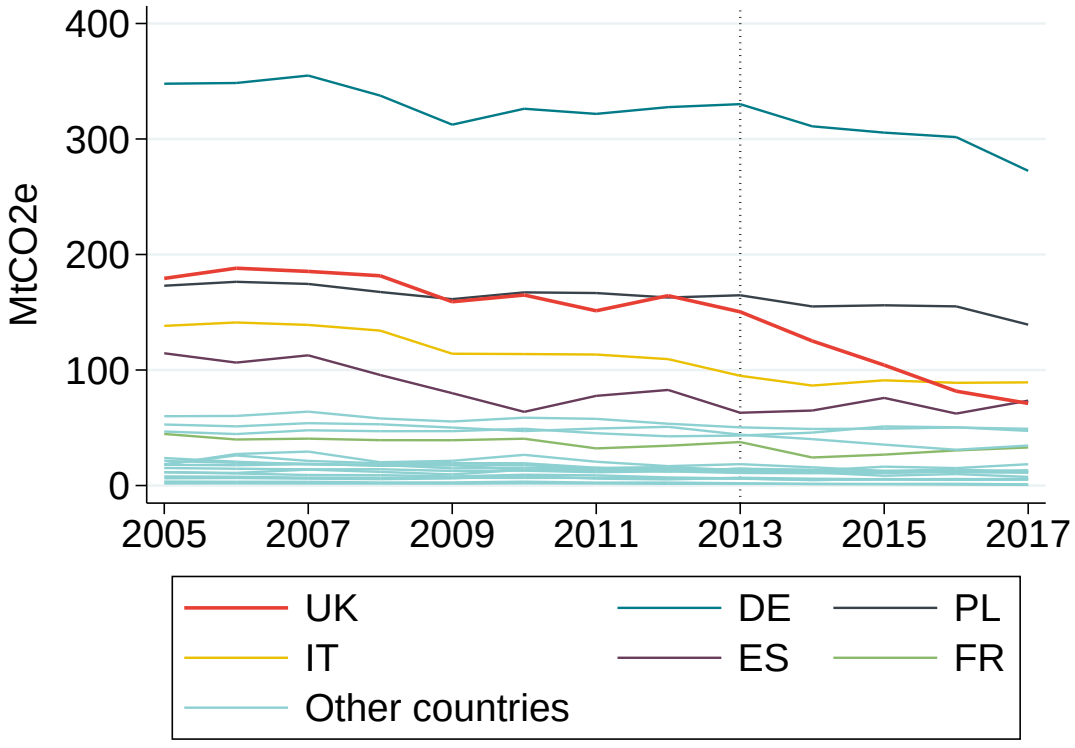


Figure: Aggregate $CO_2e$ emissions from power installations covered by the EU ETS

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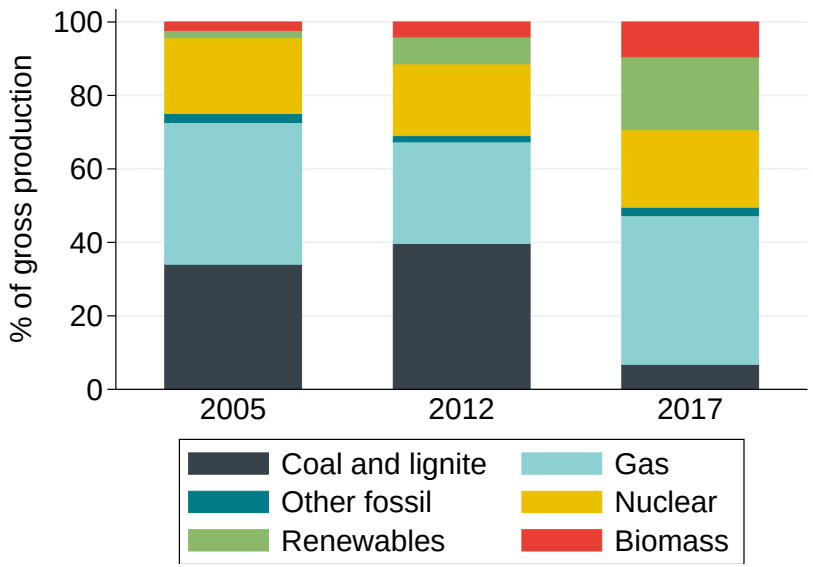
# The emission intensity channel

- Emission intensity channel can be rewritten as:

$$\frac{Q_{CO_2e}}{Q_{elec}} = \sum_i \underbrace{e_i}_{\text{emission intensity of fuel i}} \underbrace{q_i}_{\text{output produced with fuel i}} \quad (1)$$

Figure: UK power sector's input fuel mix in 2005, 2012 and 2017

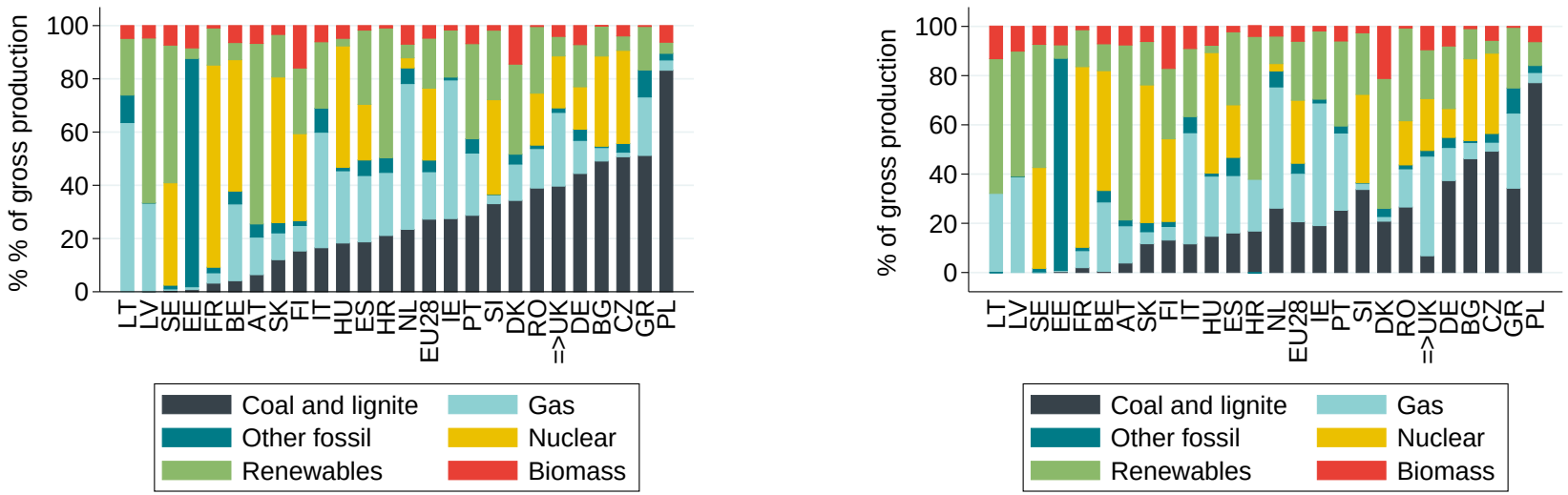



→ Strong decrease in the share of coal, compensated by an increase in gas, renewables and biomass.

Back Comparison with other countries

# The emission intensity channel

Figure: Power sector's input fuel mix in EU countries, 2012 and 2017



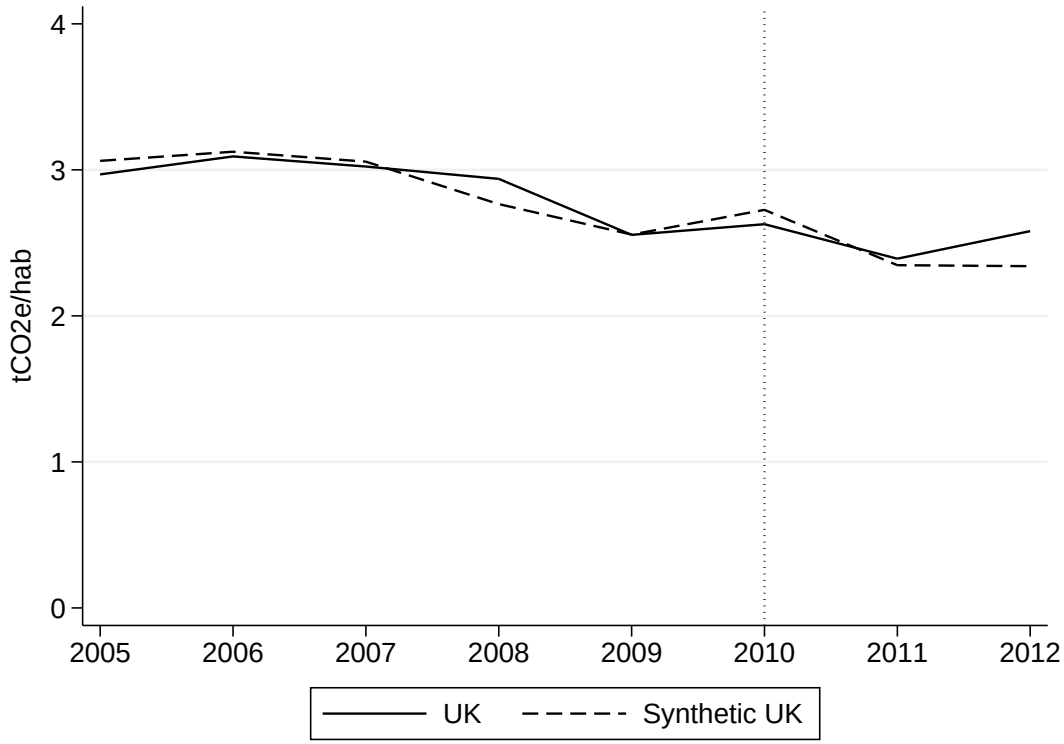

(a) 2012

(b) 2017

→ No significant change for most other countries Back

# In-time placebo test

- Assumes treatment starts in 2010 and run SCM on these new pre-treatment variables Back




$\rightarrow$ No difference between UK and synthetic UK

# SCM in theory-Estimated equation

Linear factor model:

$$Y_{ct} = \beta_{ct} T_{ct} + \delta_t + Z_{ct}\alpha + f_t' \lambda_c + \epsilon_{ct} \tag{2}$$

- $T_{ct}$: treatment dummy equal to 1 when $c = UK$ and t$\geq$2013 and 0 otherwise
- $\delta_t$: unknown common factor such as a time fixed effect
- $Z_{ct}$: vector of observed exogenous country characteristics
- $f_t$: vector of unobserved time effects or factors
- $\lambda_c$: vector of unobserved country-level effects or factor loadings
- $\epsilon_{ct}$: error term with mean 0 (unobserved transitory shocks at the country level)
- Back

# SCM in theory-Estimator of $\beta_{\mathrm{UK}t}$

Suppose:

- We have J countries, 1 treated (UK) and J-1 non-treated (the donor pool)
- $\overline{Y}^K_{\mathrm{UK}}$ is a linear combination of pre-intervention per capita power sector emissions in the UK;
- $\overline{Y}^K_j$ same for country $j$
- There exists a weighting vector $W^* = (w_1^* ... w_{J-1}^*)$ such that:

$$\sum_{j=1}^{J-1} w_j^* = 1, \tag{3}$$

$$\overline{Y}^K_{\mathrm{UK}} = \sum_{j=2}^{J} w^* \overline{Y}^K_j \tag{4}$$

$$Z_{\mathrm{UK}} = \sum_{j=1}^{J-1} w_j^* Z_j \tag{5}$$

- Then $\hat{\beta}_{\mathrm{UK}t} = Y_{\mathrm{UK}t} - \sum_{j=1}^{J-1} w_j^* Y_{jt}$ can be used as an estimator of $\beta_{\mathrm{UK}t}$ for each t$\geq$2013

# SCM in practice-Getting $W^*$

- In practice, $W^*$ is obtained by minimizing the distance between pre-treatment characteristics for the treated and weighted combination of non-treated countries ( $X_{\mathrm{UK}}$ and $X_0 W$ respectively):

$$W^* = argmin(X_{\mathrm{UK}} - X_0 W) = argmin(\sqrt{(X_{\mathrm{UK}} - X_0 W)' V (X_{\mathrm{UK}} - X_0 W)}) \tag{6}$$

- Where $V$ is a positive semi definite matrix chosen to minimize the mean squared prediction error of the outcome variable in the pre-treatment periods:

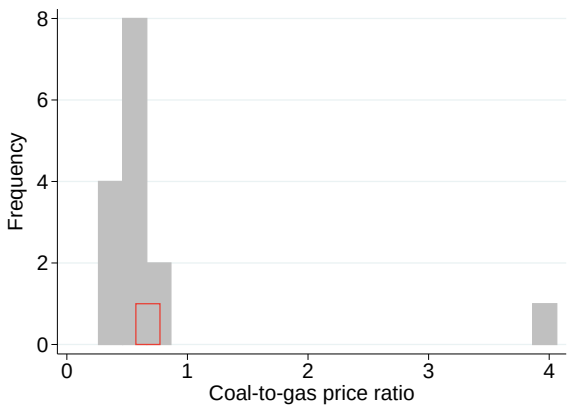
$$V^* = argmin(Y_{\mathrm{UK}} - Y_j W^*(V))'(Y_{UK} - Y_j W^*(V)) \tag{7}$$

- Back

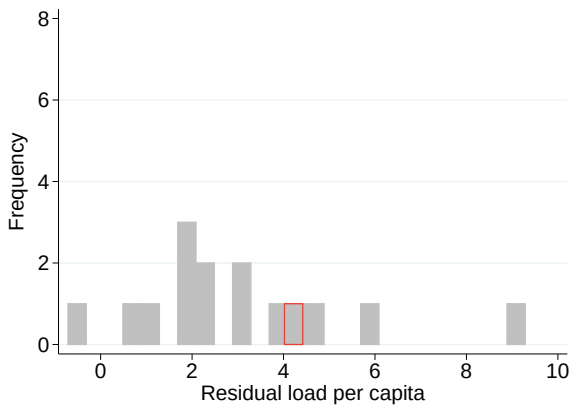
# Common support for the distribution of predictors for the UK and countries from the donor pool

- Reference year is 2010 unless stated otherwise

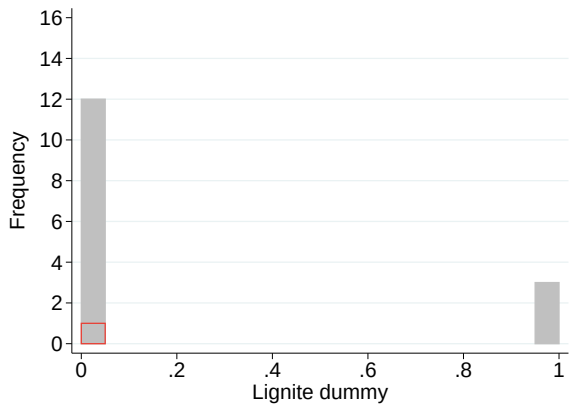
Figure: Distribution of characteristics for the UK (in red) and donor pool (in grey)




(a) Coal-to-gas price ratio



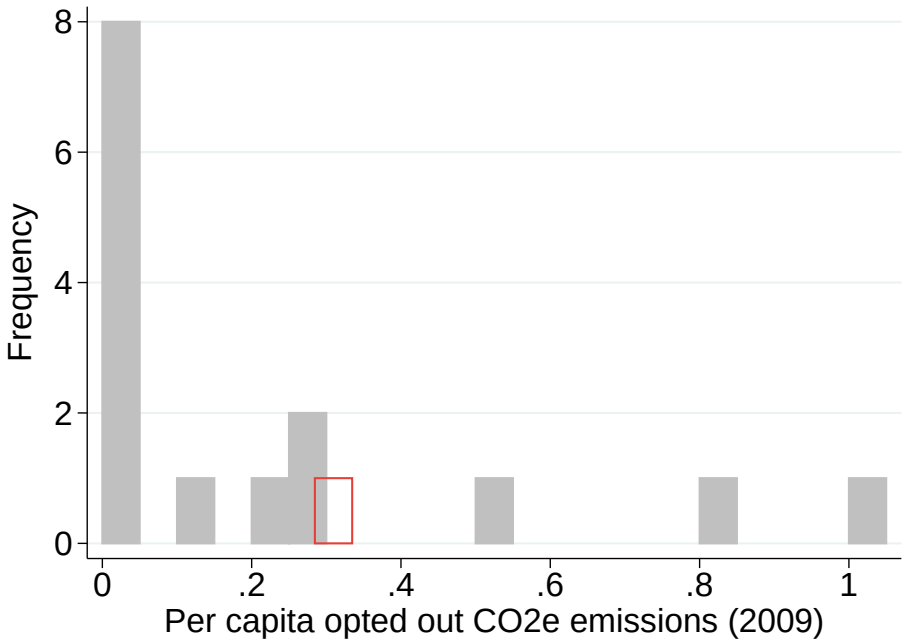

(b) Per capita residual load



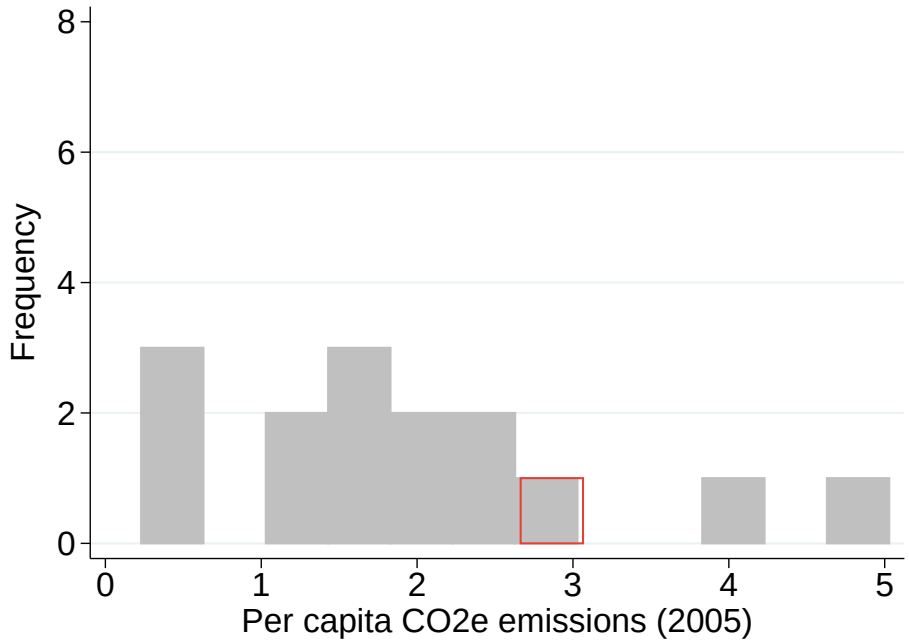

(c) Lignite dummy

# Common support for the distribution of predictors for the UK and countries from the donor pool (cont'd)

Figure: Distribution of characteristics for the UK (in red) and donor pool (in grey)




(a) Opted-out emissions per capita (2009)




(b) Per capita $CO_2e$ emissions (2005)

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# Risk of spillover

**Risk that CPS impacts other EU country power sectors via increased electricity exports to UK or waterbed effect**

- Limited interconnection limit potential for increased net imports, assess upper bound of spillover
- Context of low prices and ETS emission banking in 2013-2017 suggest waterbed effect should be low, assess upper bound Details

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# Risk of a waterbed effect

- Theoretical argument: Under a common emission cap, any emission reduction in a given country only leads to an emission increase elsewhere [Goulder and Stavins, 2011, IPCC et al., 2014]
- 2 reasons to think that the waterbed effect is limited:
  1. Doubtful whether the CPF would empirically result in a substantial increase in EUA prices: UK power installations=only 8.8% of total EU ETS verified emissions
  2. Specific context of the EU ETS at that period tends to go against a strong waterbed effect:
     - Annual aggregate demand for allowances has been below the EU-wide cap since 2008 $\rightarrow$ increase allowances *banking* rather than *direct use*?
     - Recent reform of the EU ETS and introduction of the Market Stability Reserve (MSR): a tool that can retroactively and temporarily puncture the waterbed effect [Perino, 2018]
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# EU Air quality regulation and its role in coal plant closure

- **Large Combustion Plants Directive** (LCPD; 2001/80/EC) introduced in 2004:
  - covers all combustion plants with a total rated thermal input above 50MW, irrespective of the type of fuel used.
  - sets emission limits for annual emissions of SO2, NOx and dust
  - emission limits binding since 2008 $\rightarrow$ sharp decline in emissions in 2007 and 2008 (EEA 2018)
  - opt-out option: commit not to operate the plant for more than 20,000 operational hours between 1 January 2008 and 31 December 2015. In 2015 have to either retrofit or shut down
- **Industrial Emissions Directive** (IED; 2010/75/EU) came into force in 2016 : sets lower emission limits compared to LCP. 3 options:
  1. meet the emissions limit requirements from 1 January 2016.
  2. Transitional National Plan (TNP). allows certain older plants until July 2020 to meet the emission limit requirements.
  3. Limited Lifetime Derogation (LLD): limits plants to 17,500 hours of operation between 01/01/2016 and 31/12/2023, then close
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# Role of EU air quality regulation on UK plant closure

- **LCP directive** quoted by many reports as an important driver for decarbonisation in the UK:
  - several Sandbag reports: 8GW out of the 15GW of coal opted out of the EU Large Combustion Plant Directive back in 2007, which meant that these plants needed to close by December 2015.
  - Staffel 2017 "Britain has lost half of its coal in just $3\frac{1}{2}$ years: 13.6 GW of coal closed between January 2013 and June 2016, 8 either because it had opted out of the large combustion plant directive (LCPD) (Gross et al., 2014), or because it had become loss-making.
- **IED directive**: too soon to tell: According to a Government consultation document (2016):
  - majority of remaining coal chose Transitional National Plan
  - 1 station chose LLD $\rightarrow$ must close by 2023.
  - Remaining plants: have each made investments that put them on a path to meeting the emissions limits. Compliance estimated to require investment of the order to £50m-£75m per 500MW unit for UK coal and gas fired power plants
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# Role of suport to biomass conversion

- **Support policies**
  - 2012: a specific band in the **Renewables Obligation Certificate** scheme is created to support coal-fired power plants converting to biomass (RO scheme ended in 2017)
  - 2014: **Contract for Difference**: pays a flat (indexed) rate for the electricity produced by renewables (incl biomass) over a 15-year period; the difference between the 'strike price' (a price for electricity reflecting the cost of investing in a particular low carbon technology) and the 'reference price' (a measure of the average market price for electricity in the GB market)
- **Take-up**:
  - **Drax power station** (14% of UK power sector emissions in 2012), benefited from the two schemes and intensified its biomass conversion - started in 2009 at its own initiative - in 2012.
  - **Lynemouth power station** received support under the CfD scheme and converted to biomass in 2016.
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# Synthetic UK composition and predictors' values

- Synthetic UK = 5 countries: Ireland (51.3%), Slovakia (25.7%), the Netherlands (11.1%), Finland(6.3% ) and Czech Republic (5.5%).
- Predictors:
  - Predictors' value very close in the UK and Synthetic UK, vs. difference between the UK and average donor pool
  - Main predictors: fuel price ratio and demand to be covered by combustible fuels

| Variable | Weight | UK | Synth. UK | Avg. Donor pool |
|---|---|---|---|---|
| Per capita residual load | 36.6% | 4.04 | 4.05 | 3.07 |
| Coal-gas price ratio | 15.5% | 0.52 | 0.51 | 0.71 |
| Coal-gas price ratio squared | 43.1% | 0.27 | 0.28 | 1.26 |
| Per capita opted-out emissions in 2009 | 0.05% | 0.28 | 0.24 | 0.22 |
| Lignite dummy | 1.2% | 0 | 0.06 | 0.2 |
| Per cap. emissions 2005 | 1.2% | 3.0 | 3.1 | 2.6 |
| Per cap. emissions 2012 | 2.2% | 2.6 | 2.4 | 2.1 |

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# Permutation test without outliers

- Removes countries having a pre-treatment Mean Squared Prediction Error 10 times larger than the UK

Figure: Permutation test without Denmark and Finland


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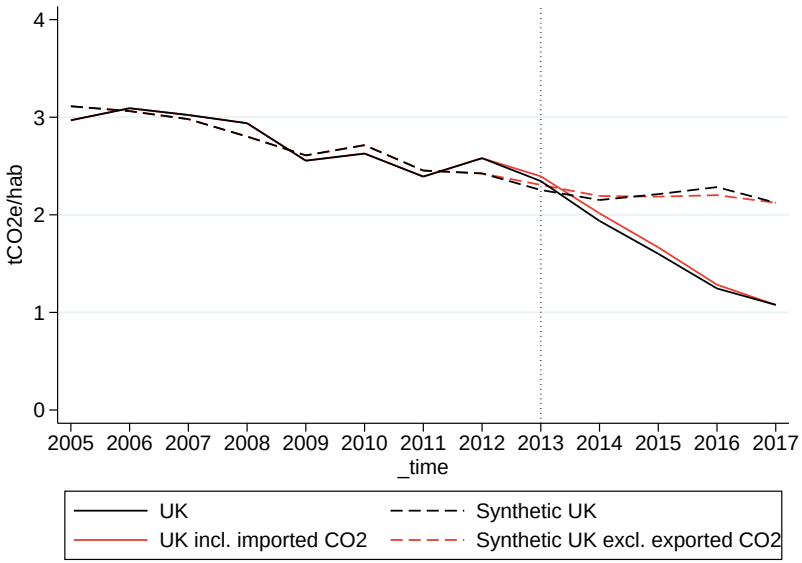
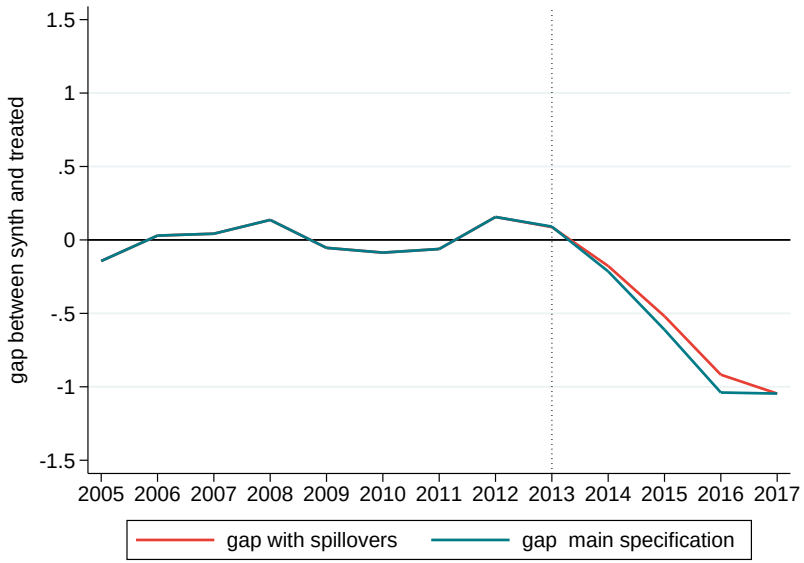
# Accounting for import spillovers

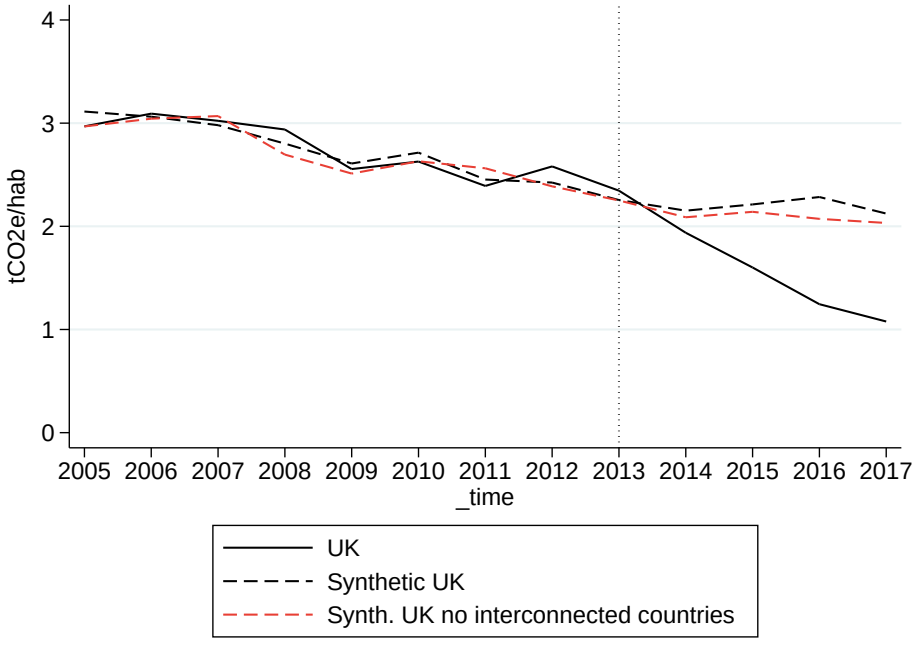
- New per capita emissions calculated by re-allocating post-2013 additional UK net imports from France, Ireland and the Netherlands to the UK
- Reduces overall impact to 169 $MtCO_2e$, probably not a significant difference No interconnection Back

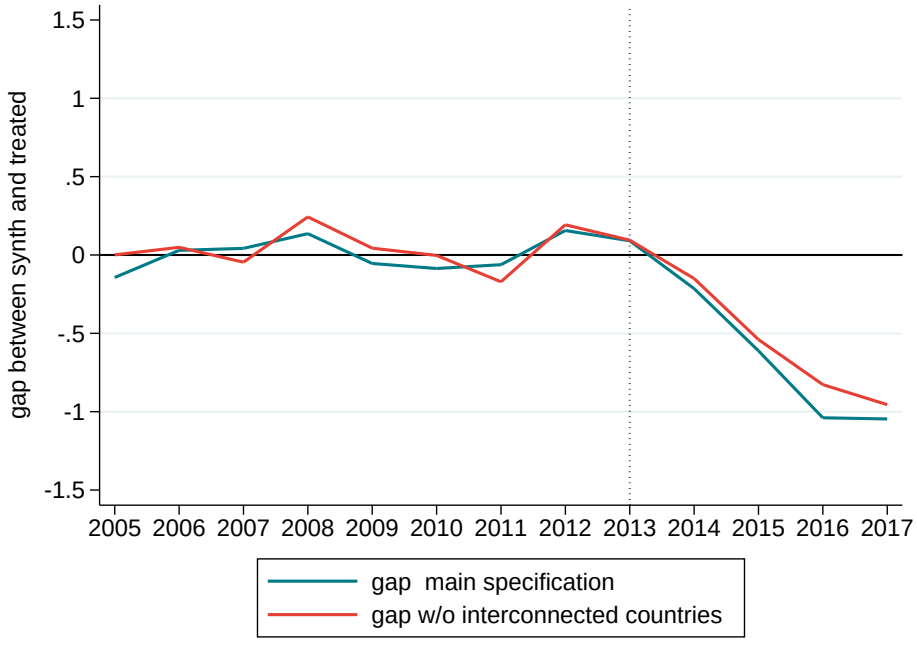


# Removing from the donor pool all interconnected countries

- Less precise fit prior to 2013 and increase in overall impact

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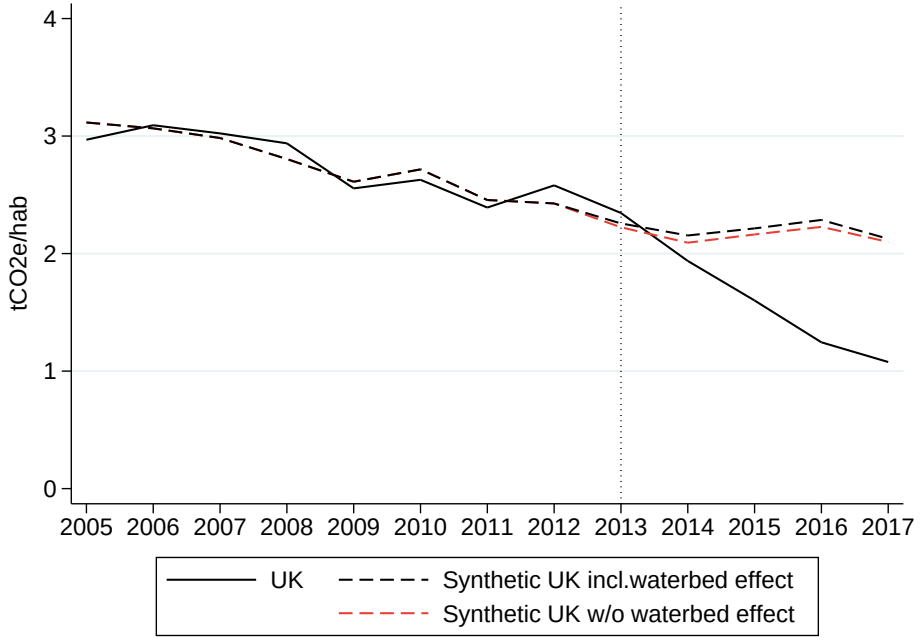
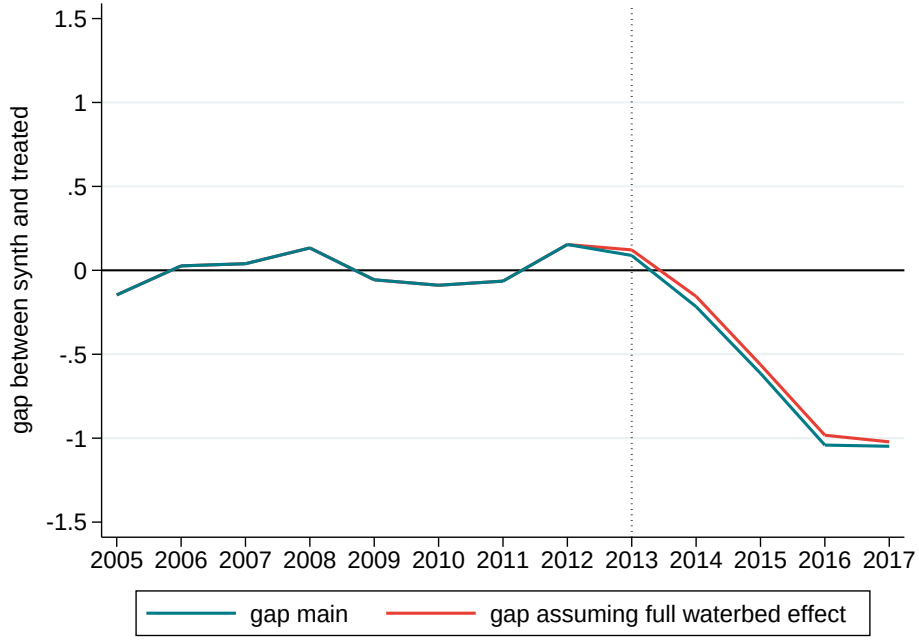
# Assuming full waterbed effect

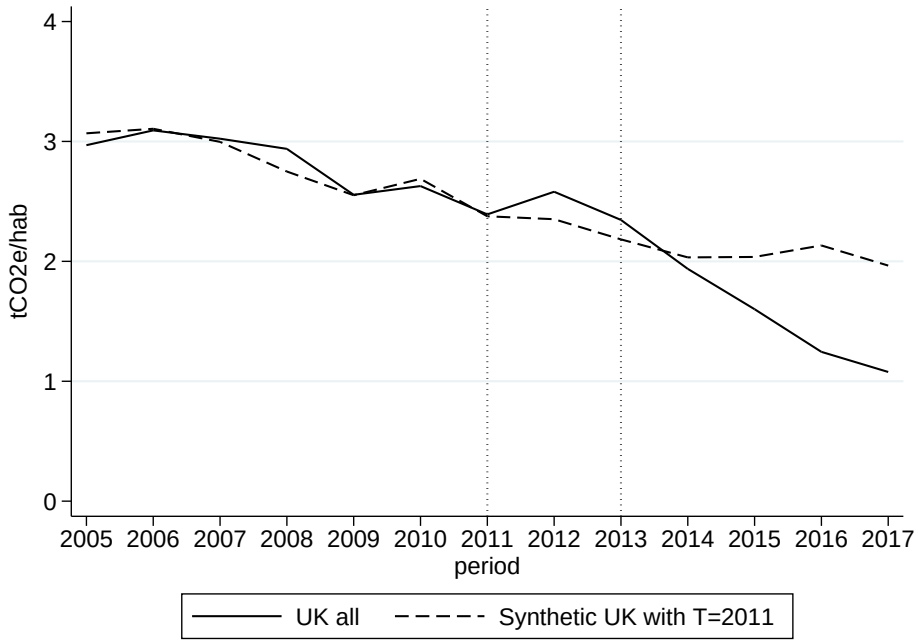
- Assume that observed per capita emissions for countries in the donor pool include a waterbed effect component:
  - the observed time decrease in UK emissions has translated in an increase **by the same amount of emissions** in other countries' power sector emissions
  - the share re-allocated depends on each country's share in 2012 power sector ETS emissions (excluding the UK)
- Impact only slightly smaller: 171Mt$CO_2$e vs 185Mt$CO_2$e Back

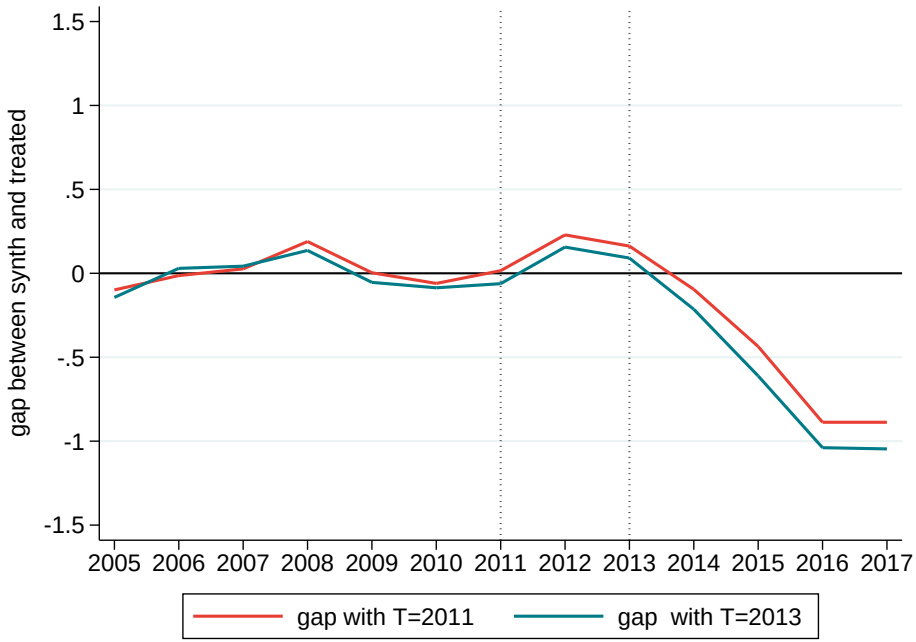


# Assuming anticipation effect

- Reduces impact to 125 $MtCO_2e$, driven by the increase in emissions from opted out plants in 2012

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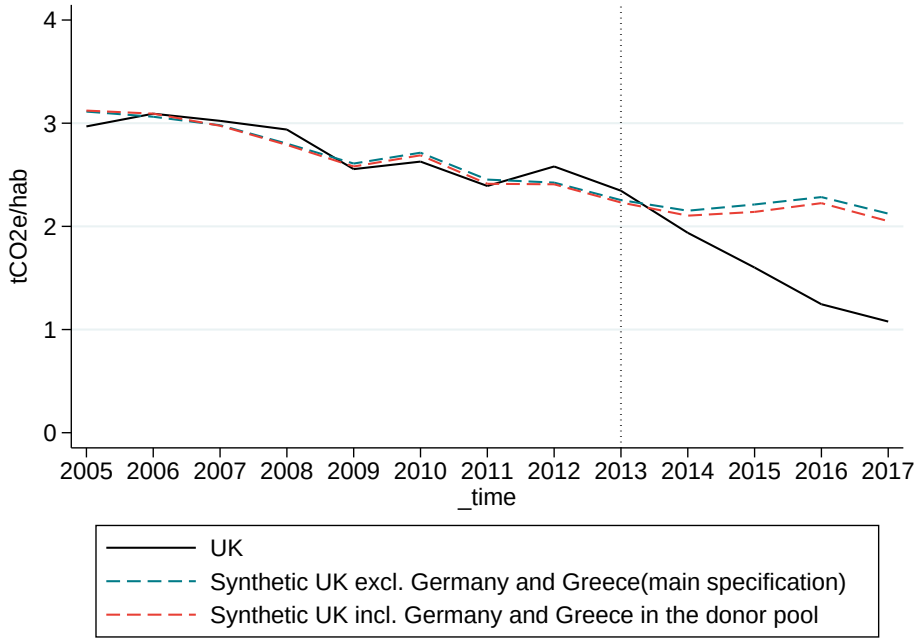
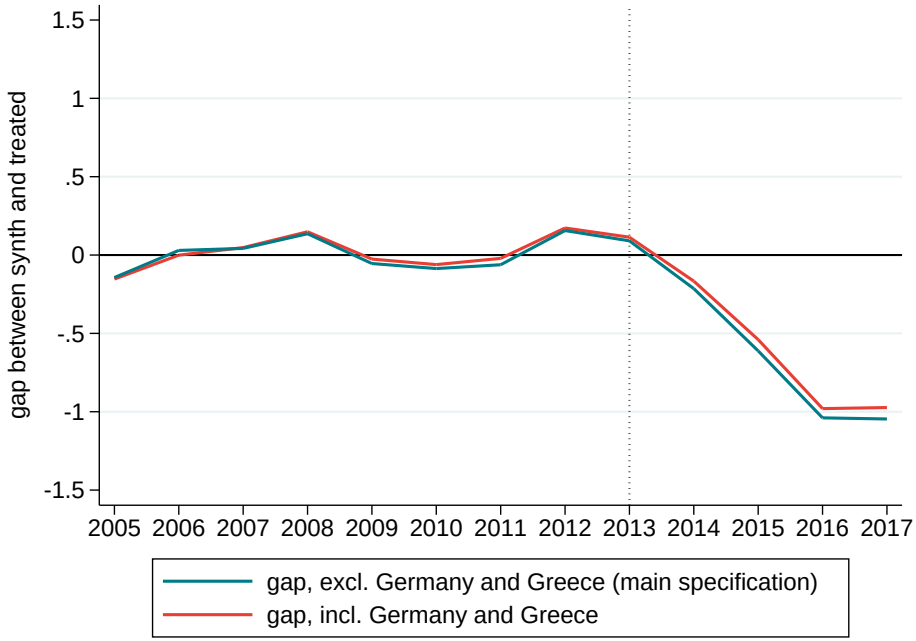
# Synthetic Control Method including Greece and Germany

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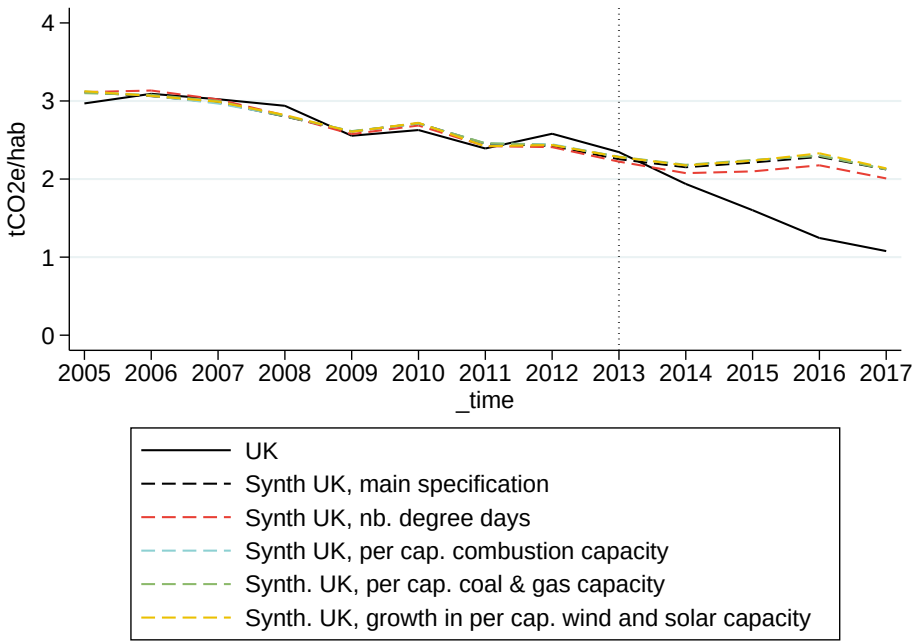
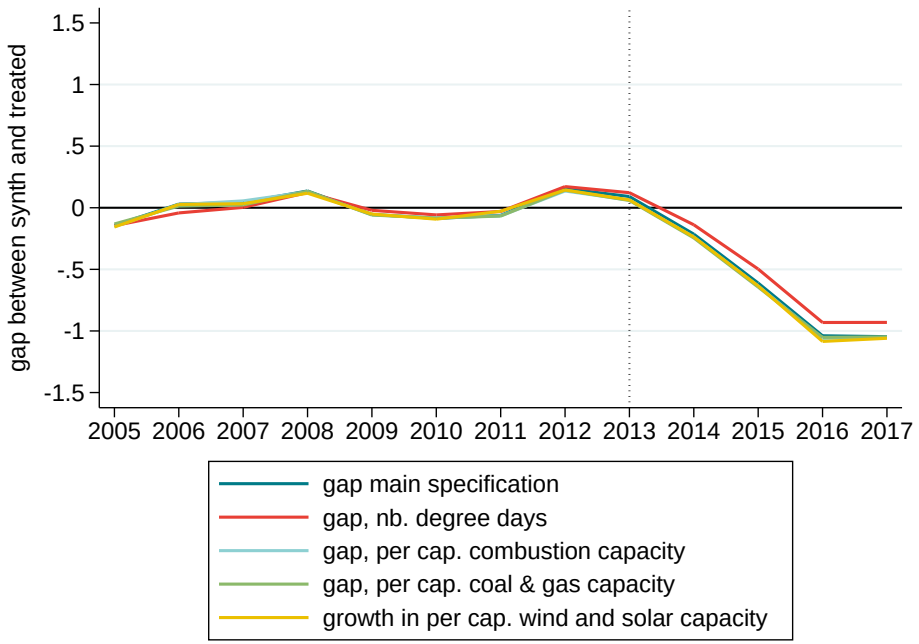
# Synthetic Control Method using alternative predictors

1. Substitute residual load with number of degree days
2. Add combustible fuels capacity
3. Add pre-treatment trend in wind and solar capacity
   - $\rightarrow$ Not much change

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# Retail electricity prices for households

- Compare retail electricity price for the average household consumer in the UK, synthetic UK and other large countries
- UK-Synthetic UK comparison suggests small increase in prices in the UK (also true in ppp?)