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INSTITUTE FOR NEW ECONOMIC THINKING AT THE OXFORD MARTIN SCHOOL
CLIMATE ECONOMETRICS

Climate policies that achieved major emission reductions: Global evidence from two decades

Dr. Moritz Schwarz

RESEARCH

CLIMATE POLICY

Climate policies that achieved major emission reductions: Global evidence from two decades

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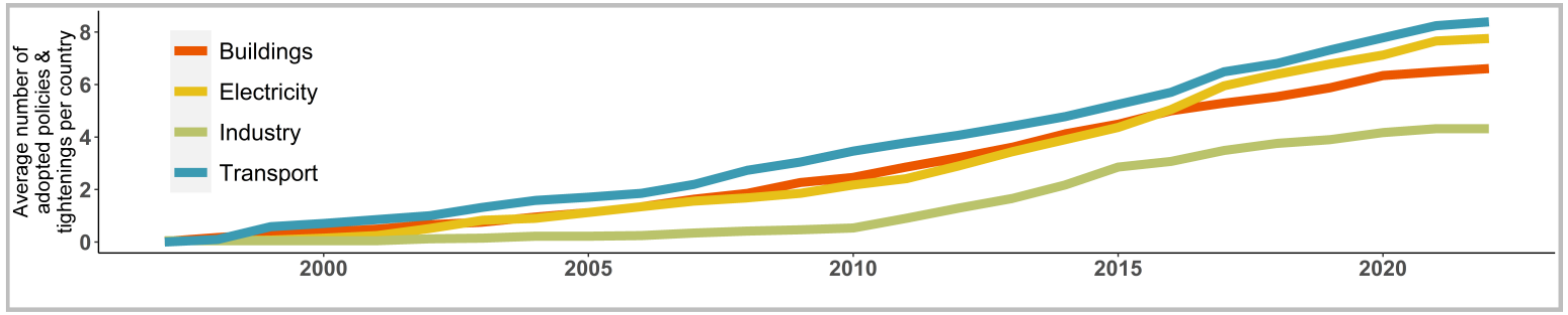
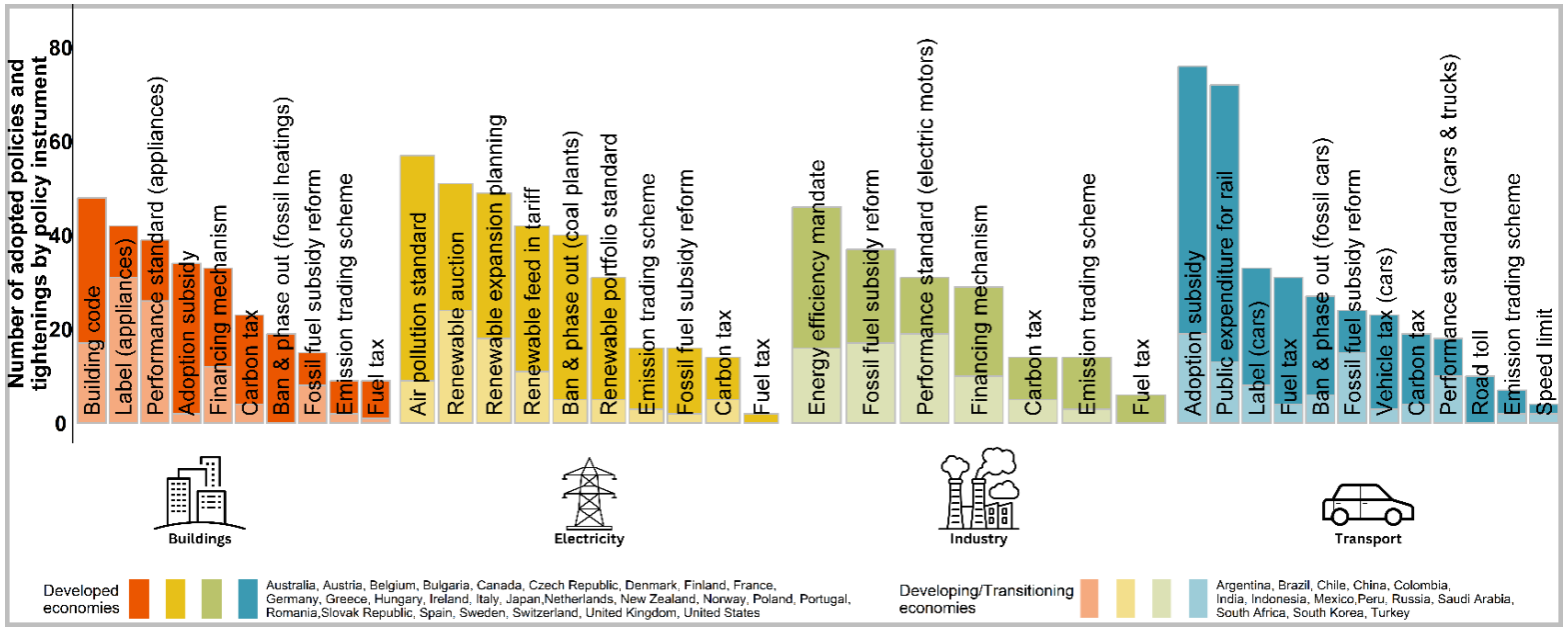
Meeting the Paris Agreement's climate targets necessitates better knowledge about which climate policies work in reducing emissions at the necessary scale. We provide a global, systematic ex post evaluation to identify policy combinations that have led to large emission reductions out of 1500 climate policies implemented between 1998 and 2022 across 41 countries from six continents. Our approach integrates a comprehensive climate policy database with a machine learning–based extension of the common difference-in-differences approach. We identified 63 successful policy interventions with total emission reductions between 0.6 billion and 1.8 billion metric tonnes CO_2. Our insights on effective but rarely studied policy combinations highlight the important role of price-based instruments in well-designed policy mixes and the policy efforts necessary for closing the emissions gap.

https://www.science.org/stoken/author-tokens/ST-2062/full (free access link)

Ever more climate policies implemented over last 20 years





... and experience with hundreds of diverse climate policy instruments

Source: OECD CAPMF data for 41 countries and the period 1998 to 2022

The policy evaluation gap

- There is **neither consensus in science nor policy** as to which types and combinations of policy instruments lead to meaningful emission reductions

- Most empirical research focuses on effect of **few headline policy instruments**; **countless other policies** are either **sparsely evaluated or not at all**

- Focus on single policies in isolation prevents systematic learning about **prevalent policy mixes**

Overview:

Global, systematic *ex-post* evaluation identifying policy combinations that have led to **large emissions reductions**

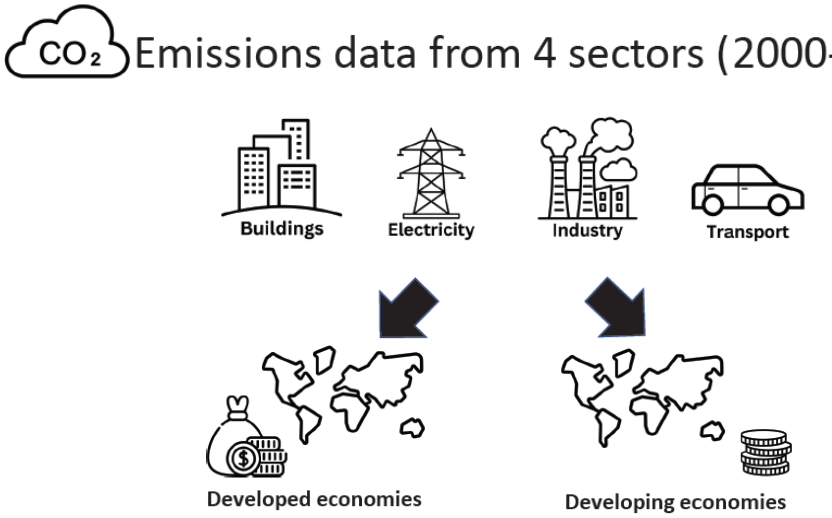
Novelty:

(1) First **causal impact assessment** at global scale based on a transparent and reproducible statistical framework

(2) New database of **1,500 climate policies from 1998-2022 across 41 countries** in six continents

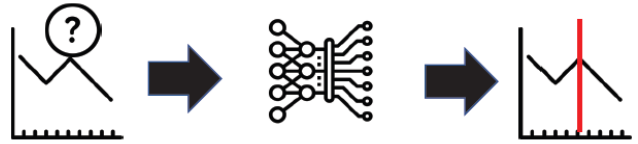
(3) Entire spectrum of instruments **without subjective, a-priori selection** for evaluation (instead: data-driven procedure using machine learning)

Step 1: Detecting emission reduction

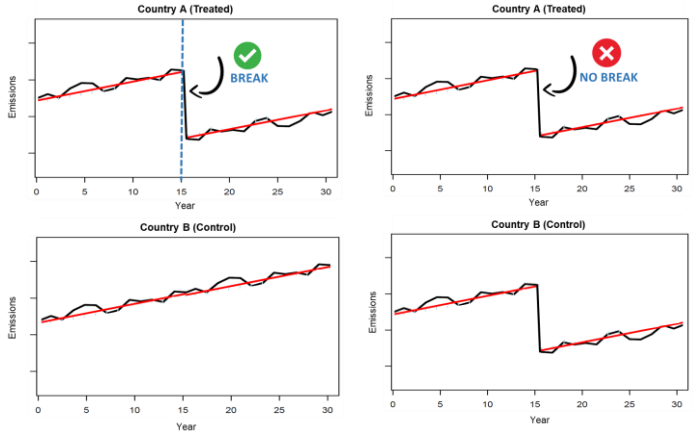


(EDGAR) Emissions Database for Global Atmospheric Research
Sector-level CO_2 emissions data across 41 countries

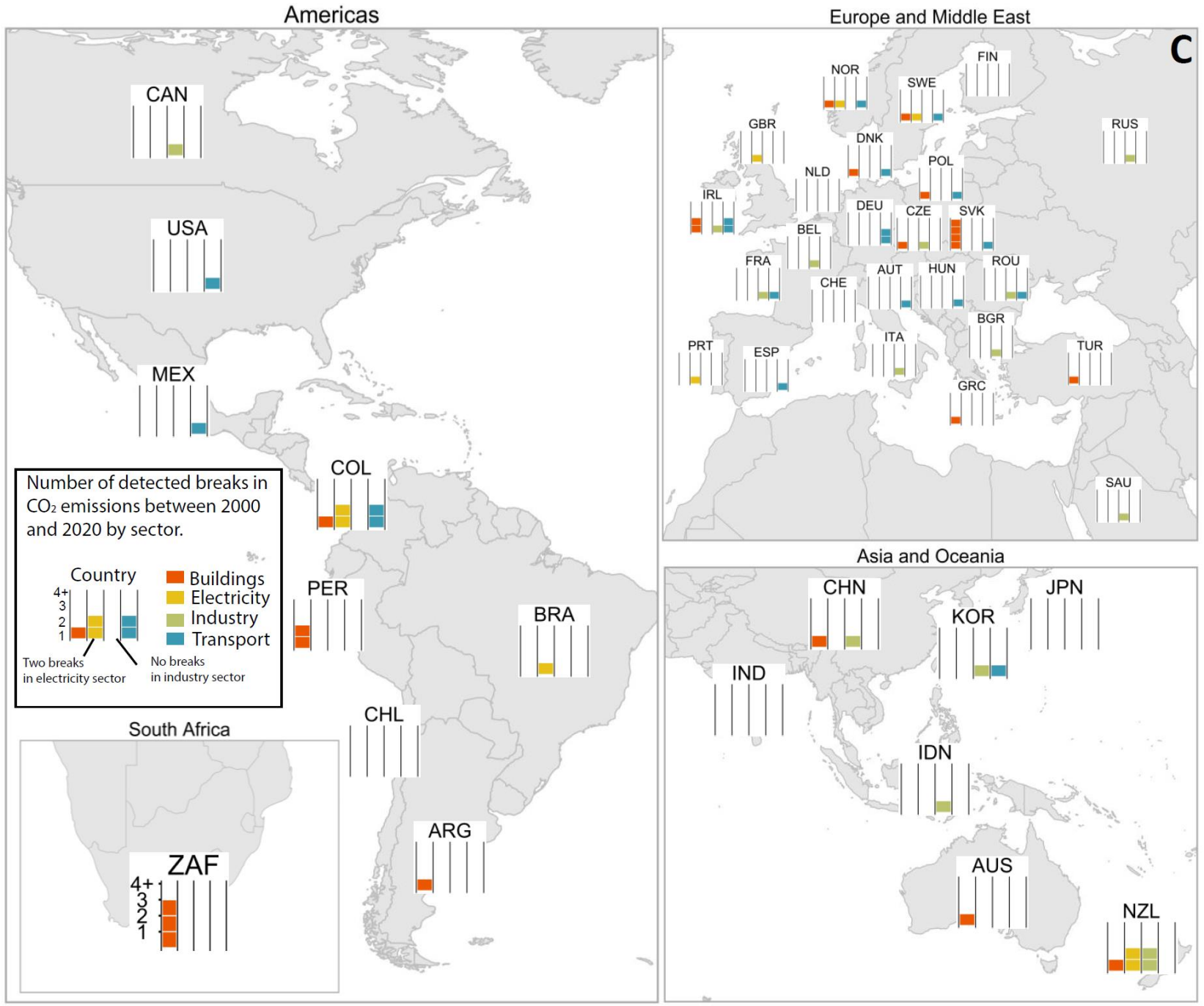
Agnostically detect structural breaks in emissions using machine learning…



… in a causal framework with control group



NB: Approach targets large emission reductions (required min. effect ≈ 5−10%)



We detect 69 breaks

… with average emission reduction of 19 percent

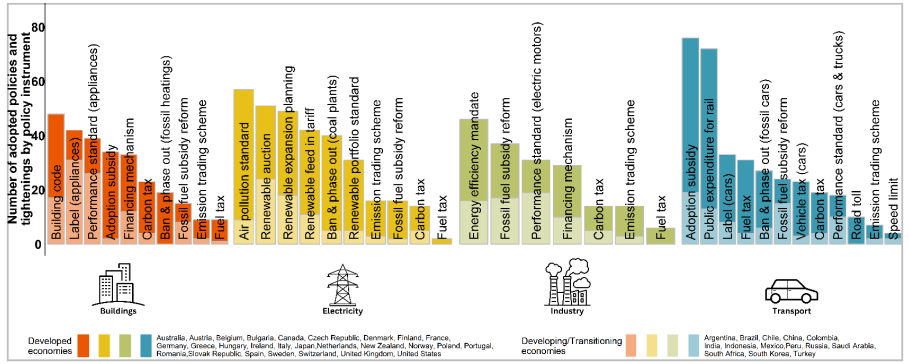
Emission reductions on a magnitude that matches zero-emission targets are possible

Step 2: Policy Attribution

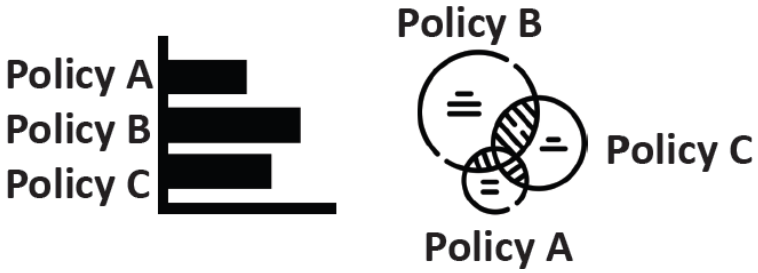
Specify policy instruments behind breaks based on comprehensive, internationally-harmonized policy inventory

(CAPMF) Climate Actions and Policies Measurement Framework

OECD database of policies implemented from 2000-2022



Analyze successful policies and policy mixes

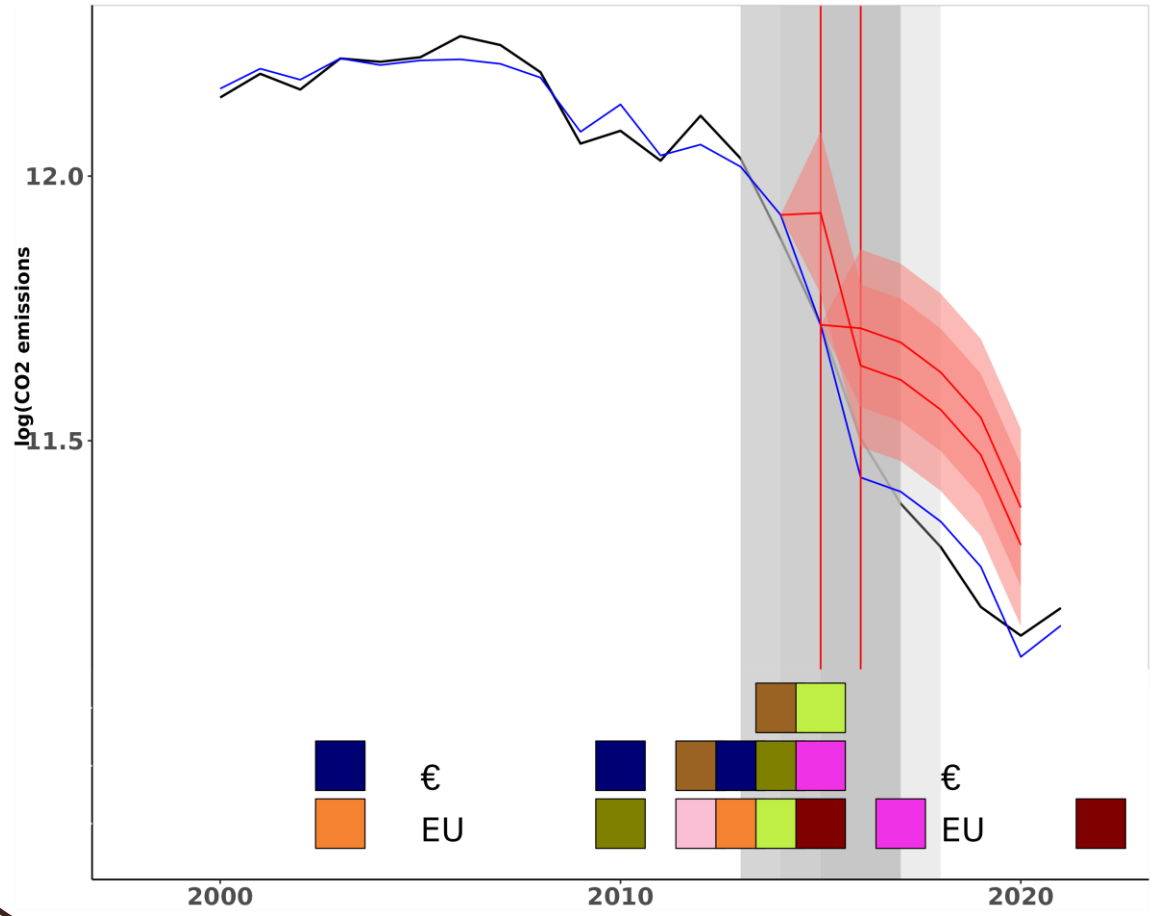


Headline results

- We identified successful policy interventions with total emission reductions between **0.6 billion and 1.8 $GtCO_2$**. UN estimates quantify a median emission gap of 23 $GtCO_2eq$ by 2030. The identified measures could close this gap by 26 – 41%.
- **Climate policies are more effective as part of a mix**: In the majority of cases, effect sizes are larger if a policy instrument is part of a policy mix rather than implemented alone.
- **Developed and developing countries have different climate policy needs**: In developed countries, pricing stands out, whereas in developing countries, regulation is the most powerful policy.
- **Pricing-based instruments tend to amplify** the effect sizes of other policy types across sectors.

Electricity

United Kingdom

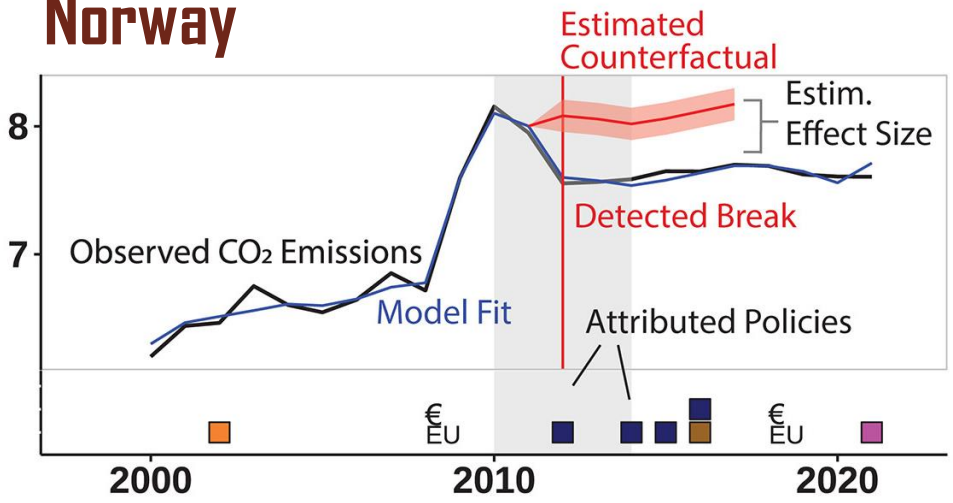


Combination of:

- mid-2013 introduction of a **carbon price floor** for UK power producers.
- *command-and-control measures* (**renewable portfolio standards, renewable expansion planning, stricter air pollution standards,** and the announcement of a **phase-out of coal power plants**)
- *other market-based incentives* (**renewable feed-in tariff and auctions**).

Transport

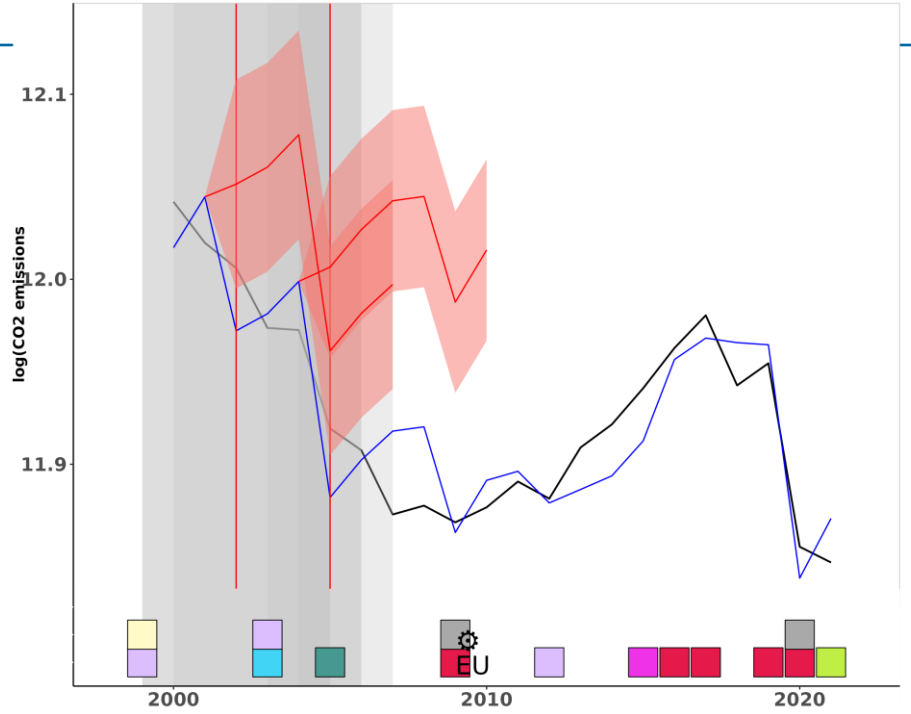
Norway



Combination of:

- **Ban & phase-out of fossil cars**
- Increased **public expenditure for rail**
- Various consumer **adoption subsidies**

Germany

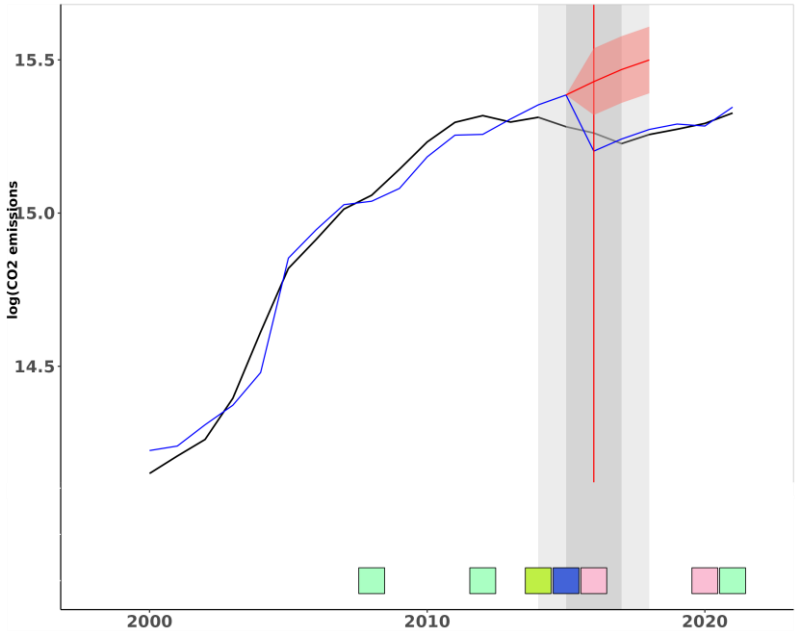


Combination of:

- **Eco-tax reform**
- **Truck toll**
- **Public expenditure for rail**
- **Fuel tax**

Industry

China

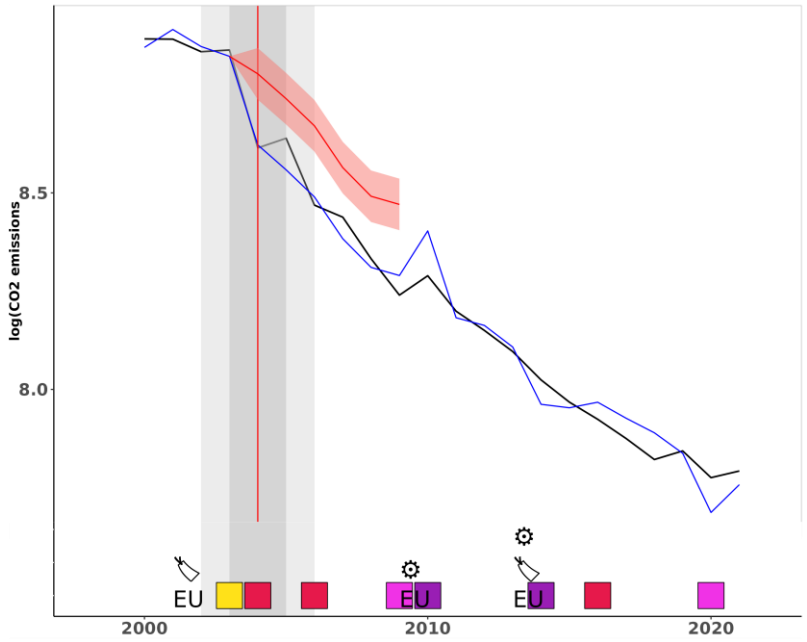


Combination of:

- Various **ETS** schemes
- Reduction of **fossil fuel subsidies**
- Strengthening of **financing mechanisms for energy efficiency investments**

Buildings

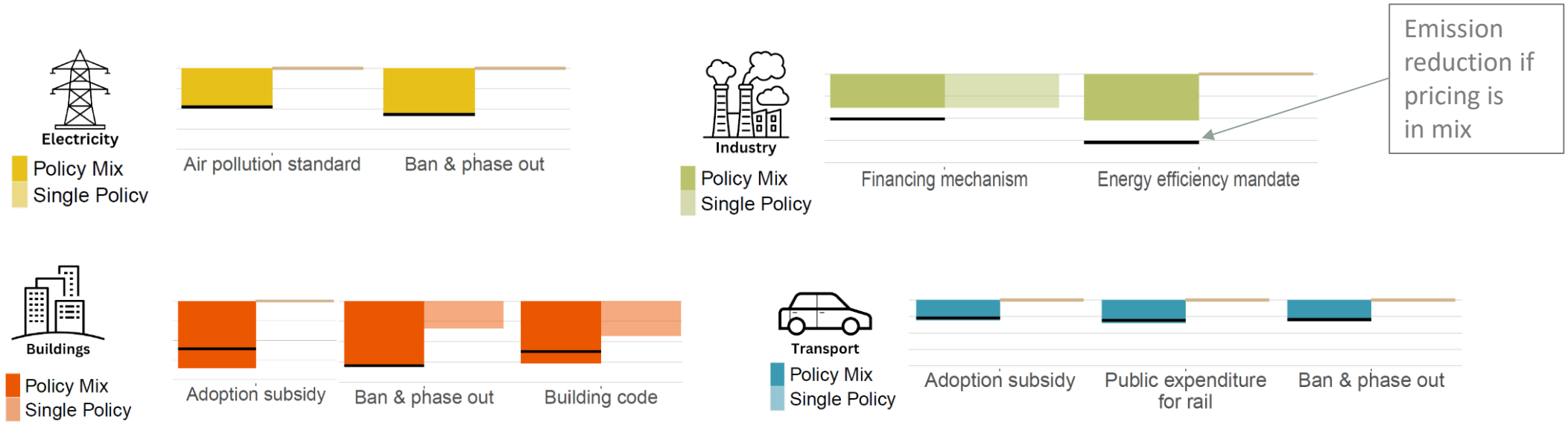
Sweden



Combination of:

- **Carbon tax**
- **Adoption subsidies** for residential heating upgrades, biomass heating systems, and energy-efficient windows

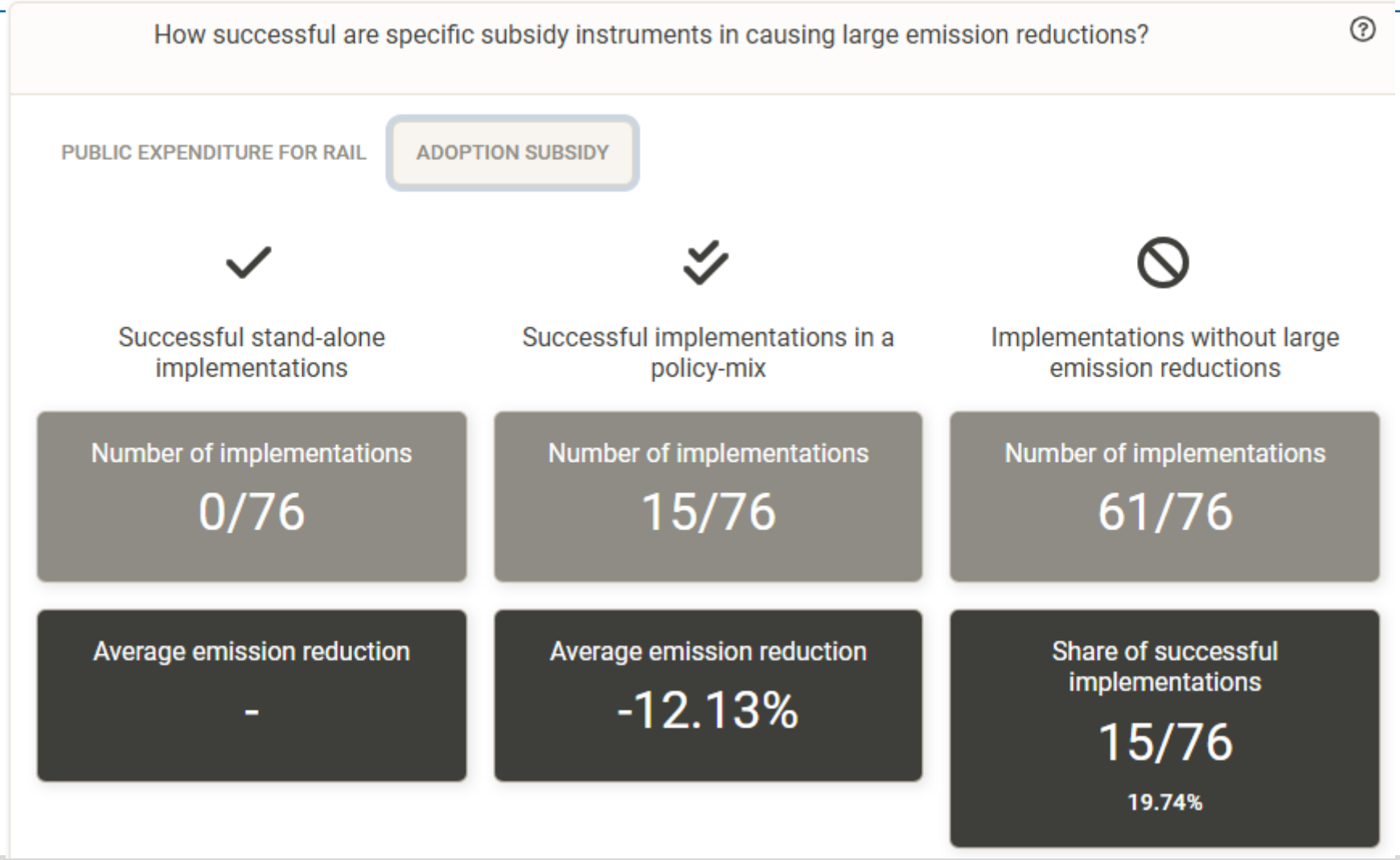
Price instruments are often the complement enabling large reductions



… make popular regulations & subsidy schemes effective (or more effective) in inducing large emission reductions

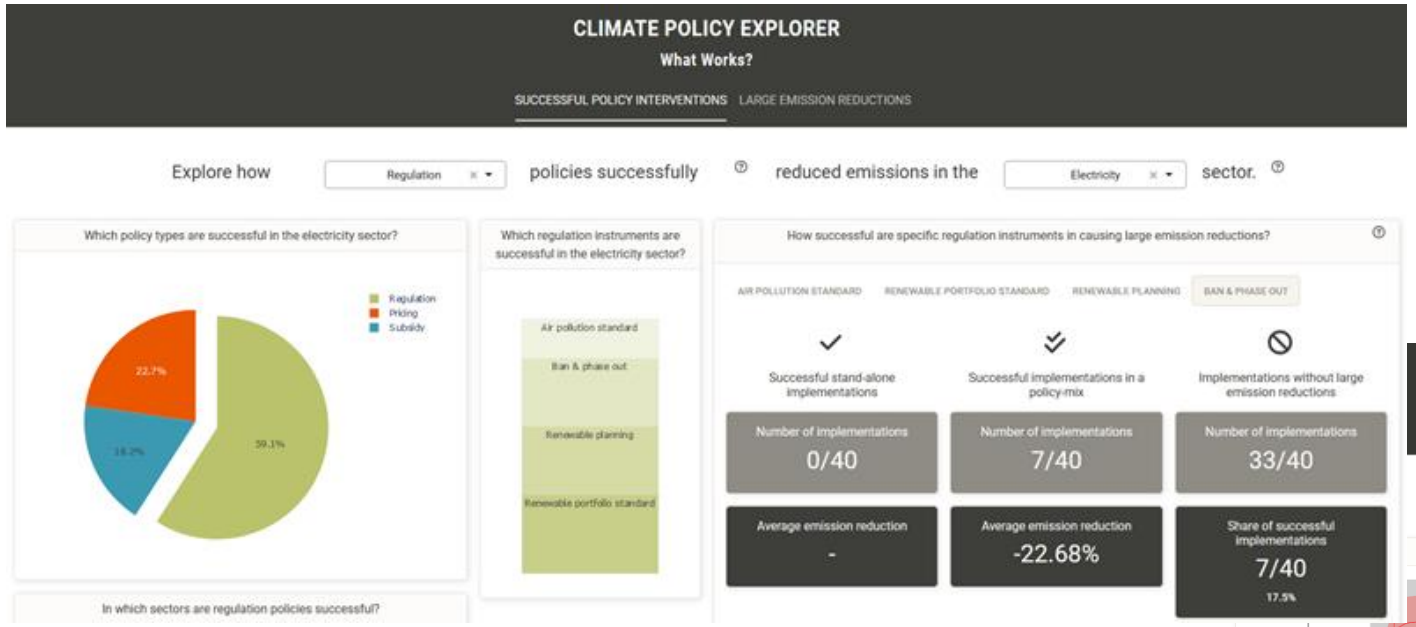
Why: Complement incentives and address limitations, such as rebound effects and narrow scope (e.g. only new cars/appliances)

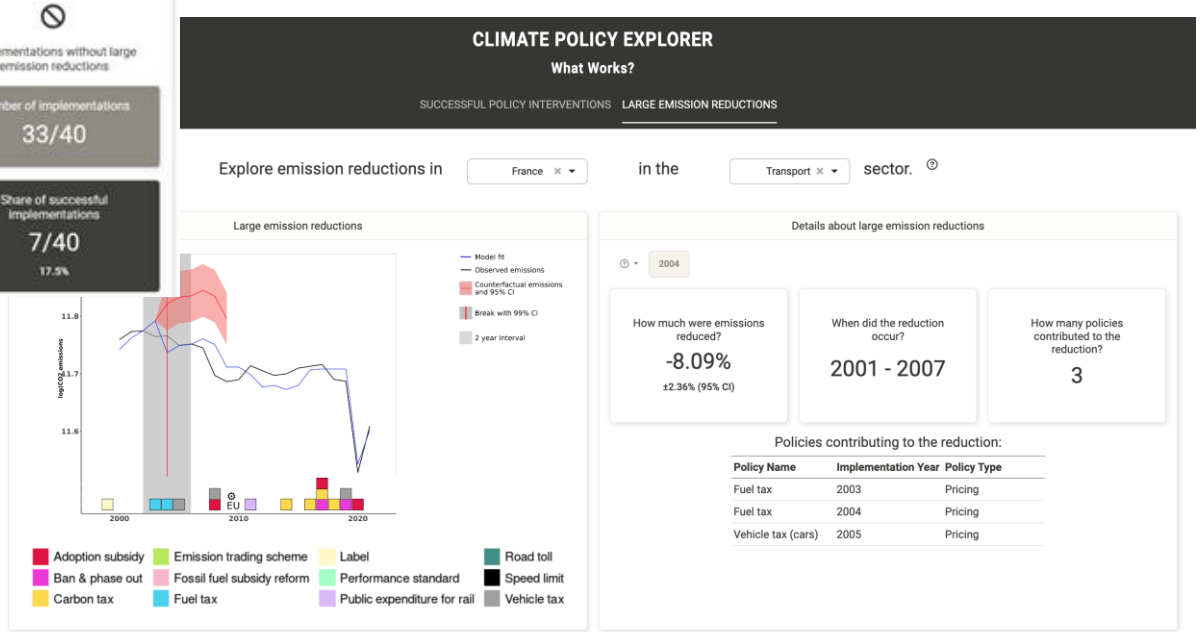
Effekt of Adoption subsidies



Climate Policy Explorer

Released alongside the paper to help point decision makers towards powerful policy designs





http://climate-policy-explorer.pik-potsdam.de/

Policy conclusions

- Focus on technology standards and avoid lock-in h**igh growth sectors** (industry, electricity in developing countries)
- Build on **carbon pricing and adoption subsidies** in established sectors
- Sectors with a large number of actors (buildings, transp.) should use more and **diverse instruments in a mix**
- Leverage key climate policy actors in non-liberalised markets like **state-owned enterprises**
- Consider the **social dimension** of policies – lack of social consideration likely leads to low ambition

Conclusions

1. Emission reductions on a magnitude that matches zero-emission targets are possible – but need to be scaled!

2. Pricing is often a critical element of effective policy mixes

3. Shift from one-size-fits-all to sector and country-specific best practices

Thank you!

Find the Climate Policy Explorer at
http://climate-policy-explorer.pik-potsdam.de/

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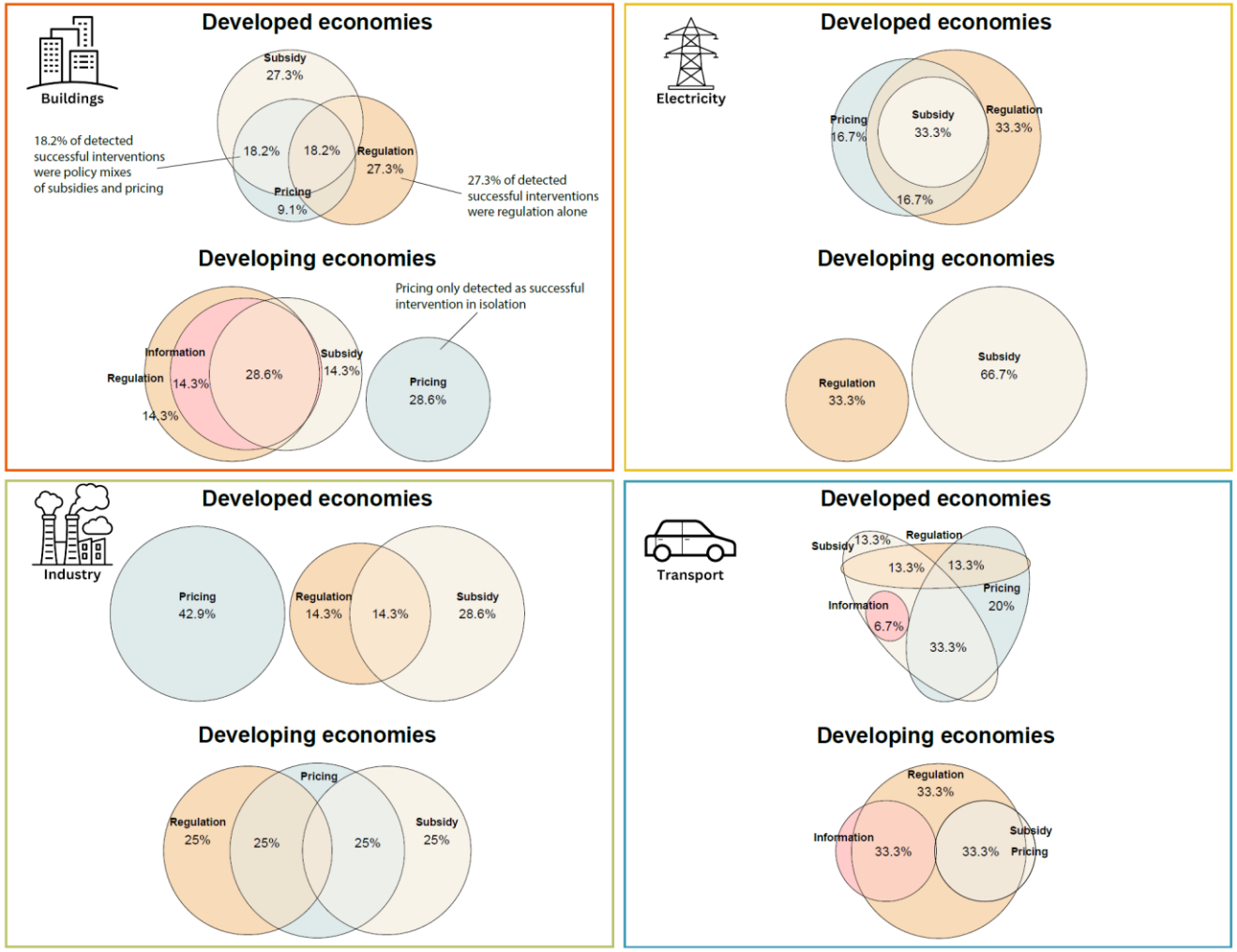
Back-up

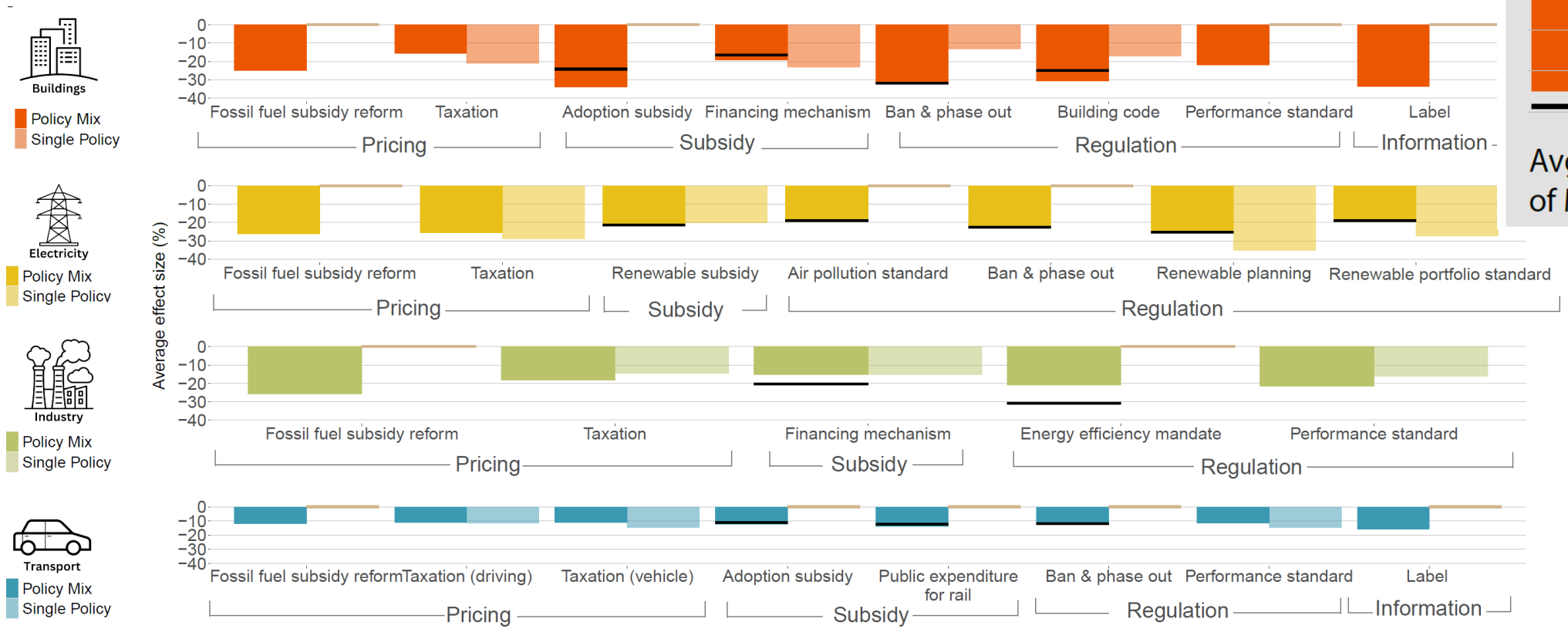
No one-size-fits-all

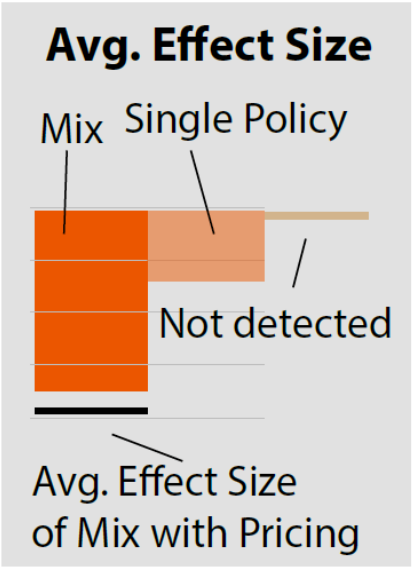


Effective policies differ across sectors & country groups

- Most complementarities in sectors with private consumers
- Pricing particularly effective in context w/ profit-maximizing firms
- Regulations and subsidies stand out more than price instruments in developing countries

Emission reduction is greater with policy mixes

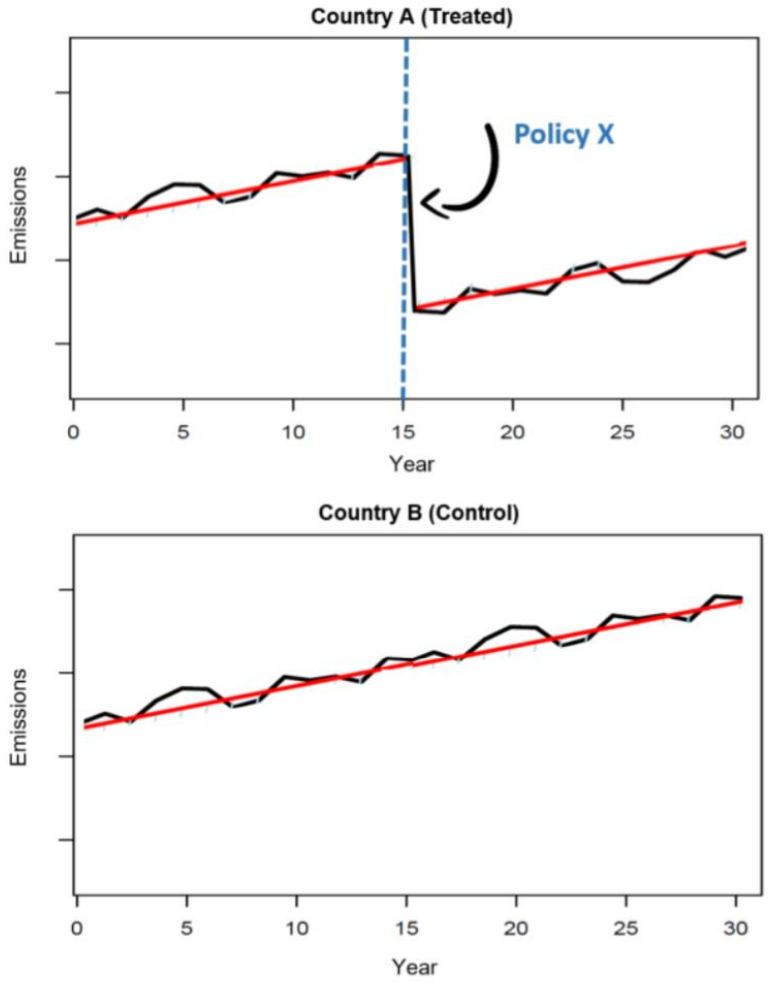




… but NOT by the shotgun principle!

Method: Standard causal approach

Known assignment & known timing of single policy intervention



Two-way fixed effects estimator (TWFE)

$$y_{i,t} = \alpha_i + \phi_t + \tau \times treat_i * post_t + \varepsilon_{i,t}$$

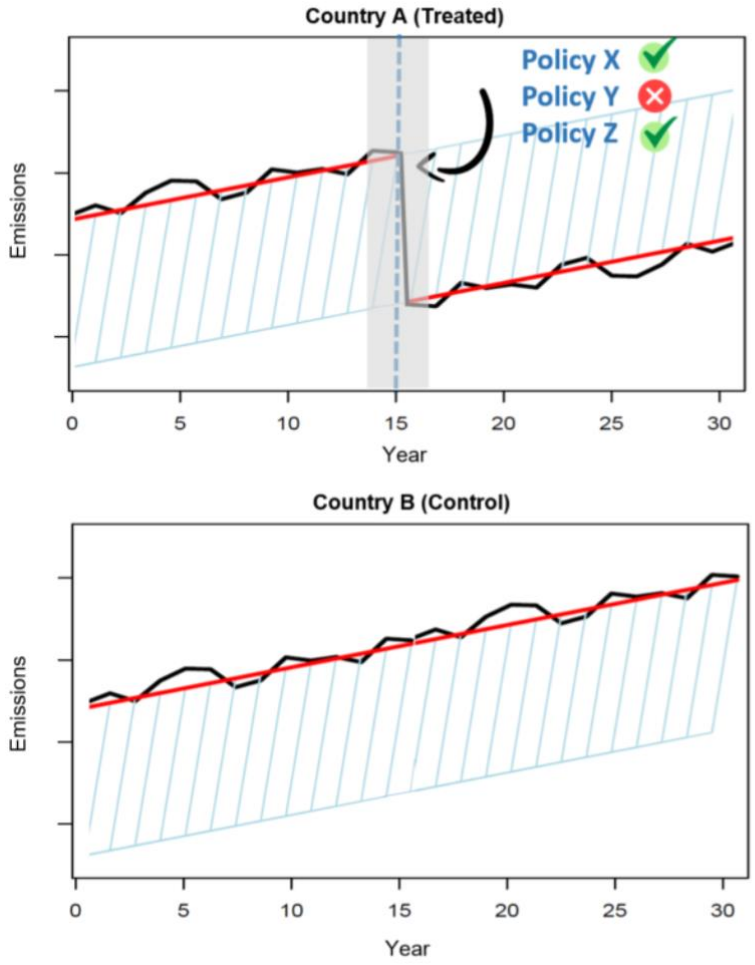
NB: Treatment effect is equivalent to break (step-shift) in treated unit's fixed effect when switching from pre- to post-treatment

$$E\left[y_{i,t} \mid treat_i = 1\right] = \alpha_i + \tau \times \mathbb{1}_{t \geq post} + \phi_t$$

Source: OECD CAPMF data for 41 countries and the period 1998 to 2022

Our "reverse" causal approach

Data-driven search for step-shifts in unit fixed effects of generalized TWFE



Step 1: Agnostically allow for step-shifts for any country at any time

$$y_{i,t} = \alpha_i + \phi_t + \sum_{j=1}^{N} \sum_{s=2}^{T} \tau_{j,s} \mathbb{1}_{\{i=j, t \geq s\}} + \varepsilon_{i,t}$$

Step 2: Apply variable selection methods from machine learning to remove all but the relevant step-shifts

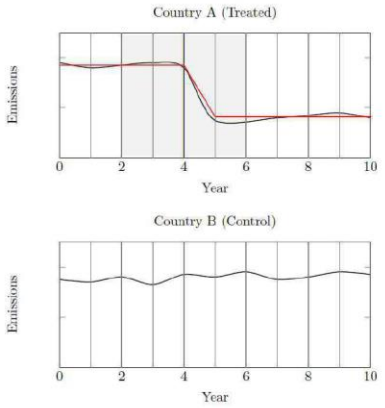
GETS block-search algorithm

Step 3: Attribute potential policy instruments to detected step-shifts based on rich CAPMF data

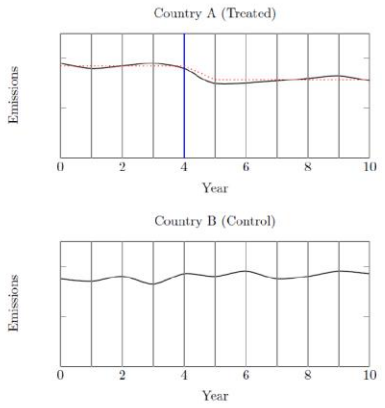
NB: Approach targets large effects (required min. effect size $\approx 5-10\%$)

Source: OECD CAPMF data for 41 countries and the period 1998 to 2022

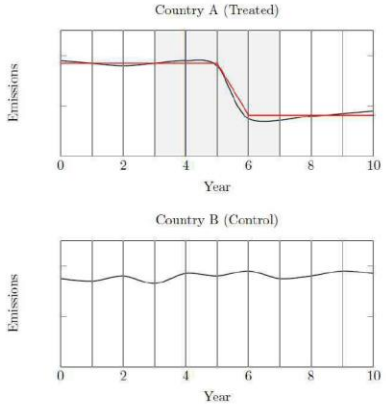
Examples of common break detection patterns



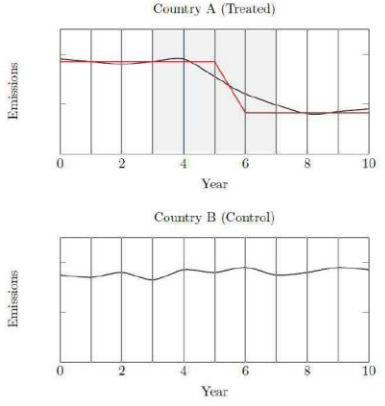
Case 1 with immediate and strong adjustment detected as a break: A priori unknown treatment date in blue; treatment detected as a step-shift in red; and the confidence interval in grey.



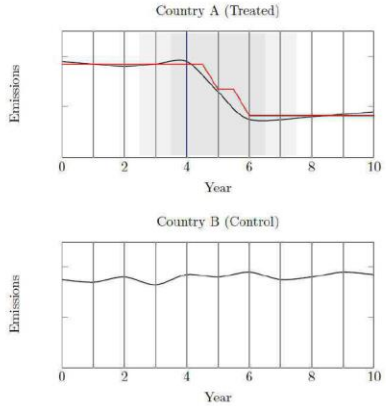
Case 2 with immediate but small adjustment not detected as a break: A priori unknown treatment date in blue; treatment not detected as a step-shift in dotted red (below minimum effect size).



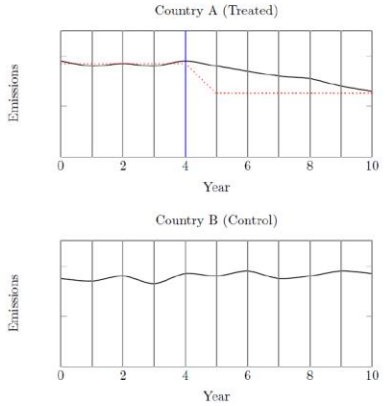
Case 3 with lagged strong adjustment detected as a break: A priori unknown treatment date in blue; treatment detected with delay as a step-shift within the break date confidence interval in red; and the confidence interval in grey.



Case 4 with gradual but strong adjustment detected as a break: A priori unknown treatment date in blue; treatment detected with delay as a step-shift within the break date confidence interval in red; and the confidence interval in grey.



Case 5 with gradual but strong adjustment detected as two breaks: A priori unknown treatment date in blue; treatment detected with delay as two step-shifts within the break date confidence interval in red; and the confidence interval in grey.



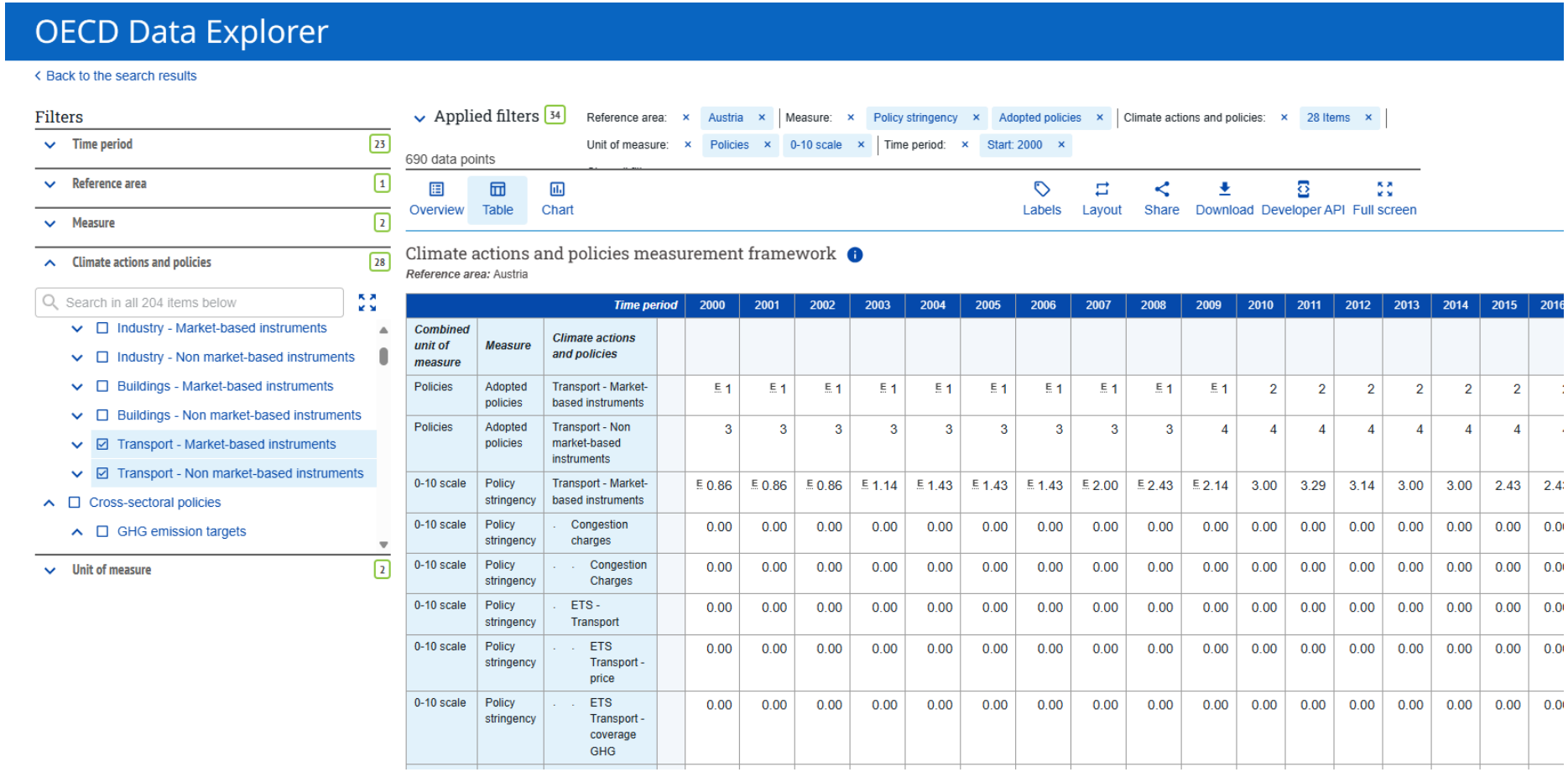
Case 6 with slowly building up adjustment not detected as a break: A priori unknown treatment date in blue; treatment not detected as a step-shift in dotted red.

Source: OECD CAPMF data for 41 countries and the period 1998 to 2022

What we cannot show in our study

- This is a small contribution in a much broader debate
- Study likely to lead to an engaged academic debate with further results and studies attempting to validate our results
- Our study focuses on „major“ emission reductions: minimum effect size is about 5-10 %
- Identification of policies within the estimated uncertainty of the structural break is challenging and perfect identification is not yet possible
- Long-term trends are difficult to capture
- The policy definition within the OECD database is just one approach to measure policy tightness

Climate Actions and Policies Measurement Framework



Combined unit of measure	Measure	Climate actions and policies	Time period	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Policies	Adopted policies	Transport - Market-based instruments		E 1	E 1	E 1	E 1	E 1	E 1	E 1	E 1	E 1	E 1	2	2	2	2	2	2	
Policies	Adopted policies	Transport - Non market-based instruments		3	3	3	3	3	3	3	3	3	4	4	4	4	4	4	4	
0-10 scale	Policy stringency	Transport - Market-based instruments		E 0.86	E 0.86	E 0.86	E 1.14	E 1.43	E 1.43	E 1.43	E 2.00	E 2.43	E 2.14	3.00	3.29	3.14	3.00	3.00	2.43	2.4
0-10 scale	Policy stringency	. Congestion charges		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
0-10 scale	Policy stringency	. . Congestion Charges		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
0-10 scale	Policy stringency	. ETS - Transport		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
0-10 scale	Policy stringency	. . ETS Transport - price		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
0-10 scale	Policy stringency	. . ETS Transport - coverage GHG		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0

Climate Actions and Policies Measurement Framework

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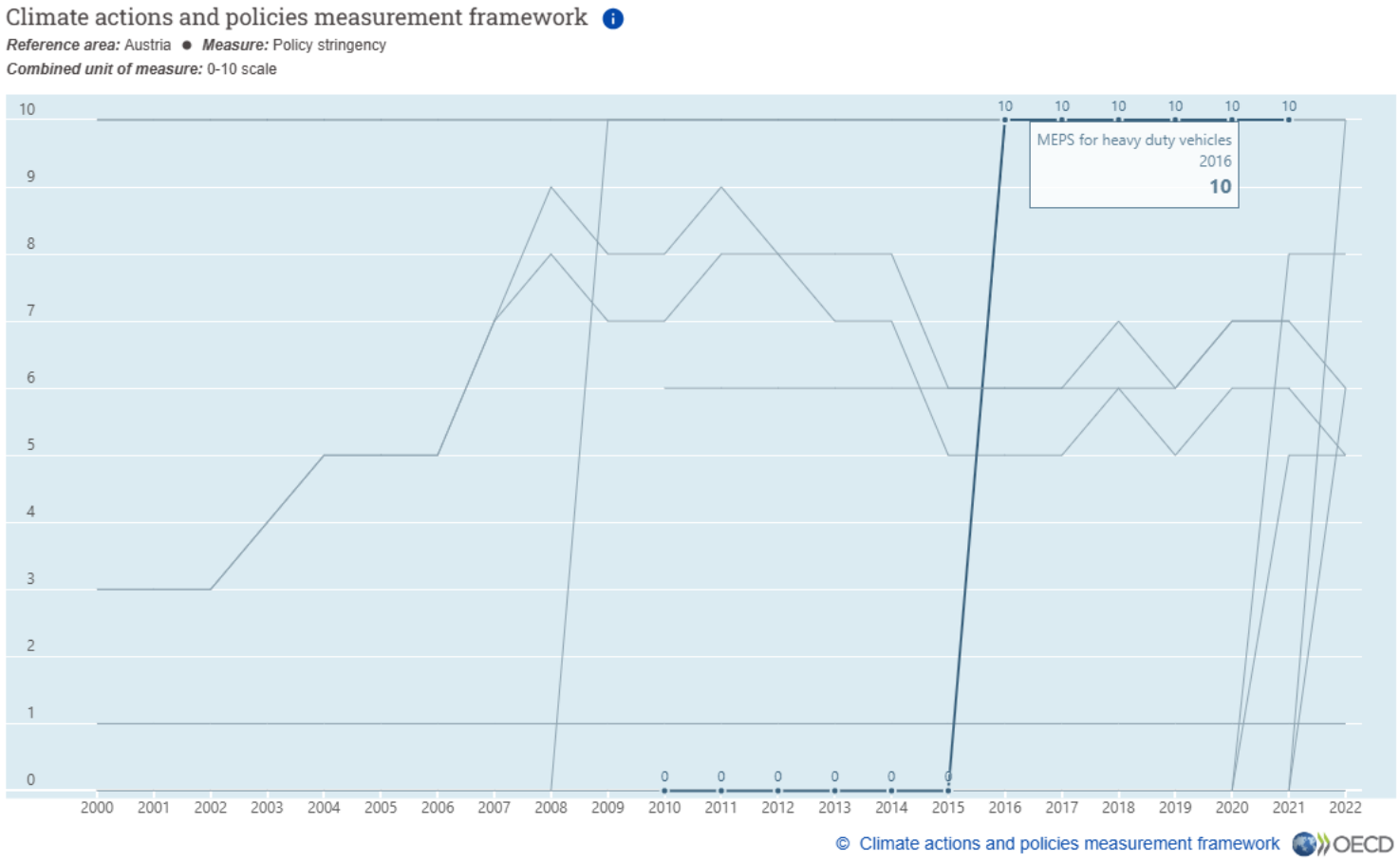

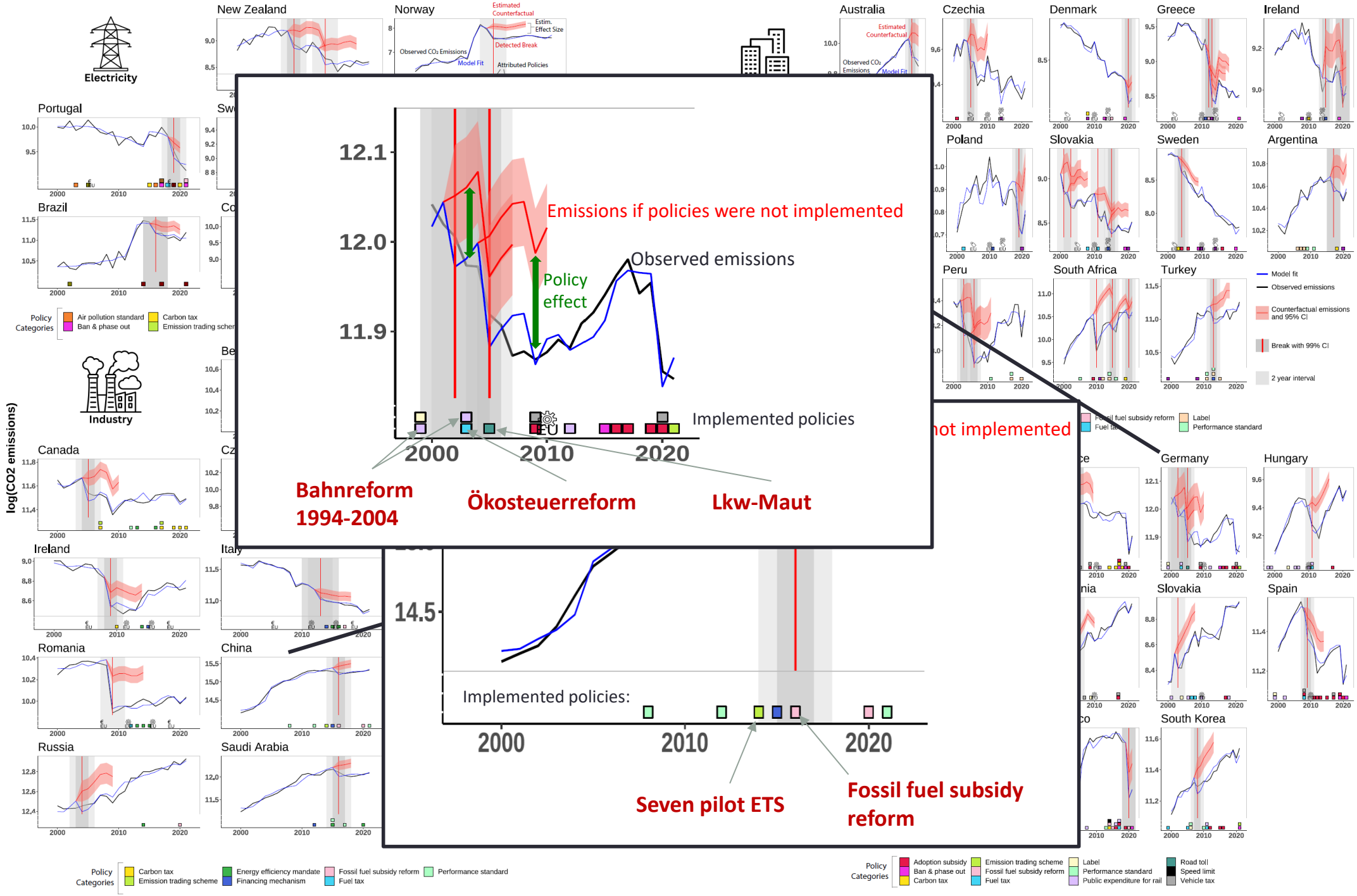
Electricity
Industry
log(CO2 emissions)
New Zealand
Norway
Estimated Counterfactual
Estim. Effect Size
Observed CO₂ Emissions
Model Fit
Detected Break
Attributed Policies
Australia
Czechia
Denmark
Greece
Ireland
Portugal
Poland
Slovakia
Sweden
Argentina
Brazil
Peru
South Africa
Turkey
Model fit
Observed emissions
Counterfactual emissions and 95% CI
Break with 99% CI
2 year interval
Canada
Germany
Hungary
Ireland
Italy
Slovakia
Spain
Romania
China
South Korea
Russia
Saudi Arabia
Emissions if policies were not implemented
Observed emissions
Policy effect
Implemented policies
Bahnreform 1994-2004
Ökosteuerreform
Lkw-Maut
Implemented policies:
Seven pilot ETS
Fossil fuel subsidy reform
Policy Categories
Air pollution standard
Ban & phase out
Carbon tax
Emission trading scheme
Energy efficiency mandate
Financing mechanism
Fossil fuel subsidy reform
Fuel tax
Performance standard
Label
Public expenditure for rail
Road toll
Speed limit
Vehicle tax
Adoption subsidy