How Do Plants Respond to a Rising Carbon Tax?

Empirical evidence on energy consumption and emissions

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Motivation I

Global warming as one of the key (if not "the" key) challenges for humankind in present times

Rise in global average temperature is predicted to (IPCC, 2016)...

- increase occurrence of natural disasters (e.g. floods, storms, heat waves, cyclones)
- raise the sea level endangering living in lowland areas (e.g. the Netherlands)
- increase mortality, especially among fragile populations (children, elderly)

Overall, global warming leads to **heavily undesirable consequences** and thus substantial **welfare losses** to society!

Motivation II

Multitude of **adverse effects** of global warming...

Exposure hazard	Health impact	Confidence[a]	Link to specific effects at the organ level	Source
Intense heat	death from heat stroke	very high	heart strain, CNS malfunction, dehydration	IPCC (2014) [61][a] WHO (2014) [62][b]
	heat stroke morbidity	very high	heart strain, CNS malfunction, dehydration	IPCC (2014) [61]
	heat exhaustion	high	heart strain, mental fatigue	IPCC (2014) [61]
	loss of work capacity			
Failed local agriculture	undernutrition	high	metabolic energy loss, heart strain, loss of work capacity	IPCC (2014) [61] WHO (2014) [62]
Lack of safe water and food	water and food-borne diseases	very high	infectious intestinal diseases, diarrhoea	IPCC (2014) [61] WHO (2014) [62]
Changed ecology	vector-borne diseases	medium	malaria, dengue fever, other insect-borne diseases	IPCC (2014) [61] WHO (2014) [62]
Reduced temperatures	cold-related mortality/morbidity	low	heart strain, but respiratory disease is more prominent	IPCC (2014) [61]
Storms/floods/droughts/fires	injuries, drowning, burns	very high	injuries (any organ can be affected)	IPCC (2014) [61]
Forced migration	undernutrition, infectious diseases, mental stress	high	disease, violence and mental health problems	IPCC (2014) [61]

Health concerns not mentioned in detail in the IPCC or WHO reports		
Intense heat	chronic kidney disease linked to dehydration	Wesseling et al., 2012 [63]
	teratogenic effects of high body temperature in pregnant women, damage to brain development	Edwards et al., 1995 [64]
	interactions with prescription drugs	Vanakoski and Seppälä, 1998 [56]
	deteriorated clinical status of people with chronic non-communicable diseases	Kjellstrom et al., 2010 [7]; Parsons, 2014 [2]
Changed pollen amounts	allergies due to pollen	USEPA, 2008 [65]
Mental stress from local impacts	mental health problems, suicides, increased violence	Berry et al., 2010 [66]
Specific hazards for working people	non-heat-related health risks: vector-borne diseases, undernutrition, poisoning in the workplace	Bennett and McMichael, 2010 [67]
Societal collapse	violence, mental stress, daily needs not supplied	Butler and Harley, 2010 [68]

Motivation III

Long-term goal: Paris Agreement (2015): Global temperature rise this century well-below 2° Celsius above pre-industrial levels

How to **counter** the negative effects of global warming?

Climate policy **instruments** to reduce carbon dioxide emissions

- Market-based instruments
  - Emission trading schemes (e.g. Swiss ETS, EU ETS)
  - Taxes (e.g. carbon taxes, taxes on gasoline)
  - Subsidizing clean energy sources (e.g. solar panels; geothermal heat pumps)

This paper: Impact of a *rising* carbon tax on plant behavior

Research question

Key research question: What is the impact of the introduction of an increasing carbon tax on plant energy consumption and emissions?

- *Ex-post* analysis of the Swiss carbon tax introduced in 2008 using plant-level (panel) data for the years 2001-2015

Substantive sub-questions

- How did plants reduce emissions (if any)?
  - Analysis of **substition patterns** between different energy sources
- How do plants respond to differences in **tax-intensity** arising due to variation in their fossil fuel mix?
  - Effect heterogeneity by tax-intensity

Swiss Carbon Tax

Nationwide introduction of the CO_2-levy in 2008 (12 CHF/t)

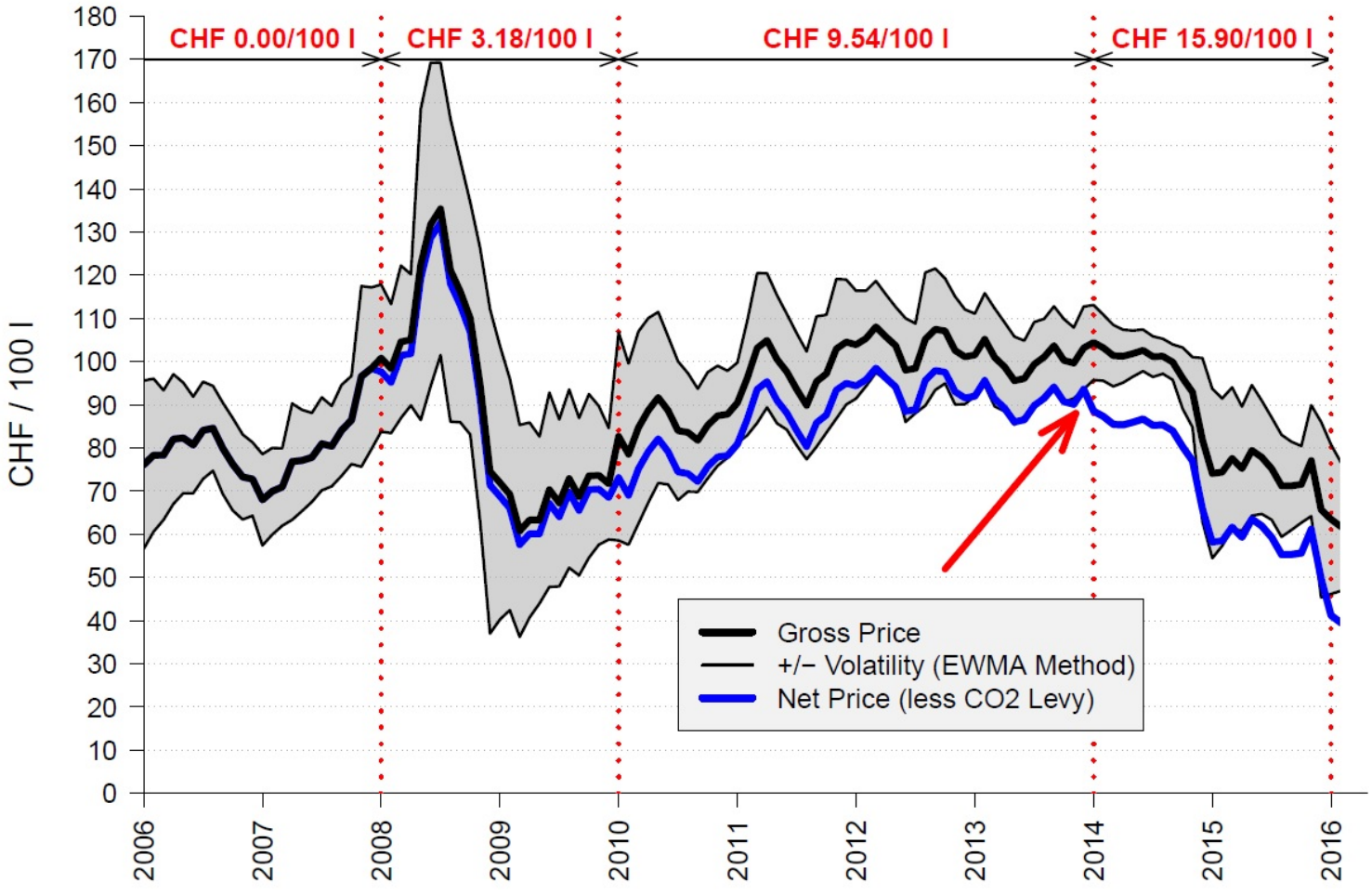
- Per unit tax on the CO_2 emissions from consumption of fossil fuels

Table: Tax burden by type of fossil fuel

Years	**Tax** CHF/t CO_2	**Light oil** CHF/TJ	**Natural gas** CHF/TJ
2008-09	12	885	673
2010-2013	36	2654	2020
2014-2016	60	4423	3366

Unique institutional setting: Carbon tax increased by 400% between 2008 and 2014 for firms active in the service and industry sector

Swiss Carbon Tax



Data I

Administrative plant-level (panel) data from the Swiss Federal Office of Energy (SFOE) for the years 2001-2015

- **Sample:** 44'909 observations from 10'290 plants active in the service and industry sector
- **Outcome variables**
  - Total energy consumption (TJ)
  - Total CO_2 emissions (tons)
  - Consumption and emissions by energy source (heavy and light oil, natural gas, wood)
    - Fossil-fuel shares (weight of, e.g., natural gas in a plants fossil fuel mix)
  - Net electricity consumption (TJ)
- Plant characteristics (number of employees, floor area, (sub)sector affiliation)

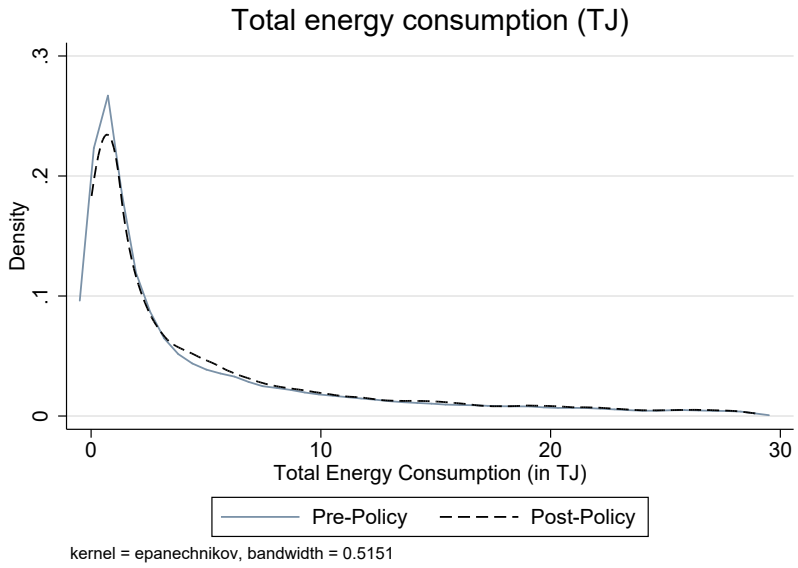
Data II

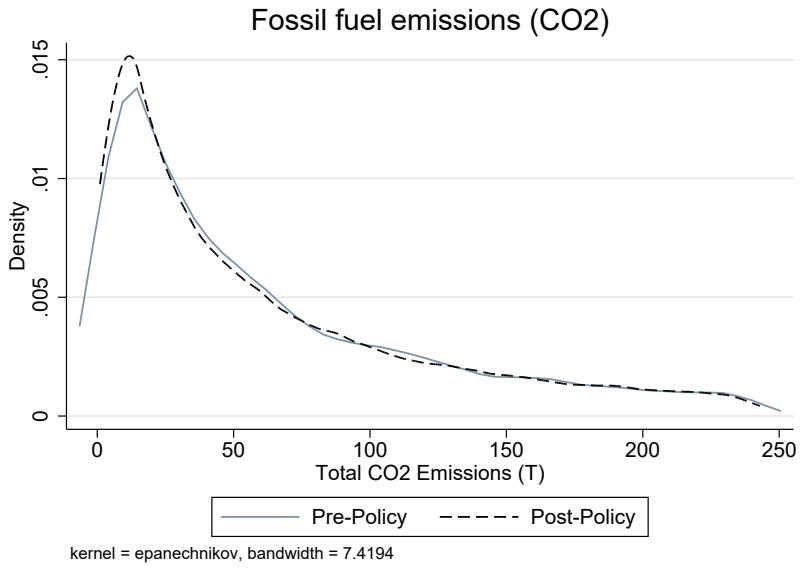
	Pre-policy			Post-policy		
	Mean	Std.Dev.	Obs	Mean	Std.Dev.	Obs
Plant outcomes						
Total Energy Consumption (in TJ)	20.88	150.05	21303	22.52	143.75	23606
Total CO_2 emissions (in tons)	611.94	4038.56	21303	589.46	3497.70	23606
Light oil (in TJ)	2.46	7.99	21303	1.73	5.47	23606
Share light oil (% fossil fuel mix)	0.70	0.44	21086	0.58	0.48	23521
Natural gas (in TJ)	6.29	58.75	21303	7.67	58.03	23606
Share natural gas (% fossil fuel mix)	0.30	0.44	21086	0.42	0.48	23521
Electricity consumption (in TJ)	8.86	69.38	21303	9.58	60.30	23606
Share electricity (% total energy cons.)	0.41	0.24	21303	0.46	0.24	23606
Plant characteristics						
Service sector	0.47	0.50	21303	0.48	0.50	23606
Full-time employees	96.46	185.16	21303	122.83	252.15	23606
Part-time employees	21.57	79.18	21303	32.98	108.69	21454
Gross Floor Area (m^2)	9089.84	24081.56	21303	10784.02	24916.98	23606

- Slight drop in average emissions post-policy ($\approx$ -20 tons)
- Shift away from light oil to natural gas and electricity consumption

Data III

Big picture: Energy consumption (in TJ) and emissions (in tons)

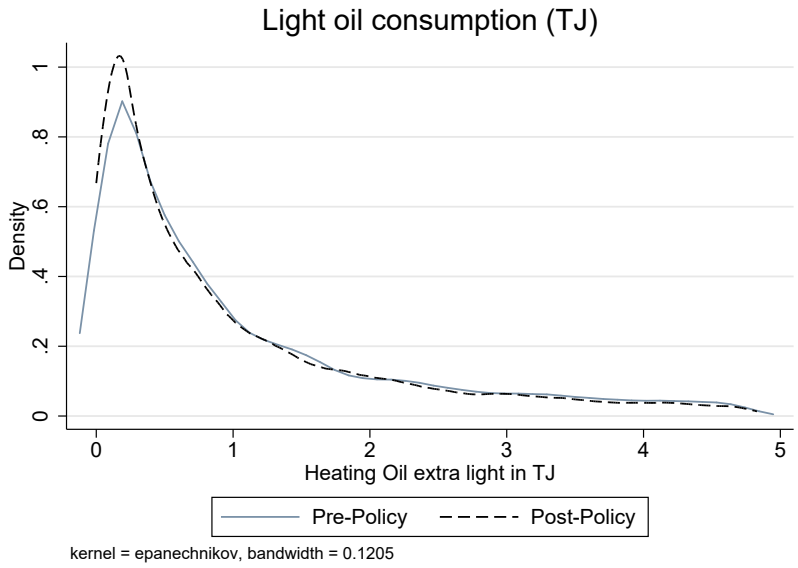


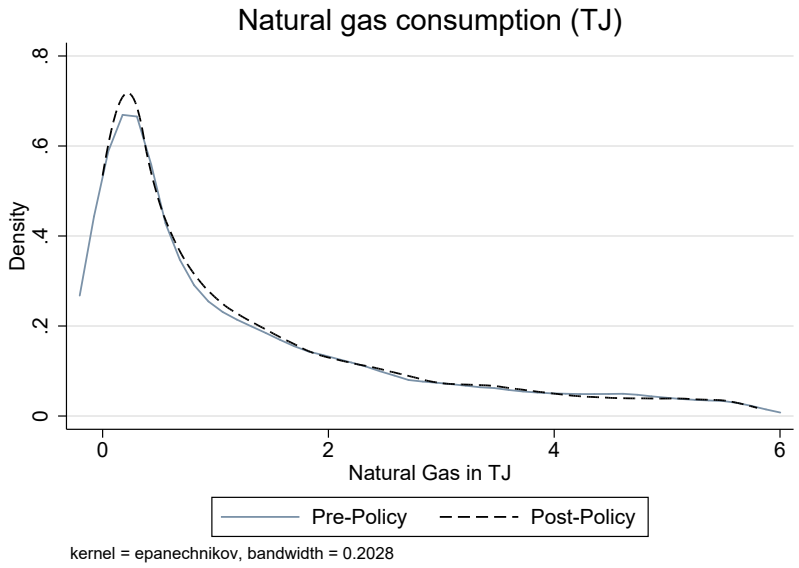


- Low amounts of energy consumption less likely post-policy
- Low amounts of emissions significantly more likely post-policy

Data IV

Big picture: Light oil and natural gas consumption (in TJ)

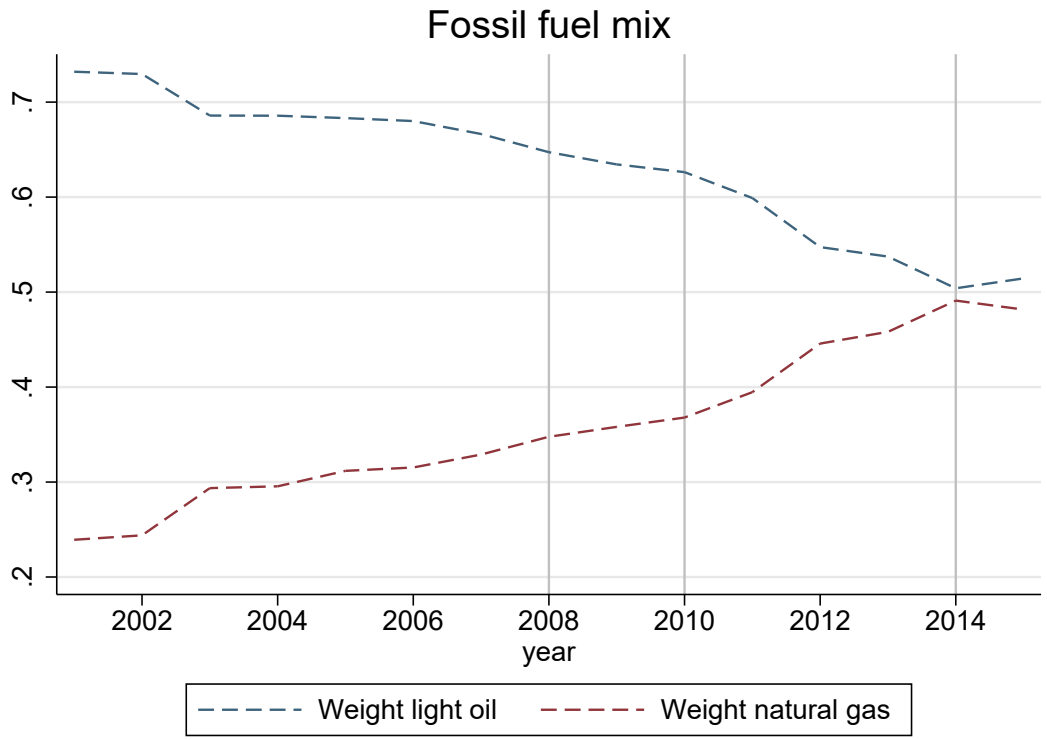




- Drastic reduction in light oil consumption post-policy
- Slight increase in natural gas consumption post-policy

Data V

Big picture: Evolution of fossil-fuel mix



- Distinct trend away from light oil towards natural gas starting in the early 2000s

Empirical strategy

Empirical goal: Estimate the impact of the time-varying carbon tax on plant energy consumption and emissions

Key econometric challenge

- Disentangling the effects of the carbon tax from other factors determining plant emissions/consumption
  - For example, plant emissions crucially depend on firm size and technology **besides** the level of the carbon tax
  - Credible identification of the impact of the carbon tax thus hinges on the ability to convincingly isolate its impact from these other factors (i.e. selection-on-observables assumption)
- Inclusion of dynamics causes the well-known **Nickell bias**

Empirical Strategy

How to capture the impact of the carbon tax on plant behavior?

Bias-corrected dynamic fixed effects specifications to estimate the *average* policy effect

$$y_{it} = \alpha_i + \phi y_{it-1} + \tau_t D_t + \lambda t + x'_{it}\beta + A'_t\gamma + \varepsilon_{it} \quad (1)$$

- y_{it}: energy consumption/emission for plant i in year t
- α_i: plant fixed effect (capturing, e.g, production technology)
- D_t: Binary indicators for the different post-policy periods when the carbon tax was increased
- x_{it}: Time-varying plant characteristics (e.g. plant size)
- A_t: Time-varying aggregate factors (e.g. economic activity indicators, energy prices)

Results I - Average policy effects

Carbon policy effects				
Outcome Variable	**ln(Total cons)**		**ln(CO_2 Emissions)**	
$D_{2008-09}$ (12 CHF/t CO_2)	0.01	0.02***	-0.02**	-0.01
	(0.1)	(0.00)	(0.01)	(0.01)
$D_{2010-13}$ (36 CHF/t CO_2)	-0.01	0.01	-0.06***	-0.05***
	(0.01)	(0.01)	(0.01)	(0.01)
$D_{2014-15}$ (60 CHF/t CO_2)	-0.04***	0.00	-0.12***	-0.06***
	(0.01)	(0.01)	(0.02)	(0.02)
Lagged outcome	No	Yes	No	Yes
Plant fixed effects	Yes	Yes	Yes	Yes
Time trend	Yes	Yes	Yes	Yes
Plant characteristics	Yes	Yes	Yes	Yes
Economic activity indicators	Yes	Yes	Yes	Yes
Number of Observations	44909	28644	44909	23810

- Hardly any change in total energy consumption after the introduction of the carbon tax
- Significant and increasing (!) reduction in CO_2 emissions

Results II - Substitution patterns

Outcome Variable	**Light oil (Y/N)**		**ln(Light oil)**		**Natural gas (Y/N)**		**ln(Natural gas)**		**ln(Electricity)**	
$D_{2008-09}$ (12 CHF/t CO_2)	0.01	0.00	-0.03*	-0.03*	0.00	0.01*	-0.04	-0.02	0.03***	0.03***
	(0.00)	(0.00)	(0.02)	(0.02)	(0.00)	(0.00)	(0.02)	(0.02)	(0.01)	(0.01)
$D_{2010-13}$ (36 CHF/t CO_2)	-0.02***	0.00	-0.10***	-0.09***	0.01**	0.00	-0.05	-0.04	0.01	0.03***
	(0.01)	(0.01)	(0.02)	(0.02)	(0.00)	(0.00)	(0.03)	(0.03)	(0.01)	(0.01)
$D_{2014-15}$ (60 CHF/t CO_2)	-0.03***	0.00	-0.21***	-0.08**	0.02***	0.01	-0.10**	-0.06*	-0.03**	0.01
	(0.01)	(0.01)	(0.03)	(0.03)	(0.01)	(0.01)	(0.04)	(0.03)	(0.01)	(0.01)
Lagged outcome	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
Plant fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time trend	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Plant characteristics	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Economic activity indicators	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of Observations	44909	28399	32628	20387	44909	28399	18406	11334	44909	28399

- Significant negative impact of the carbon tax on light oil consumption both at the intensive and extensive margin
- Significant reduction in natural gas consumption but (!) higher likelihood of choosing natural gas post-policy

Empirical Strategy

How to capture the response of plants exposed to different **tax-intensities** based on their fossil-fuel mix?

$$y_{it} = \alpha_i + \alpha_i t + \tau D_{it} + x'_{it}\beta + \varepsilon_{it} \quad (2)$$

- y_{it}: energy consumption/emission for plant i in year t
- α_i: plant fixed effect (capturing, e.g, production technology)
- $\alpha_i t$: plant-specific time trend
- D_{it}: $=1$ for pure light oil consumer (pre-policy); $=0$ if pure natural gas consumer
- x_{it}: Time-varying plant characteristics (e.g. plant size)

Results III - Tax intensity estimates

Outcome Variable	**ln(CO_2 Emissions)**		
High $tax_{2008-09}$	-0.03	-0.03	-0.04*
	(0.03)	(0.03)	(0.02)
High $tax_{2010-13}$	-0.10**	-0.11***	-0.07*
	(0.04)	(0.04)	(0.04)
High $tax_{2014-15}$	-0.12**	-0.13**	-0.07
	(0.05)	(0.05)	(0.05)
Plant characteristics	Yes	Yes	Yes
Plant fixed effects	Yes	Yes	Yes
Year fixed effects	Yes	No	Yes
Sector-year fixed effects	No	Yes	No
Plant-specific time trends	No	No	Yes
Number of Observations	28809	28809	28809

- Tax intensity significantly influences plant emissions
- Emission reductions increase with the tax burden

Conclusion

So, how do plants respond to a rising carbon tax?

- Significant and increasing reductions in emissions as a response to the carbon tax (up to -12%***)
- Substitution of light oil with natural gas
- Significant reductions in both consumption of light oil and natural gas post-policy
- Plants with a carbon-intensive fossil fuel mix show a stronger response to the carbon tax
- Similar response to the carbon tax in terms of emission reductions both in the service and industry sector
- Results are robust to a series of robustness checks (balanced panel, constant fossil fuel mix sample, etc.)

Thank you for your attention!