Renewable Energy and its Impact on Thermal Generation

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POWER SYSTEMS WITH RENEWABLES

- Competitive advantage of renewables in terms of marginal cost
  - Thermal generation units at risk
  - Which specific units affected depends on the amount of installed renewable capacity
  - Result: Lower average spot market prices [see, e.g., Green and Vasilakos, 2010, Woo et al., 2011, Würzburg et al., 2013, Paraschiv et al., 2014, Clò et al., 2015], and also change in price variance [see, e.g., Wozabal et al., 2015]
- Renewables lead to less emissions in the power sector. Effects highly heterogeneous [see, e.g., Novan, 2015, Graff Zivin et al., 2014, Cullen, 2013]
  - Spatial: Across markets, depending on the power generation mix
  - Within-markets
    - Temporal: Across time/demand
    - Impact depends on the amount of installed renewable capacity

Power systems with renewables (cont'd)

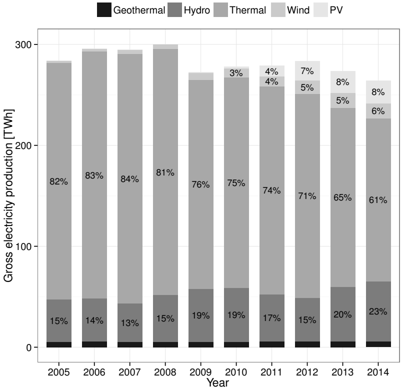
- What about emission factors?
  - Short-run
    - Excessive load-cycling may lead to higher emissions relative to output
    - Part-load operation (lower capacity factor)
  - Long-run: Market pressure may lead to investment in more efficient/flexible thermal plants

What's the Exact Effect?

Katzenstein and Apt [2009]: CO_2 emissions may be 20% higher than expected if power fluctuations caused no additional emissions

Power systems with renewables (cont'd)

- Empirical study of the Italian power market
- Intermittent renewables: Wind and photovoltaics (PV)
- Time span: 2005 to 2014



Research question

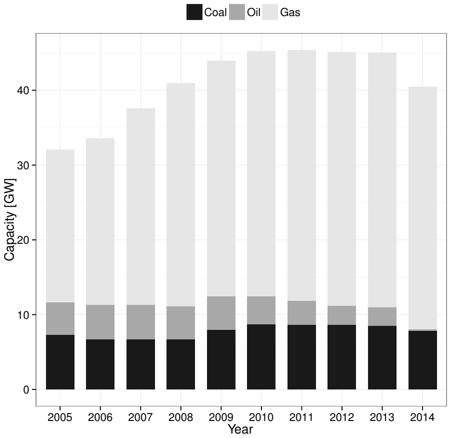
How do thermal plant emission factors change if the system is challenged by intermittent renewables?

COMBING VARIOUS DATA SOURCES

1. Gestore dei Mercati Energetici (GME)
   - Accepted spot market bids (day-ahead,intra-day, and balancing), hourly on generation unit level
2. EU ETS Transaction log
   - Verified CO_2 emissions, yearly on installation level
3. REF-E (Italian consulting company)
   - Power plant database
4. TERNA (TSO), ENTSO-E
   - Data on infeed from renewables, consumption, imports/exports

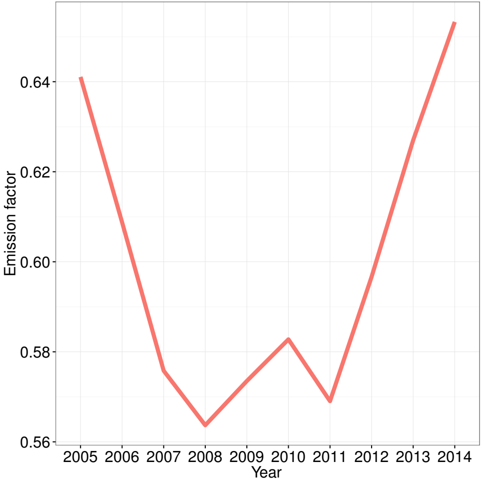
MATCHING

- 93/98 matched installations (219 generators)
- 73% of Italy's total thermal production
- 96% of Italy's emissions in the power sector



EMISSION FACTORS

- $\forall i = 1, \ldots, 93$ and $t = 2005, \ldots, 2014$
- Emissions: $E_{i,t}$
- Awarded spot market quantities: $Q_{i,t}$
- Emission factor: $\phi_{i,t} = \frac{E_{i,t}}{Q_{i,t}}$



ECONOMETRIC MODEL

$$\ln(\phi_{i,t}) = \beta_1 \ln(D'_t) + \beta_2 \ln(R_t) + \beta_3 X_{i,t} + \epsilon_{i,t} \quad (1)$$

- System-specific explanatory variable: $D'_t = (D_t - H_t - I_t)$ and generated electricity from wind and photovoltaics (R_t)
- Installation-specific explanatory variables: FE for each installation, commissioning year $Y_{i,t}$, and the fuel cost structure $F_{i,t}, (X_{i,t} = (Y_{i,t}, F_{i,t}))$
- $\epsilon_{i,t} = \mu_i + \nu_{i,t}$, whereas μ_i denotes the unobservable installation-specific fixed effect and $\nu_{i,t} \sim \text{IID}(0, \sigma^2_\nu)$

IDENTIFICATION

1. Baseline regression using all thermal installations (all)
2. Only base-load installations (base)
3. Only peak-load installation (peak)
4. Only installations which have changed capacity during the period (new)
5. Accounting for Italy's zonal market (zonal)

REGRESSION RESULTS

	(all)	(base)	(peak)	(new)	(zonal)
Residual demand	−0.119	−0.093	0.102	−.082	
	(0.096)	(0.116)	(0.195)	(0.078)	
Renewables	0.025**	0.022**	0.051*	0.021	
	(0.008)	(0.008)	(0.021)	(0.011)	
Commissioning year	−27.345***	−18.953**	−7.626	−26.226***	−26.135***
	(6.076)	(5.202)	(10.120)	(6.508)	(6.499)
Fuel cost structure	−0.005	−0.031	0.044	0.016	0.003
	(0.031)	(0.042)	(0.062)	(0.054)	(0.003)
Residual demand (zone)					−0.107*
					(0.029)
Renewables (zone)					−0.010*
					(0.004)
R^2 within/between	0.23/0.50	0.17/0.59	0.13/0.08	0.23/0.39	0.22/0.49
Observations	723	510	213	249	723
Installations	89	65	27	28	89

Notes: Robust standard errors clustered by installation reported in parentheses. Asterisks indicate statistical significance at 5% (*), 1% (**), and 0.1% (***) levels.

So What?

- Share of increased inefficiency in comparison to offset emissions?
  - First order effect $((\mathrm{d}\ln(E_{i,t}))/(\mathrm{d}\ln(R_t)) = \beta_2')$

	(all)	(base)	(peak)	(new)	(zonal)
β_2	0.025	0.022	0.051	0.021	0.010
β_2'	−0.315	−0.250	−0.686	−0.369	−0.113
$\beta_2'/(\beta_2' - \beta_2)$	93%	92%	93%	95%	92%

Discussion and Policy Consequences

- Renewable production *increases* emission factors of the average plant
  - (Absolute) effect even stronger when considering only peak-load plants
  - Evidence of long-term effect (coefficient of renewables not statistically significant if sample restricted to new plants)
- Our estimates are less pessimistic than in Katzenstein and Apt [2009]; System view is important (burden sharing!)
- Policy consequences
  - System-specific perspective: Storage, transmission, demand side management (load shifting)
  - Installation-specific perspective: Better design of thermal plants

Thank you for your attention!

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Working Paper Available!

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