The impact of renewables on electricity prices and congestion in a regime switching model: Evidence from the Italian grid

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'a mini-workshop... within a workshop'

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Motivation (I)

- **Energy islands** in the EU 2030 Energy and Climate Package: Baltic states, Cyprus, ...
- ... and **Sicily**
  - Only connected with the Italian peninsula (Calabria)
  - 1000 MW interconnection capacity
    $\Rightarrow$ Line congested in import for about 75% of the hours in 2012
  - Little competitive pressure
  - Soaring renewable energy (RE) supply (15.4% wind, 7.5% PV), but lack of hydropower (only 2.3% of total electricity supply) for flexibility and storage
  - Strategic for the interconnection between Italy and Northern Africa (if political conditions allow it)

Motivation (II)

- **Merit order effect** of RE...
  - Saenz de Miera et al. (2008), Twomey and Neuhoff (2010), Sioshansi (2011), Ketterer (2014)
- ...possibly offset by a **congestion effect**
  - North Norway: RE crowding out hydropower and causing congestion (Førsund et al. 2008)
  - Germany: Kunz (2013)
  - Guerci and Sapio (2012): simulations on the Italian grid

Motivation (III)

- Risks
  - Threatening to offset the benefits from increased transport capacity (Sorgente-Rizziconi cable)
  - If there is a differential impact on congestion in import and in export, location-specific impact of RE

    $\Rightarrow$ Subsidizing renewables irrespective of their location: inefficient
- But RE may *relieve* congestion
  - RE can be a substitute for imported electricity
  - Distributed RE are substitutes for transport capacity

This paper

- Goals
  - The impact of renewables on congestion in the Sicily-Southern Italy transmission line
  - Congestion effect vs. merit order effect
- Methods
  - Regime switching model of electricity prices with *known* regimes...
    - congestion/ no congestion (Haldrup and Nielsen 2006)
  - ...but with endogenous switching
    - depending on demand and RE supply

Model (I)

- Two market zones, a and b
  - D_{it}: electricity demand
  - R_{it}: renewable energy supply
  - P_{it}: price remunerating conventional plants
    ($i \in \{a, b\}$, $t =$ time)
- Linked by a cable of capacity K, congested with probability π_t
  - Zonal separation if congestion $C_t = 1$
    $\Rightarrow P_{at} \neq P_{bt}$
  - Zonal integration if congestion $C_t = 0$
    $\Rightarrow P_{at} = P_{bt} = P_t$

Model (II)

- **Price equation**, zone i:

$$\ln P_{it} = C_t \ln P_{it}^{c} + (1 - C_t) \ln P_{it}^{nc} \tag{1}$$

where c: *congested*, nc: *non congested*

- **Switching equation**:

$$\pi_t \equiv Prob\{C_t = 1 | \mathbf{x}_{it}\} = \frac{e^{\mathbf{x}_{it}'\eta}}{1 + e^{\mathbf{x}_{it}'\eta}} \tag{2}$$

where $\mathbf{x}_{it} = \{D_{at}, D_{bt}, R_{at}, R_{bt}\}$

- In what follows: Derive an expression for price in each regime (congested / non-congested)

Model (III)

Non congested regime

- National supply function

$$S_t = R_t + \alpha_t P_t^{\beta} \tag{3}$$

  - $\alpha_t, \beta > 0$
  - $D_t = D_{at} + D_{bt}$
  - $R_t = R_{at} + R_{bt}$

- Market clearing: $S_t = D_t$, hence:

$$P_{it}^{nc} = \left(\frac{D_t - R_t}{\alpha_t} \right)^{\frac{1}{\beta}} \tag{4}$$

and after a reparametrization,

$$\ln P_{it}^{nc} = \theta_t + \gamma \ln(D_t - R_t) \tag{5}$$

Model (IV)

Congested regime

$$\ln P_{it}^{c} = \theta_{it} + \gamma_i \ln(D_t - R_t) \tag{6}$$

- ...if the zonal supply function has the same shape as the national one
- θ_t and θ_{it} can depend on market power and fuel costs

Model (V)

- Replacing Eq. 5 and 6 in Eq. 1, for zone i:

$$\ln P_{it} = C_t \left[\theta_{it} + \gamma_i \ln(D_{it} - R_{it})\right] + (1 - C_t) \left[\theta_t + \gamma \ln(D_t - R_t)\right] \quad (7)$$

- Conditional expectation of the zonal price, $\overline{\ln P_{it}}$:

$$\overline{\ln P_{it}} = \pi_t \left[\theta_{it} + \gamma_i \ln(D_{it} - R_{it})\right] + (1 - \pi_t) \left[\theta_t + \gamma \ln(D_t - R_t)\right] \quad (8)$$

Model (VI)

How elastic is the electricity price in a zone to changes in its RE supply?

$$\frac{\partial \overline{\ln P_{it}}}{\partial \ln R_{it}} = \underbrace{-\pi_t \gamma_i \frac{\frac{R_{it}}{D_{it}}}{1-\frac{R_{it}}{D_{it}}} - (1-\pi_t)\gamma \frac{\frac{R_t}{D_t}}{1-\frac{R_t}{D_t}}}_{merit-order-effect} + \tag{9}$$

$$+ \underbrace{\eta_{Ri}\pi_t(1-\pi_t)\left[\theta_{it} - \theta_t + \ln \frac{D_{it}^{\gamma_i}}{D_t^{\gamma}} + \ln \frac{(1-\frac{R_{it}}{D_{it}})^{\gamma_i}}{(1-\frac{R_t}{D_t})^{\gamma}}\right]}_{congestion-effect}$$

- R_{it}/D_{it}: RE penetration rate in zone i

Econometric specifications

Table : Model specifications.

Specif.	**RE sources** in switching eq.	**Frequency**	**Filters**
1	total n.d. RE	hourly	none
2	total RE	”	”
3	solar, wind, geo	”	”
4	solar, wind, geo, hydro	”	”
5	total n.d. RE	daily	VPF (Janczura et al.)
6	total RE	”	”
7	solar, wind, geo	”	”
8	solar, wind, geo, hydro	”	”

Zone of interest: **Sicily**
Connected zone: **rest of Italy** (South + Center-South + Center-North + North + Sardinia)

Estimation methods

- MLE
  movestay Stata package (Lokshin and Sajaia 2004)
  - Problem: lack of convergence in daily series
- Two-Stage Residual Inclusion (Terza et al. 2008)
  - 1^{st} stage: MLE of logit congestion model
  - 2^{nd} stage: MLE of log-linear price model, including residuals from the 1^{st} stage, with bootstrapped standard errors
  - Consistency advantage with respect to e.g. two-stage predictor substitution

Data

- Italian Power Exchange (IPEx) data
  - Day-ahead market
  - Uniform price auction
  - Zonal pricing
- Data sources
  - Prices, demand, residual supply: GME (market operator) - www.mercatoelettrico.org
  - Congestion: dummy equal to 1 when Sicilian price differs from the price in the South zone, 0 otherwise.
  - RE supply by source (wind, solar, hydro, geothermal): Terna (TSO) - www.terna.it/
- Period: Jan 1, 2012 - Sep 30, 2013

Results: hourly (non filtered) series

Table : Price equation estimates. Dependent variable: log-price in Sicily.

	(1)		(2)		(3)		(4)	
Non congested								
$\ln(D_t - R_t)$, n.d.	0.671***	(17.71)			0.745***	(20.60)		
$\ln(D_t - R_t)$			0.724***	(16.58)			0.669***	(17.61)
Constant	-3.200***	(-9.04)	-3.488***	(-8.17)	-3.851***	(-11.18)	-3.068***	(-8.20)
Daily dummies	yes		yes		yes		yes	
Congested								
$\ln(D_t - R_t)$, n.d.	0.637***	(7.67)			0.639***	(7.53)		
$\ln(D_t - R_t)$			0.478***	(3.70)			0.419***	(3.63)
ln RSI, t	0.0250***	(6.72)	0.0316***	(6.51)	0.0253***	(6.71)	0.0351***	(8.28)
Constant	-0.212	(-0.35)	0.976	(1.03)	-0.228	(-0.37)	1.387	(1.64)
Daily dummies	yes		yes		yes		yes	
Observations	15336		15336		15336		15336	

t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Results: hourly (non filtered) series

Table : **Switching equation** estimates. Dependent variable: congestion between Sicily and South.

	(1)		(2)		(3)		(4)	
r. of Italy regressors								
ln D_t	-0.551***	(-4.33)	-1.041***	(-8.35)	-0.928***	(-6.08)	-0.877***	(-6.72)
ln R_t, non disp.	-0.0742**	(-2.82)						
ln R_t			0.321***	(7.20)				
ln Wind					-0.0571**	(-2.80)	-0.0441**	(-2.61)
ln PV					0.169***	(9.36)	0.104***	(6.88)
ln Geoth.					1.609***	(4.35)	0.839**	(2.58)
ln Hydro							0.236***	(7.34)
ln Pump st.							-0.0452***	(-7.74)
Sicilian regressors								
ln D_t	3.528***	(19.09)	3.802***	(17.28)	3.588***	(19.12)	2.064***	(11.62)
ln R_t, non disp.	-0.260***	(-7.83)						
ln R_t			-0.270***	(-8.64)				
ln Wind					-0.220***	(-7.56)	-0.147***	(-7.92)
ln PV					-0.247***	(-9.48)	-0.157***	(-7.20)
ln Hydro							0.0613***	(5.49)
ln Pump st.							-0.0872***	(-10.47)
Constant	-18.01***	(-20.28)	-18.68***	(-18.80)	-25.53***	(-9.33)	-11.90***	(-4.55)
Daily dummies	yes		yes		yes		yes	
Observations	15336		15336		15336		15336	

t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Results: daily filtered series, total non-dispatchable RE

	Price eq.		Switching eq.	
Hour	γ_{Sicily}	γ	$\eta_{RE,Sicily}$	$\eta_{RE,RoI}$
1	0.405***	0.732***	-0.669***	0.122
2	0.239***	0.284	-0.514***	-0.540**
3	0.341**	0.498**	-0.492***	-0.390
4	0.407***	0.471**	-0.499***	-0.346
5	0.229**	0.358*	-0.420***	-0.412
6	0.279***	0.603**	-0.592***	-0.270
7	0.370***	0.695***	-0.785***	-0.018
8	0.551***	0.552*	-1.608***	-0.238
9	0.435***	0.572	-2.193***	0.868
10	0.435***	0.566	-2.861***	1.392*
11	0.253***	-0.285	-3.554***	1.078
12	0.435***	0.564	-3.382***	0.531
13	0.447***	-0.121	-2.893***	0.622
14	0.625***	0.600	-2.283***	0.759
15	0.369***	0.731	-1.891***	0.513
16	0.367***	-0.052	-1.538***	0.590
17	0.359***	0.699	-1.970***	1.182***
18	0.391***	0.429	-2.526***	1.393***
19	0.409***	0.325	-2.780***	1.821***
20	0.394***	0.544	-1.086**	-0.291
21	0.293***	0.383	-1.281**	0.567
22	0.301***	0.819	-1.606***	0.270
23	0.168***	-0.016	-1.500***	-0.224
24	0.219***	0.032	-0.875***	-0.137

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Results: daily filtered series, separate non-disp. RE

	Price eq.		Switching eq.			
Hour	γ_{Sicily}	γ	$\eta_{wind,Sicily}$	$\eta_{wind,RoI}$	$\eta_{solar,Sicily}$	$\eta_{solar,RoI}$
1	0.400***	0.703***	-0.662***	0.067		
2	0.240***	0.310	-0.532***	-0.220		
3	0.351***	0.551**	-0.490***	-0.298		
4	0.422***	0.522***	-0.481***	-0.247*		
5	0.238***	0.435**	-0.428***	-0.192		
6	0.283***	0.648**	-0.607***	-0.097		
7	0.375***	0.732***	-0.705***	0.085	0.178	0.068
8	0.550***	0.569*	-0.907***	0.044	-0.084	0.156
9	0.452***	0.719	-0.648***	-0.161	0.330	0.586
10	0.455***	0.686	-0.859***	-0.012	-0.131	0.517
11	0.260***	-0.245	-1.019***	0.105	0.874	0.480
12	0.429***	0.552	-0.938***	0.062	0.407	-0.319
13	0.444***	-0.129	-1.127***	0.238	-0.711	0.072
14	0.630***	0.632	-0.929***	0.199	-0.765*	0.354
15	0.394***	0.784*	-0.825***	-0.104	-0.005	0,436
16	0.404***	0.145	-0.875***	0.001	0.125	0.200
17	0.356***	0.623	-1.584***	0.367	0.007	0.408
18	0.390***	0.421	-2.792***	1.052***	0.901	-1.021**
19	0.401***	0.340	-2.683***	0.961**	2.545**	0.469
20	0.392***	0.507	-1.068**	-0.177	-0.246	1.784**
21	0.293***	0.429	-1.247**	0.340		
22	0.304***	0.912	-1.635***	0.225		
23	0.169***	-0.035	-1.511***	-0.094		
24	0.221***	0.052	-0.877***	-0.044		

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Summarizing the results

- Merit order effect
  - Larger RE supply brings the electricity price down
  - Less so in the congested regime
- Congestion effect
  - Total non-dispatchable RE relievies congestion from both sides
  - Total RE (including hydro) associated with more congestion from the peninsula
  - Solar power: directional congestion effect (from the peninsula)
  - Opposite effects of wind (congestion relieving) and hydro (congestion aggravating) from both side

Thank you very much for your attention!