Renewable flows and congestion in the Italian power grid: Binary time series and vector autoregressions

Flussi di rinnovabili e congestione nella rete elettrica italiana: Serie storiche binarie e autoregressioni vettoriali

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Abstract This paper estimates the impact of renewables on congestion in the Sicily-Southern Italy transmission line, using data for 2012, through a binary autoregression of congestion probabilities, and a vector autoregressive (VAR) model that allows to explore the dynamic interactions between RE supply, market power exercise, and congestion patterns.
Abstract *In questo lavoro, viene proposta una stima econometrica dell'effetto della produzione di energia rinnovabile sulla congestione nella linea di trasmissione tra la Sicilia e l'Italia meridionale, attraverso una autoregressione binaria delle probabilità di congestione, e una autoregressione vettoriale (VAR) che consente di esplorare le interazioni dinamiche tra offerta di energia rinnovabile, esercizio del potere di mercato e congestione.*

Key words: Renewable energy sources, electricity market, transmission grid, congestion, logit, VAR.

1 Introduction

The Sorgente-Rizziconi cable is a 380 kV line that by 2016 will bring the interconnection capacity between Sicily and the Italian peninsula from the existing 1000 MW to 3000 MW. This would relieve the bottleneck that led to higher prices in Sicily than in the rest of the country for about 80% of the hours in 2012, put local generators under competitive pressure, and improve the expected returns from interconnection between Italy and Northern Africa (see the book edited by Cambini and Rubino, 2014). However, the soaring renewable energy (RE) penetration rates at both ends of the cable may impact on the congestion probability and on the *direc-*

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tion of congestion depending on the location of new RE plants, threatening to offset the benefits from increased transport capacity.

Based on data from the Italian Power Exchange (Section 2), the paper seeks to understand the impact of renewables on congestion in the Sicily-Southern Italy transmission line by means of a binary autoregression of congestion probabilities (Section 3), and a vector autoregressive (VAR) model (Section 4). Conclusions are in Section 5.

2 Data and variables

Electricity market data for the year 2012 have been collected from the Italia Power Exchange (IPEX) website (www.mercatoelettrico.it), concerning the wholesale day-ahead market.[1] These hourly-frequency data include: zonal prices in Euros/MWh, zonal sold and purchased quantities in MWh, and zonal market power indicators (Herfindahl-Hirschmann Index, HHI; and Residual Supply Index, RSI).Sold quantities for individual RE technologies (wind, photovoltaics, hydropower, fossil fuels) are also used. For each variable and zone, 8760 data points are available.

Three different congestion indicators are alternatively taken as dependent variables. *Congestion* is a binary variable equal to 1 when prices in Sicily and in the South zone differ, 0 otherwise. Following Haldrup and Nielsen (2006), directional *congestion from Sicily* is equal to 1 when the Sicilian electricity price is lower than in the South zone, 0 otherwise; and *congestion to Sicily* equal to 1 when the Sicilian price is higher. Summary statistics for the sample are given in Table 1.[2] The line that is most often congested connects Sicily with the limited production pole of Rossano, in Calabria, which is in turn linked with the South zone. Sicily is also relatively rich in renewables, with a 15% penetration rate in 2012, well above a national average of about 5%.

3 Logit analysis

A first econometric exercise concerns the estimation of a *dynamic* logit model, i.e. a logit model that handles time dependencies by including lagged values of the

[1] The wholesale market is run 24/7 with a hourly frequency. When the transmission lines are used below capacity, the same price is received by all generating companies across Italy. Whenever congestion arises, the market is split in up to 6 zones (North, Center-North, Center-South, South, Sicily, and Sardinia), 5 limited production poles, and 6 virtual foreign zones, and zonal prices dispersion arises.

[2] Unit root tests (Augmented Dickey-Fuller, Phillips-Perron) performed on the time series of electricity prices, demand, and supply variables cannot reject the null of stationarity. Hence, no first differencing is needed before performing the econometric analysis.

Table 1 Summary statistics.

	Units	Obs.	Rel. freq.		Min	Max
Congestion		8783	.841		0	1
Congestion from Sicily		8783	.085		0	1
Congestion to Sicily		8783	.756		0	1
			Mean	**Std. Dev.**		
Price, Sicily	Eur/MWh	8783	95.28	48.69	0	3000
Price (PUN), Italy	Eur/MWh	8783	75.48	22.17	12.14	324.2
Demand, Sicily	MWh	8783	2267.26	423.27	1344.61	3445.04
Demand, Italy	MWh	8783	33620.01	6849.05	19532.33	50393.79
Wind power production, Sicily	MWh	8783	334.28	308.63	0	2318
Wind power production, Italy	MWh	8783	1499.92	1092.75	11	6783
Solar power production, Sicily	MWh	8783	4.764	7.459	0	27
Solar power production, Italy	MWh	8783	107.162	152.073	0	525
HHI, Sicily		8783	3249.96	663.26	1358.27	6777.84
RSI, Sicily		8783	139.93	224.46	0	2141.2

congestion binary variable.[3] Duration dummies are added, following Beck, Katz, and Tucker (1998), to avoid downward biases in standard errors and inefficiency, as well as day-of-week dummies.[4]

Table 2 reports estimates of logit models where the dependent variable is, alternatively, congestion, congestion from Sicily, and congestion to Sicily. Regressors include: lagged congestion, duration dummies, power demand, the outputs from non-despatchable renewables (wind and photovoltaics),[5] referred to both Sicily and the aggregate of all other zones, and market power indicators for Sicily (all in natural logarithms).[6]

The results in Table 2 (left-most columns) show that congestion is more likely to occur in hours when demand in Sicily and solar power supply in the continent are high, less likely when demand is high in the rest of Italy. Strangely enough, a larger supply of wind power from Sicily decreases the congestion rate. Market power has a negative impact on congestion, but only when measured as the HHI (there is no statistical significance attached to the RSI).

The estimates of models for directional congestion are clearer. According to the results in the central columns of Table 2, congestion from Sicily happens when Sicily shows an unfavorable balance between (low) demand and (high) RE outputs, and when this balance is reversed in the continent (high demand, low RE outputs).

[3] The logit is preferred over the probit, because it lends itself to an easier economic interpretation of the coefficients, as elasticities of the log-odds of congestion with respect to the explanatory variables.

[4] Duration dummy d_k is equal to 1 if the k hours elapsed from the last congestion episode. Duration dummy coefficients are not reported for space reasons. The constant is omitted due to multicollinearity issues.

[5] Outputs from hydropower and fossil-fueled plants are not explicitly included, because they are set strategically, but their effects are captured by market power indicators.

[6] Market power indicators for the rest of Italy are not considered, as for most hours, continental Italy and Sardinia constitute an approximately competitive macrozone. The minimum of the RSI is zero, hence the logarithm has been taken after adding 1.

Both market power indicators enter significantly in the regressions, with positive signs. The opposite patterns characterize congestion when energy flows from the continent to Sicily (right-most columns): congestion probabilities are positively correlated with Sicilian demand and rest-of-Italy RE supply, negatively correlated with continental demand, Sicilian RE outputs, and Sicilian market power. Overall, market power exercise in Sicily seems to exacerbate power flows from Sicily to continental Italy. Interestingly, flows of solar power from the continent significantly affect congestion, whereas wind power supply does not.

Table 2 Dynamic logit models of congestion and directional congestion - Sicily-South transmission line

	Congestion		**Cong. from Sicily**		**Cong. to Sicily**	
Congestion, *t*-24	0.710***	0.867***				
	(8.16)	(10.08)				
Cong. from Sicily, *t*-24			1.283***	1.350***		
			(9.07)	(9.14)		
Cong. to Sicily, *t*-24					1.366***	1.562***
					(16.29)	(18.49)
log Demand, Sicily	3.104***	3.436***	-2.883***	-4.989***	3.146***	4.760***
	(7.60)	(8.16)	(-5.12)	(-8.14)	(7.40)	(10.37)
log Demand, rest of Italy	-0.511	-2.151***	1.691***	3.659***	-0.739*	-3.252***
	(-1.51)	(-6.84)	(3.66)	(7.89)	(-2.08)	(-9.44)
log Wind, Sicily	-0.308***	-0.295***	0.168**	0.220***	-0.308***	-0.321***
	(-6.77)	(-6.46)	(2.92)	(3.66)	(-7.01)	(-7.21)
log Wind, rest of Italy	-0.0874	-0.156**	-0.141	-0.0234	0.0240	-0.0602
	(-1.57)	(-2.78)	(-1.86)	(-0.30)	(0.44)	(-1.07)
log Solar, Sicily	-0.0870	-0.284***	0.791***	1.105***	-0.339***	-0.640***
	(-1.05)	(-3.57)	(4.83)	(6.30)	(-3.73)	(-7.00)
lof Solar, rest of Italy	0.0943*	0.201***	-0.637***	-0.857***	0.307***	0.464***
	(2.46)	(5.45)	(-8.21)	(-10.30)	(7.16)	(10.71)
log HHI, Sicily	-1.747***		0.669**		-1.702***	
	(-11.80)		(3.04)		(-10.97)	
log RSI, Sicily		0.0260		0.302***		-0.114***
		(1.62)		(12.02)		(-6.84)
Observations	8747	8747	6100	6100	8700	8700

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

4 VAR analysis

Time dynamics in market power indicators is hardly exogenous for more than a reason: generating companies have more room to exercise market power under congestion. Additionally, larger RE production translates into lower residual demand and hence is expected to tighten competition.

A (reduced form) VARX model seems a useful way of handling the endogeneity of market power. Endogenous variables considered here are (log-)electricity prices in Sicily, (log-)market power (only the RSI), and congestion.[7] The matrix of exogenous variables includes day-of-week dummies, (log-)demand, (log-)wind outputs, and (log-)solar outputs in Sicily and in the rest of Italy.[8]

As shown by the results in Table 3, prices in Sicily display some persistency over a daily horizon (positive autoregressive coefficients), a positive dependence on the lagged RSI and on past congestion, and move along with demand and RE outputs, regardless of the geographical location of demand and supply sources. The downward pressure on electricity prices due to renewables found here confirms previous results (see the survey in Sapio 2014).

The RSI does not depend significantly on past prices, perhaps because companies participating to the market have fully exploited their learning potential, and is serially correlated over time, meaning that days of high market power tend to occur in a row. Surprisingly, lagged congestion has no effect on market power. Market power in Sicily responds negatively to RE supply wherever located. Positive drivers are demand, wind production in the rest of Italy and photovoltaic supply in Sicily.

Finally, congestion shows persistence, as in the logit model, and some dependence on lagged prices only when it is caused by energy flows from the continent. There is no dependence on lagged market power. The impact of demand and RE outputs on congestion does not depart from expectations. Notice that, here again, the impact of wind power flowing from the continent on congestion towards Sicily is not significant. To understand why, consider that wind power from the rest of Italy has also a negative impact on Sicilian market power. This in turn may stimulate supply from thermal energy sources in Sicily, making congestion *from* Sicily more likely.

5 Conclusion

The foregoing results, if confirmed by further empirical works, would imply that the installation of new wind power capacity in continental Italy should be privileged over Sicilian wind. A couple of empirical issues are yet unsolved. One is the possible collinearity of RE outputs at both sides of the Sicily-South interconnection. Another issue concerns the VAR and the assumption of linearity of the congestion equation. Estimating the Qual VAR model pioneered by Dueker (2005) seems the way to go.

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[7] The results of VAR models featuring the HHI as the market power index are available on request.

[8] The number of lags of the dependent variables is chosen according to likelihood-based criteria, that indicate a 24 hours lag.

Table 3 Vector autoregressive models of electricity prices, market power, and congestion - zone: Sicily

	Congestion		Cong. from Sicily		Cong. to Sicily	
	coeff.	*t*-stat.	coeff.	*t*-stat.	coeff.	*t*-stat.
log Price, Sicily						
log Price, Sicily (*t* - 24)	0.334***	(35.68)	0.339***	(35.00)	0.317***	(30.76)
log RSI, Sicily (*t* - 24)	0.00617***	(4.73)	0.00645***	(4.80)	0.00758***	(5.66)
Congestion (*t* - 24)	0.0378***	(4.24)				
Cong. from Sicily (*t* - 24)			-0.0214	(-1.75)		
Cong. to Sicily (*t* - 24)					0.0494***	(5.53)
log Demand, Sicily	0.781***	(21.85)	0.788***	(22.02)	0.766***	(21.30)
log Demand, rest of Italy	0.438***	(12.75)	0.437***	(12.68)	0.450***	(13.07)
log Wind, Sicily	-0.0531***	(-15.76)	-0.0546***	(-16.23)	-0.0535***	(-15.96)
log Wind, rest of Italy	-0.0236***	(-5.74)	-0.0239***	(-5.80)	-0.0236***	(-5.76)
log Solar, Sicily	-0.0531***	(-10.08)	-0.0541***	(-10.27)	-0.0528***	(-10.03)
log Solar, rest of Italy	0.00158	(0.60)	0.00188	(0.71)	0.000533	(0.20)
Constant	-7.053***	(-32.63)	-7.070***	(-32.65)	-6.987***	(-32.26)
log RSI, Sicily						
log Price, Sicily (*t* - 24)	-0.0416	(-0.64)	-0.104	(-1.56)	-0.0357	(-0.50)
log RSI, Sicily (*t* - 24)	0.477***	(52.79)	0.481***	(51.66)	0.475***	(51.27)
Congestion (*t* - 24)	-0.126*	(-2.04)				
Cong. from Sicily (*t* - 24)			-0.0995	(-1.17)		
Cong. to Sicily (*t* - 24)					-0.0731	(-1.18)
log Demand, Sicily	3.146***	(12.72)	3.083***	(12.46)	3.146***	(12.64)
log Demand, rest of Italy	2.455***	(10.32)	2.495***	(10.46)	2.447***	(10.25)
log Wind, Sicily	-0.192***	(-8.25)	-0.190***	(-8.16)	-0.189***	(-8.15)
log Wind, rest of Italy	-0.117***	(-4.12)	-0.117***	(-4.10)	-0.117***	(-4.10)
log Solar, Sicily	-0.181***	(-4.97)	-0.178***	(-4.88)	-0.180***	(-4.93)
log Solar, rest of Italy	-0.0527**	(-2.87)	-0.0566**	(-3.08)	-0.0523**	(-2.84)
Constant	-45.97***	(-30.72)	-45.73***	(-30.53)	-46.00***	(-30.64)
Congestion indices						
log Price, Sicily (*t* - 24)	0.0888***	(7.87)	-0.0362***	(-4.18)	0.0683***	(5.25)
log RSI, Sicily (*t* - 24)	-0.00180	(-1.15)	0.000205	(0.17)	0.000278	(0.16)
Congestion (*t* - 24)	0.148***	(13.77)				
Cong. from Sicily (*t* - 24)			0.278***	(25.34)		
Cong. to Sicily (*t* - 24)					0.315***	(27.95)
lacq_sici	0.472***	(10.96)	-0.369***	(-11.52)	0.779***	(17.18)
lacq_nosici	-0.106*	(-2.55)	0.241***	(7.81)	-0.314***	(-7.22)
lgen_sici_Wind	-0.0499***	(-12.31)	0.00914**	(3.03)	-0.0544***	(-12.85)
lgen_nosici_Wind	-0.0149**	(-3.01)	-0.0151***	(-4.09)	0.00115	(0.22)
lgen_sici_PhotovoltaicMeas	-0.0313***	(-4.93)	0.0177***	(3.76)	-0.0445***	(-6.70)
lgen_nosici_PhotovoltaicMeas	0.0161***	(5.05)	-0.0211***	(-8.87)	0.0336***	(10.01)
Constant	-1.834***	(-7.05)	0.687***	(3.54)	-2.304***	(-8.42)
Observations	8696		8696		8696	

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

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