Electricity market integration and volatility export effects: The case of the SAPEI cable

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Abstract: In this paper, we estimate volatility transmission patterns before and after the inauguration of a new cable linking two electricity market zones that are rich in intermittent renewables. Using daily wholesale electricity prices in Sardinia and in two neighboring market zones in the 2005-2015 time window, we focus on the effects of the SAPEI cable, fully operational since March 2011. VAR-GARCH-in-mean estimates indicate that the SAPEI cable allowed for stronger volatility transmission from a net importing zone, such as Sardinia, than towards the island, and for higher conditional correlations between prices across the cable. Moreover, volatility from Sardinia is associated with lower mean zonal prices in the Northern zone.

Keywords: Electricity; market integration; transmission; volatility; VAR-GARCH-in-mean.

1. Introduction[1]

In a highly symbolic move, the Sardinian electricity system was fully integrated with the Italian grid on March 17, 2011, as part of the celebrations for the 150th anniversary of the Italian unification. A new HVDC interconnection, named SAPEI (SArdinia-Italian Peninsula), links Fiume Santo (in Sardinia) and Latina (in the Italian mainland), covering 420 km under the sea and 15 km on land. Reaching a 1600 m depth below sea level in the Thyrrhenian Sea, it is considered the deepest submarine power cable in the world. Its total capacity is 1,000 MW at 500 kV of voltage. SAPEI is owned and operated by Terna, the Italian State-owned

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[1] We would like to thank Vania Statzu for valuable information on the Sardinian energy system, as well as participants to the Energy Finance Italia workshop (Camerino, 10 December 2015), the 2015 Energy Finance Christmas Workshop (Paris, 17-18 December 2015), and to the 16th CIRIAF congress (Assisi, 7-9 April 2016) for very constructive comments. The usual disclaimer applies.

transmission system operator. The converter stations in Latina and Fiume Santo entered into operation in 2009, and the official inauguration was held upon laying a second submarine cable.

Until 2009, Sardinia was only connected to the Italian peninsula through the Sardinia-Corse-Italy (SACOI) cable, with a smaller transmission capacity (300 MW). Before 2011, the Sardinian wholesale price was often above the average national price, signaling a chronic supply shortage in a region characterized by scarcity of hydropower sources. Meanwhile, concerns of increasing volatility in Sardinian electricity prices are raised by a number of events. A large Alcoa aluminum plant, with a capacity of 150,000 tons, was shut down in 2012, affecting industrial power demand on the island. The project of a new gas pipeline, GALSI, linking Algeria and Sardinia, would further reduce power demand by bringing on the island a substitute for electricity heating. On top of these, blossoming renewables have mitigated the Sardinian dependence on imports, which was the primary motivation behind the SAPEI cable.

In this perspective, the benefits for Sardinia of the new interconnection cannot be quantified without accounting for time-varying volatility effects. The physical integration of volatile markets (e.g. Sardinia and the newly connected, renewables-rich southern zones) may either dilute the local volatility, due to more efficient balancing of intermittent energy outputs, or it may translate into higher volatility overall, depending on the changing patterns of zonal neighborhoods implied by congestion patterns. Volatility transmission may affect the average price in neighboring zones by “exporting” the merit order effect associated with renewables.

In this paper, we explore volatility transmission issues by estimating multivariate VAR-GARCH-in-mean models, using daily data on electricity prices in Sardinia and in the other IPEx market zones in the 2005-2015 time window. We seek to compare the volatility transmission and GARCH-in-mean effects before and after the inauguration of the SAPEI cable.

The proposed research is a worthwhile endeavor for a number of reasons. First, this is a case study on the price effects of new transmission lines. Following basic economic theory, market integration should bring all local prices closer to marginal costs (e.g. Neuhoff and Newbery 2005, Boffa et al. 2010, Boffa and Sapio 2015). Yet, market integration may also lead to valuation anomalies, in which power flows against the efficient direction (Bunn and Zachmann 2010, McInerney and Bunn 2013, Bunn et al. 2015). Market power export effects have also been detected (see Ehrenmann and Neuhoff 2008, Boffa and Scarpa 2009, de Villemeur and Pineau 2012). These effects depend on the pricing mechanism at work, on the size of the link (Moselle et al. 2006) and, importantly, on intermittency of renewable sources (McInerney and Bunn 2013).

Second, this is a case study whose implications may be generalized to some extent. One key issue in decarbonization policy is how to ensure stable prices and security of supply in regions that are rich in intermittent renewables, but lack the flexibility guaranteed by hydropower (this is the case with Texas, see Woo et al. 2011, and with Sicily, e.g. Sapio 2015, Sapio and Spagnolo 2016). There is, moreover, a topological and resource similarity with the Irish-Scottish-British interconnection examined by Valeri (2009) or McInerney and

Bunn (2013), with the link between France and the Iberian countries (Ciarreta and Zarraga 2012, 2015), and with the Australian market zones (Worthington et al. 2005, Higgs 2009).

Third, the present case can give insights on the value, for long-range interconnections, of solving within-country bottlenecks. Before the *spring revolutions*, Sardinia was a candidate for the implementation of interconnections with Northern Africa (see the book by Cambini and Rubino 2014, especially the chapters by L'Abbate et al. 2014 and Sapio 2014). The effects of possible new HVDC links between Algeria and Sardinia on the north-ward flows of renewable energy have been simulated by Brand and Zingerle (2011) among others.

Upon estimating a VAR-GARCH-in-mean model, the results show that: (i) volatility transmission from Sardinia becomes stronger after the inauguration of the SAPEI cable; (ii) volatility transmission from Sardinia, a net electricity importer, is stronger than volatility transmission from South, a net exporter; (iii) volatility from Sardinia affects the mean prices in the neighboring zones, for instance it mitigates North prices, exporting the merit order effect associated with renewables; (iv) the conditional correlations between Sardinia and South prices, based on the model estimates, converge to unity after the SAPEI cable was inaugurated.

The layout of the paper is the following. Section 2 outlines the background literature. Section 3 describes the data and the econometric model. The main findings are summarized and discussed in Section 4, before the concluding remarks offered in Section 5.

2. Background

2.1 The Italian power industry

Day-ahead wholesale trading of electricity takes place in the Italian Power Exchange (IPEx), managed by State-owned Gestore dei Mercati Energetici (GME). The IPEx day-ahead market is a closed, non-discriminatory, uniform-price double auction. Each day, market participants can submit bids and offers valid for each hour of the next day, used by GME to clear the market using a merit order rule. Wholesale demand for electricity can be considered as price-inelastic. End users who have not switched to competitive retailers are served by the publicly-owned company Acquirente Unico (single acquirer), and the available evidence cast doubts on the efficacy of existing demand responsiveness programs, despite the relatively good diffusion of meters in Italy.

If transmission constraints do not bind, all day-ahead supply offers are remunerated by the same price, the System Marginal Price, except for holders of long-term contracts, who receive the contract price, and subsidized plants, receiving the regulated tariffs. The optimal dispatch solution involves the calculation of zonal prices when lines are congested, in which case the Italian grid is segmented into up to 6 market zones (North, Center-North, Center-South, South, Sicily, and Sardinia) and 5 limited production poles.

Figure 1 depicts the zonal markets in Italy, along with the transmission lines that are most relevant in this paper: SAPEI, SACOI, and the link between Center-North and Center-South. In addition, it also shows the inter-zonal differences in the diffusion of the most volatile renewable power source, wind power. As it can be noticed, Sardinia and the southern regions are the most vulnerable to wind power intermittency, unlike the northern ones. Hence they are expected to be the strongest sources of volatility transmission.

Figure 1. Map of Italy showing the zonal markets (North, Center-North, Center-South, South, Sicily, Sardinia) along with the physical links of interest for the paper (SACOI, SAPEI, and the link between Center-South and Center-North) and the installed with capacity (in varying degrees of green) as of 2010 (sources: GSE 2010; Guerci and Sapio 2012).

Based on GME Annual Reports (from 2005 to 2014), one can identify trade flows across zones. Specifically, Sardinia, and Sicily are characterized as net importers; North is a net exporter to Center-North; Center-North is a net importer from both North and Center-South; Center-South is a net importer from South and a net exporter to Center-North; South exports to both Sicily and Center-South.

2.2 Multivariate GARCH models of energy prices

Multivariate GARCH models have been widely applied to study volatility spillovers in energy markets, e.g. the linkages among the prices of different energy commodities. This is the case with Serletis and Shahmoradi (2006) on electricity and gas prices; Soytas and Oran (2011) and Sadorsky (2012) on oil prices and stock prices of energy companies; Liu et al. (2013) on carbon and energy prices, among others. Closer to our research goals, volatility spillovers among zonal or regional electricity prices have been analyzed in a number of articles.

Worthington et al. (2005) estimated a multivariate GARCH model on a dataset of zonal prices quoted on the Australian National Electricity Market (NEM). Their results highlighted that while mean spillovers were limited by physical transfer constraints, significant own-volatility and cross-volatility spillovers could be detected in all zonal markets. Using an updated dataset on the same market, Higgs (2009) focused on the effects of a new

Queensland and New South Wales Interconnector (QNI) inaugurated in 2001, and on its capacity increase occurred in 2004. Her estimates show that the the very volatile conditional correlations of the involved zonal prices narrow down after the inception of the QNI. A similar effect is detected after the introduction of the Murraylink interconnector in 2002 between South Australia and Victoria. In contrast, the prices of New South Wales and Victoria, linked from the beginning of the sample period, displayed interdependent and mean-reverting conditional correlations. Although based on a different methodology (copulas), the results in Ignatieva and Truck (2011) reveal that temporal synchronization in price spikes across regional markets that are well connected is stronger.

The France-Spain-Portugal link has been explored by Ciarreta and Zarraga (2012) using bivariate GARCH for each couple of connected countries (France-Spain, Spain-Portugal). Ciarreta and Zarraga (2015) enlarged their sample to include also Austria, Germany, and Switzerland. Evidence of dynamic conditional correlation is detected for the pairs Spain-Portugal, Germany-Austria, and Switzerland-Austria, whereas no cross volatility transmission is found between Spain and France, nor between Germany and France. This work, too, hints that market integration depends largely on increasing interconnections and on efficient rules of market operation.

The Sardinian case shares analogies also with the triangular interconnection patterns involving Ireland, England, and Scotland. An interconnector between Ireland and Wales, indeed, has been incepted in 2012, adding to the existing HVDC between Scotland and Northern Ireland. Irish electricity prices have been historically higher than in Great Britain, signaling a supply shortage on the green island, which is mainly satisfied through fossil fuel imports and increasingly by means of wind power supply. This case, however, has mainly been explored through simulations, with the goals of assessing the efficiency of the regional markets (Devitt et al. 2011), understanding the effects of physical integration on renewable energy investments (Diffney et al. 2009, Denny et al. 2010) as well as what interconnector size is needed to make Ireland and Great Britain fully integrated and competitive (Valeri 2009). The econometric analysis in McInerney and Bunn (2013) shows that auction prices for transmission rights are undervalued against the expected arbitrage direction, an inefficiency presumably caused by wind intermittency, the Irish pricing rules, and market power by dominant generators.

Concerning the Italian power exchange, in previous research Bollino and Polinori (2008) estimated contagion among zonal Italian markets through a simultaneous equations model. Reg-ARFIMA-GARCH models have estimated, using zonal Italian prices, by Gianfreda and Grossi (2012). Sapio (2015) and Sapio and Spagnolo (2016) estimated regime-switching models to investigate the congestion patterns involving Sicily, whereas a broader analysis of congestion in the Italian grid is performed in the on-going work by Ardian et al. (2015). Finally, results from Multivariate GARCH are useful to assess the efficiency and feasibility of markets for transmission rights and the design of optimal hedging strategies, as done by Malo and Kanto (2006) and Mahringer et al. (2015).

3. Empirical analysis

3.1 Data and variables

Data on the wholesale day-ahead zonal electricity prices (in Eur/MWh) have been collected from the IPEx website (www.mercatoelettrico.org) for the period Jan 1, 2005–Jul 31, 2015. These data are originally recorded with a hourly frequency.

The econometric analysis shall be performed on daily time series of zonal electricity prices. Time aggregation of the hourly zonal prices on a daily horizon, by taking daily averages.[2] We focus on the Sardinia zone and on two contiguous aggregated zones. One, which we call North, is the aggregate of the Centro-Nord (with which Sardinia was historically connected) and Nord zones. The other aggregate zone is hereby called South and is the aggregate of Centro-Sud and Sud (and of the Calabria zone until 2009). We exclude Sicily from aggregation, as it was often physically separated due to congestion. The North price, p_n , is defined as the load-weighted average of Nord and Centro-Nord prices; a similar definition holds for the South price, p_s . A dummy, taking unit value since March 17, 2011, takes up the effects of the new SAPEI cable.[3] Daily oil and gas prices have been sourced from Eikon, a Thomson-Reuters database.

For each variable, 3846 daily data points are available. The descriptive statistics, presented in Table 1, show that all zonal prices decreased after the cable, both in mean and median, but there is a slight increase in the standard deviation in both Sardinia and South – presumably because of the larger renewables penetration.

Unit root tests (Augmented Dickey–Fuller, Phillips–Perron) performed on the time series of zonal electricity prices reject the null of non-stationary mean. The null of stationarity tested through the KPSS is rejected, too.[15] We thus do not need to test for cointegration. Yet, because of spikes and seasonal effects we have treated the zonal log-prices by means of the recursive filter on (log-)prices (RFP) proposed by Janczura et al. (2013).[4]

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[2] Taking the median daily prices would entail a problem: the "median hour" would change every day, questioning the comparability of successive price observations in the daily frequency sample.

[3] It would be interesting to include renewable energy production in the analysis, since Sardinia and the South aggregate zone are rich in wind and solar power. Yet, gaps in the Terna database before 2012 prevented this. We also exclude congestion and market power indicators as we would incur a dimensionality issue in estimating the model. One may suppose that lagged price partly incorporates the effects of renewables and congestion on market clearing in previous days.

[4] The RFP filter (Janczura et al. 2013) proceeds through the following steps:

(i) the short-term seasonal is removed by means of 7-day moving averages;

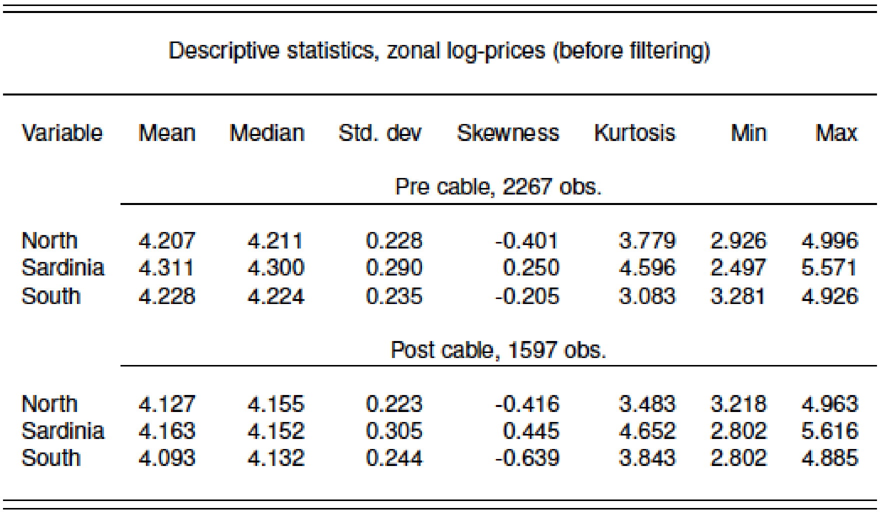
(ii) a Daubechies 5 wavelet is computed as the long-term seasonal component and subtracted;

(iii) outliers are identified as the observations lying more than 3 standard deviations away from the mean of the deseasonalized prices;

(iv) outliers are replaced by the average offer price for the corresponding week-day.

Filtering allows to interpret the data as short-term deviations from seasonals and long-term trends.

Table 1. Descriptive statistics for zonal electricity log-prices in North, Sardinia, and South (before filtering). The sample size covers the period 01/1/2005-31/7/2015, for a total of 3864 observations. The new cable started operating on 17/3/2011.



Descriptive statistics, zonal log-prices (before filtering)

Variable	Mean	Median	Std. dev	Skewness	Kurtosis	Min	Max
	Pre cable, 2267 obs.						
North	4.207	4.211	0.228	-0.401	3.779	2.926	4.996
Sardinia	4.311	4.300	0.290	0.250	4.596	2.497	5.571
South	4.228	4.224	0.235	-0.205	3.083	3.281	4.926
	Post cable, 1597 obs.						
North	4.127	4.155	0.223	-0.416	3.483	3.218	4.963
Sardinia	4.163	4.152	0.305	0.445	4.652	2.802	5.616
South	4.093	4.132	0.244	-0.639	3.843	2.802	4.885

3.2 Econometric model

We represent the first and second moments of electricity prices in Sardinia, North and South of Italy using a VAR-GARCH(1,1)-in-mean process.[5] In its most general specification, the model takes the following form:

$$x_t=\alpha+w_t+\beta x_{t-1}+\theta h_{t-1}+\delta f_{t-1}+u_t \qquad [1]$$

Where $x_t=(\log p_{n,t}, \log p_{i,t}, \log p_{s,t})$ - respectively, log-prices in North, Sardinia ("i" stands for "island"), and South at time *t*. We control for energy shocks by including in the mean equation either the oil or the gas prices, $f_{t-1}=(\log p_{Oil,t-1}, \log p_{Gas,t-1})$. The vector of residuals $u_t=(u_{n,t}, u_{i,t}, u_{s,t})$ is trivariate and normally distributed with zero mean and a conditional variance covariance matrix given by:

$$H_t=\{h_{j,k,t}\} \qquad [2]$$

where $j\in\{n,i,s\}, k\in\{n,i,s\}$.

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[5] The model is based on the GARCH(1,1)-BEKK representation proposed by Engle and Kroner (1995).

The parameters vector of the mean log price equation is defined by the constant $\alpha=(\alpha_n,\alpha_i,\alpha_s)$, the weekend dummy w_t . The autoregressive terms allow for mean log price effects from Sardinia into North (β_{in}) and South (β_{is}) before the cable, and after ($\beta_{in}*,\beta_{is}*¿$). The GARCH-in-mean parameters allows for Sardinia volatility effects into mean log-prices in North (θ_{in}) and South (θ_{is}).

Although GARCH-in-mean terms are seldom found in the cited literature, one theoretical reason for including them is that markets house risk-averse agents, whose decisions take account of volatility and can in turn affect prices. GARCH-in-mean effects are also consistent with convexity in the supply stack (Petersen and Dahl 2010). Econometrically speaking, we note that previous works included GARCH-in-mean terms for forecasting purposes (e.g. Liu and Shi 2013, Efimova and Serletis 2014), and that such effects allow for non-Gaussian log-price distributions even if one assume Gaussian error terms.

The parameter matrices for the variance equation are defined as C_0 , which is restricted to be upper triangular, and the two matrices A and G . In order to account for the possible effects of the new SAPEI cable, we include a dummy variable (denoted by *) with a switch on 17 March 2011, i.e. on the day of the new cable starting activity. Therefore, the second moment will take the following form:

$$H_t=C_0{}'C_0+A'\{e_{j,t-1}e_{k,t-1}\}A+G'H_{t-1}G \qquad [3]$$

where the *A* matrix collects the own- and cross-zonal ARCH effects, and the *G* matrix includs the own- and cross-zonal GARCH effects. The parameters $a_{i,n}$ and $a_{i,s}$ measure the ARCH effects from Sardinia to North and South volatility, respectively, whereas ($a_{i,n}+a_{i,n}^{¿}$) and ($a_{i,s}+a_{i,s}^{¿}$)measure the full effects after the 2011 new cable introduction. Similarly, GARCH effects before and after the cable are denoted by $g_{i,n}$, $g_{i,s}$, $g_{i,n}+g_{i,n}^{¿}$, $g_{i,s}+g_{i,s}^{¿}$. The term in curly brackets indicates the matrix of squared error terms, where *j* and *k* run across the three zonal markets under consideration. Equation (3) models the dynamic process of H_t as a linear function of its own past values H_{t-1} and past values of the squared innovations.

The BEKK representation guarantees by construction that the covariance matrix in the system is positive definite. The BEKK model is preferred over the DCC because we deal with a small system of just three price equations. The conditional correlations between the Sardinian, North, and South zonal electricity prices are defined as follows:

$$\rho_{i,n,t}=h_{i,n,t}/\sqrt{h_{i,i,t}}\sqrt{h_{n,n,t}} \qquad [4]$$

$$\rho_{i,s,t}=h_{i,s,t}/\sqrt{h_{i,i,t}}\sqrt{h_{s,s,t}} \qquad [5]$$

Given a sample of *T* observations, a vector of unknown parameters ϕ and a 3-dimensional vector of variables x_t , the conditional density function for model (1) is:

[6]

The log-likelihood function is:

$$L=\sum_{t=1}^{T} f\left(x_t ; I_{t-1}, \phi_t\right) \qquad [7]$$

The standard errors are calculated using the quasi-maximum likelihood methods of Bollerslev and Wooldridge (1992), which is robust to the distribution of the underlying residuals.

4. Results

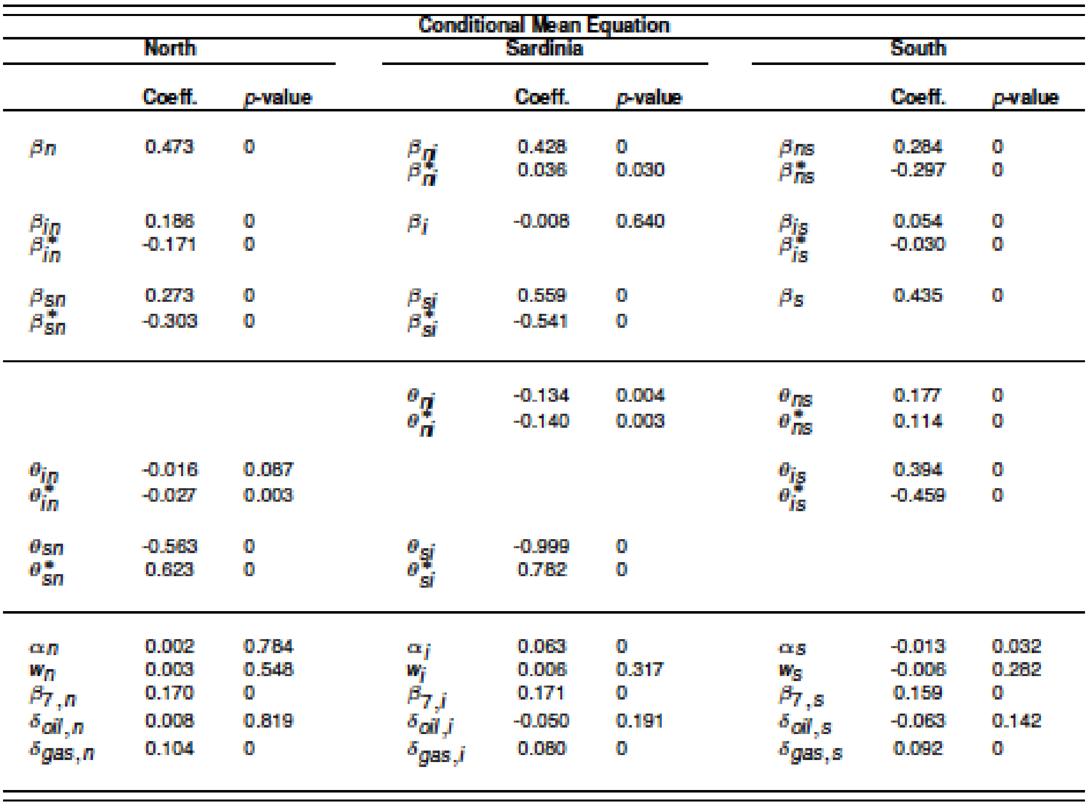
In order to test the adequacy of the models, Ljung-Box portmanteau tests have been performed on the standardized and squared residuals. Overall, the results indicate that the VAR-GARCH(1,1)-in-mean specification captures satisfactorily the persistence in price levels and squares of all the series considered. Causality effects in the conditional mean and variance vary in magnitude and sign across the three markets. Note that the signs on cross-market volatilities cannot be determined. The estimated coefficients of the VAR-GARCH(1,1)-in-mean model, with the associated robust standard errors, are presented in Tables 2 (conditional mean equation) and 3 (conditional variance equation).

Table 2 shows positive and significant first-order autocorrelation in North and South, similarly sized (slightly below 0.5 in both cases), but not in Sardinia. Cross-zonal correlations are all positive and significant, yet they are dampened in some links. Specifically, \beta_{in}^{*}, \beta_{si}^{*}, \beta_{ns}^{*}, and \beta_{sn}^{*} are similar in magnitude as pre-cable coefficients \beta_{in}, \beta_{si}, \beta_{ns}, and \beta_{sn}, but opposite in sign. In the more strongly integrated post-cable market, zonal prices are expected to move together, and removing trends and seasonals, as we do, should only leave a small residual correlation. This is what we find, except for the North-Sardinia link, the one characterized by tighter transmission constraints, where \beta_{ni}^{*} adds to the pre-cable coefficient \beta_{ni}.

Table 2, however, shows contrasting results concerning the GARCH-in-mean effects. Coefficient θ_{is} , the effect of Sardinian volatility on Southern mean log-prices before the cable, is positive and significant. Yet, $\theta_{is}^{¿}$ is negative and significant, so that the overall effect, taking account of the cable, is negative. Similarly, we find negative and significant effects of Sardinian volatility on Northern mean log-prices, both before (θ_{in}) and after the cable ($\theta_{in}*¿$).

As to control variables, we find no significant weekend effects, perhaps because the price in each zone is significantly correlated with its seventh lag. Gas prices display positive, significant, and similarly sized coefficients in all three zones, but this is not the case for oil prices.

Table 2. Estimates of the VAR-GARCH-in-mean model: conditional mean equation, autoregressive and control coefficients.



				Conditional Mean Equation				
	North			**Sardinia**			**South**	
	Coeff.	***p*-value**		**Coeff.**	***p*-value**		**Coeff.**	***p*-value**
β_n	0.473	0	β_{ni}	0.428	0	β_{ns}	0.284	0
			β^*_{ni}	0.036	0.030	β^*_{ns}	-0.297	0
β_{in}	0.186	0	β_i	-0.008	0.640	β_{is}	0.054	0
β^*_{in}	-0.171	0				β^*_{is}	-0.030	0
β_{sn}	0.273	0	β_{si}	0.559	0	β_s	0.435	0
β^*_{sn}	-0.303	0	β^*_{si}	-0.541	0			
			θ_{ni}	-0.134	0.004	θ_{ns}	0.177	0
			θ^*_{ni}	-0.140	0.003	θ^*_{ns}	0.114	0
θ_{in}	-0.016	0.067				θ_{is}	0.394	0
θ^*_{in}	-0.027	0.003				θ^*_{is}	-0.459	0
θ_{sn}	-0.563	0	θ_{si}	-0.999	0			
θ^*_{sn}	0.623	0	θ^*_{si}	0.782	0			
α_n	0.002	0.784	α_i	0.063	0	α_s	-0.013	0.032
w_n	0.003	0.548	w_i	0.006	0.317	w_s	-0.006	0.282
$\beta_{7,n}$	0.170	0	$\beta_{7,i}$	0.171	0	$\beta_{7,s}$	0.159	0
$\delta_{oil,n}$	0.008	0.819	$\delta_{oil,i}$	-0.050	0.191	$\delta_{oil,s}$	-0.063	0.142
$\delta_{gas,n}$	0.104	0	$\delta_{gas,i}$	0.080	0	$\delta_{gas,s}$	0.092	0

Note: Standard errors (S.E.) are calculated using the quasi-maximum likelihood method of Bollerslev and Wooldridge (1992), which is robust to the distribution of the underlying residuals. The effect of the 2011 new cable introduction is measured by parameters with *.

Table 3 turns to the conditional variance equation, focusing on ARCH effects and GARCH effects. The former are interpreted as spillovers, the latter as contagion, but both types of effects convey information on volatility transmission. In interpreting the results, notice that the sign of the coefficients included in the A and G matrices are not relevant, as both matrices enter the H matrix through quadratic forms. Hence we shall only focus on statistical significance.

In Table 3, comparing g_{is} and $g_{is}*¿$, both statistically significant, shows that contagion from Sardinia to South was increasingly strong after the cable. That there was some effect even before the cable is not against reason, since Sardinia and the South were nevertheless linked indirectly through common neighbors. $g_{is}*¿$, measuring contagion from a net importer, is also stronger than $g_{si}*¿$, the estimated contagion from the South (a net exporter) to Sardinia. Finally, the ranking between Sardinia-South and Sardinia-North contagion is not clear: $g_{in}=0.569$ higher than $g_{is}=0.433$ before the cable, but comparing the coefficients after the cable, there seems to be a stronger spillover from Sardinia to South. Hence, there is some indication, albeit not clear, that volatility transmission between two zones that are rich in renewables (Sardinia and South) is stronger than between zones that differ in that respect (Sardinia and North).

The results on ARCH effects go along the same lines. Volatility spillovers from Sardinia to South seem stronger, yet there is no significant change after the cable ($a_{is}*¿$ not significant), while the cable stengthens the volatility spillovers from Sardinia to North ($a_{in}*¿$ significant). Volatility spillovers from the net exporter (South) to the net importing island (Sardinia) were weaker even before the cable (compare a_{si} with a_{si}).

Finally, the conditional correlations between Sardinia and South log-prices (Figure 2, upper panel) derived from the VAR-GARCH(1,1)-in-mean model are visibly closer to 1 (perfect correlation) after the inauguration of the cable, than before, when they fluctuated wildly. Expectedly, no similar the effect is detected when observing the Sardinia-North correlations (Figure 2, lower panel). Correlations remain volatile and well below 1 on average even after the cable. The interconnection capacity between Sardinia and Center-North is rather limited, possibly explaining this result.

Table 3. Estimates of the VAR-GARCH-in-mean model: conditional variance equation, A matrix (ARCH effects, spillovers) and G matrix (GARCH effects, contagion).

Conditional Variance Equation								
North			Sardinia			South		
	Coeff.	*p*-value		Coeff.	*p*-value		Coeff.	*p*-value
a_n	0.975	0	a_{ni}	-0.005	0.414	a_{ns}	0.025	0.009
			a^*_{ni}	0.015	0.031	a^*_{ns}	-0.023	0.005
a_{in}	0.006	0.751	a_i	0.733	0	a_{is}	0.244	0
a^*_{in}	0.041	0.065				a^*_{is}	-0.033	0.156
a_{sn}	0.031	0	a_{si}	0.022	0.010	a_s	0.948	0
a^*_{sn}	-0.005	0.565	a^*_{si}	-0.001	0.867			

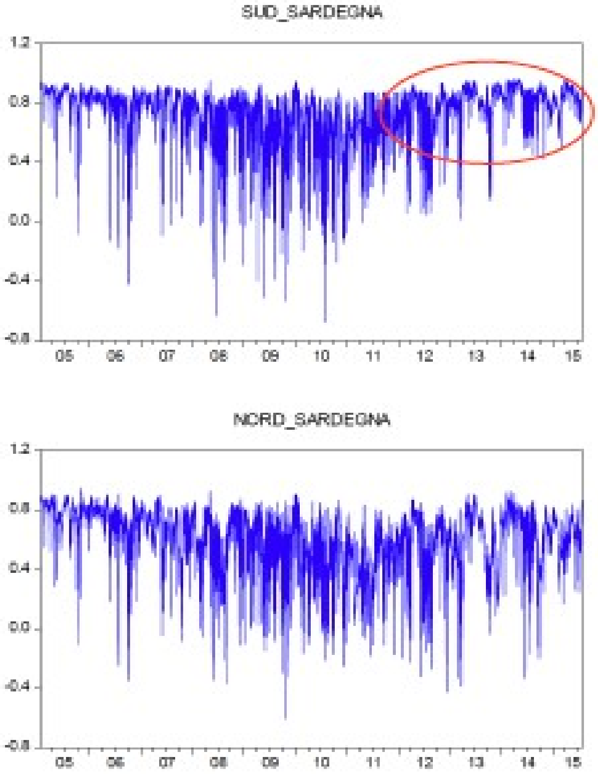
A matrix: spillovers
Strongest from Sardinia to South; No significant change after the cable

Conditional Variance Equation								
North			Sardinia			South		
	Coeff.	*p*-value		Coeff.	*p*-value		Coeff.	*p*-value
g_n	0.150	0	g_{ni}	-0.031	0.114	g_{ns}	-0.141	0
			g^*_{ni}	0.105	0	g^*_{ns}	0.044	0.253
g_{in}	0.569	0	g_i	-1.108	0	g_{is}	0.433	0.001
g^*_{in}	-0.674	0				g^*_{is}	0.995	0
g_{sn}	-0.141	0	g_{si}	0.046	0.126	g_s	0.136	0.001
g^*_{sn}	0.019	0.606	g^*_{si}	0.065	0			

G matrix: contagion

Note: The covariance stationarity condition is satisfied by all the estimated models, all the eigenvalues of A' A + G' G being less than one in modulus. Note that in the conditional variance equation, the sign of the parameters is not relevant.

Figure 2. Conditional correlations between Sardinia and South log-prices (upper panel) and between Sardinia and North log-prices (lower panel) between 2005 and 2015, as estimated through the VAR-GARCH-in-mean model. The red circle highlights the post-cable correlations.



4.2. Discussion and some theoretical insights

In providing an interpretation to the estimated patterns, it is useful to start from three stylized pieces of evidence, grounded in the existing literature: (i) intermittency in renewables is the main determinant of zonal price volatility in a short time horizon; (ii) the statistical properties of zonal prices diverge if there is insufficient transmission capacity; (iii) congestion in export is alleviated by increased local renewable energy supply (the import substitution effect highlighted by Sapio 2014, 2015 and Ardian et al. 2015), whereas congestion in import is aggravated. Focusing on volatility transmission patterns, a first result in our analysis is that *volatility transmission from a renewables-rich importing zone (Sardinia) is positive and increasing after the new link.*

In explaining this result, we acknowledge that a higher zonal supply of renewables is a major determinant of zonal price volatility, but in an importing zone this is also reducing the probability of congestion, making volatility transmission easier. The new SAPEI cable should have made this even easier between Sardinia and South from 2011 on. Indeed, we have found that volatility transmission is stronger for the importing zones, such as Sardinia, that are richer in renewables, and less so for the North, which is a net importer but it is characterized by a lower renewables penetration rate.

Conversely, and by the same token, volatility caused by renewables in an exporting zone causes congestion, therefore decoupling the zone from the neighbors. This is a possible explanation behind our second result: v*olatility transmission from a renewables-rich exporting zone (South) is weaker.*

A further insight on volatility transmission starts from the notion that increased interconnection can help balancing the volatile renewable energy outputs. Yet, the effectiveness of balancing relies upon the spare flexibility of the neighboring zone, which is low if the zone is rich in renewables. This may be the reason why volatility transmission between Sardinia and South, that before the cable was only indirect through common neighboring zones, becomes positive and stronger thanks to SAPEI: v*olatility transmission is strongest from a renewables-rich importing zone (Sardinia) to a renewables-rich exporting zone (South).*

The results on GARCH-in-mean effects shed light on yet another relevant economic channel. *Volatility in a renewables-rich importing zone, such as Sardinia, translate into higher prices in the neighboring South zone before the cable*. This may be explained by convexity in supply stacks: wider shifts in the supply stack, due to renewables, would cause market clearing to occur more frequently on the steep part of the supply stack, corresponding to higher average prices.

After the cable inception, higher zonal volatility correlates with lower prices in the neighboring zones. This can be the case if the merit order effect of renewables is "exported" through the new link. Interestingly, previous theoretical work (e.g. Boffa and Scarpa 2009) had highlighted market power export effects, but in context involving strategic supply from fossil-fueled power plants. Our results suggest that market power export vanishes when intermittent sources, that escape short-run strategizing, are prominent in the supply stack. Alternatively, volatility may cause higher reliance by risk-averters on long-term contracts, defined on the average national electricity price, yielding in turn pro-competitive effects (lower prices) in the neighboring zones. However, the latter effect is more likely to hold at the national level, rather than locally.

5. Conclusion

In this paper, we have explored volatility transmission patterns among zonal electricity prices before and after the inauguration of a new interconnection line linking two zones that are rich in intermittent renewables. A VAR-GARCH-in-mean model has been estimated using daily data on average electricity prices in Sardinia and in two neighboring market zones in the 2005-2015 time window, focusing on the effects of the SAPEI cable that is fully operational since March 2011. The results show that the SAPEI cable allowed for stronger volatility transmission from Sardinia, and that such volatility affected the mean zonal prices in the neighboring zones, mitigating the North prices. The conditional correlations between Sardinia and South prices, based on the model estimates, converge to unity after opening the SAPEI cable.

These results are consistent with a theoretical depiction of the electricity market and network wherein zonal price volatility, due to intermittent renewables, flows more easily from a net importer to its neighboring zones, than from a net exporting zone, because renewables can alleviate congestion if they perform an import substitution function.

Further research will be devoted to assessing the value of the changed volatility patterns and comparing it with the investment cost of the new infrastructure, in light of the projected increase in renewables penetration and of the changes in electricity demand on the island.

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