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"THE IMPACT OF RES AND FOSSIL FUELS ON BALANCING PRICES IN THE ITALIAN ELECTRICITY MARKET"

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Abstract

I empirically investigate the impact of RES and fossil fuels generation on Italian balancing markets, by studying electricity hourly price dynamics from 2016 to 2018 in the balancing (MSD and MB) sessions. The zonal time-series of balancing prices and volumes are initially described and analyzed, therefore they are seasonally adjusted, evaluating their variation from the median values, and tested, for their remaining long-memory autocorrelation. RES and fossil fuels production units are examined zone by zone to discover possible correlation among them. The final model takes into account the differences between up and down-regulation and separately analyzes each Italian zone, providing some evidence of similarities about firms' competitiveness and Transmission System Operator's extra costs. The outcomes find an increasing market power among energy firms created by conventional units' usage and an ambiguous impact of controllable and variable renewable energy (VRE) sources, whose production may provoke opposite effects depending on the zone and the regulation analyzed.

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Introduction

The layout of global energy systems has significantly changed over the past decades, in particular considering the last 20 years of innovation, efficiency improvement and economic development. Conventional power sources have been gradually substituted with renewable resources, in the so-called *decarbonization* of the planet, in order to cease greenhouse gases' emissions into the atmosphere. This transition has heavily affected energy production, distribution and consumption, since many treaties and policies have been implemented to effectively realize this energy turnaround. Energy markets have not escaped the effects of the large penetration of renewable energy sources into the energy generation mix, especially in Italy where energy production from renewables sources grew rapidly and consistently from the last years of 2000s, reaching more than 100 TWh in 2017[1].

Theoretically, a larger penetration of RES should reduce energy prices in day-ahead markets given the lower marginal prices of renewable sources with respect to conventional fossil fuels, like coal, oil and natural gas. However, this work doesn't investigate the Italian day-ahead market, but it observes how Italian balancing markets have behaved during the last years, how often they are used and why balancing markets' prices have moved. The aim of this thesis is to further investigate the impact of renewable energy sources on balancing prices of the Italian electricity market. To carry out this project, I analyze the electricity markets' data, starting from the two balancing markets and the day-ahead market and I adopt an Autoregressive model, including as explanatory variables RES and fossil fuels' quantities, to study their weights on balancing prices.

The work is organized as follows. Chapter 1 gives a brief explanation of Italian Electricity Market and its balancing mechanism, focusing on the costs of the Italian Transmission System Operator and reviewing the past literature about the relationship between renewable energy sources and balancing markets. Chapter 2 performs the analysis, examining data and their characteristics, dwelling on the seasonality of time series and testing the explanatory variables. Chapter 3 illustrates the model used and lists the results of each zone in both regulations.

[1] Data available from TERNA website.

Chapter 1

Italian Electricity Market

The Italian electricity market (also called Italian Power Exchange or IPEX) is the Italy's spot to exchange electricity through bids and offers and it's composed by several and different markets, managed by Gestore del Mercato Elettrico (GME), depending on the products delivered. GME organizes its structure in the following markets:

- The Day-Ahead Market (*Mercato del Giorno Prima* or MGP), that is the biggest market in the Italian electricity system in which producers and consumers may sell and purchase electricity for the next days; it starts at 8 AM of the ninth day before the day of delivery and closes at 12 PM of the day before of the delivery day.

- The Intra-Day Market (*Mercato Infragiornaliero* or MI), which allows to submit additional offers and bids; it takes place in 7 sessions: MI1, MI2, MI3, MI4, MI5, MI6 and MI7. MI1 starts after the closing of MGP, whereas MI7 closes at 3:45 PM of the delivery day.

- The Ancillary Services Market (*Mercato dei Servizi di Dispacciamento* or MSD), where TERNA S.p.A. (the Italian Transmission System Operator or TSO) provides the dispatching services needed to manage and control the power system. It's composed of a scheduling phase (MSD *ex-ante*) divided in 6 sub-stages (MSD1, MSD2, MSD3, MSD4, MSD5 and MSD6) and the balancing market (*Mercato del Bilanciamento* or MB), also divided in 6 sessions, in which secondary and tertiary reserves are exchanged between generators and TSO, to maintain the system balanced. The MB data - in GME - is separated in Secondary Reserve (in Italian "Riserva Secondaria") and Other Services (in Italian "Altri Servizi").

Every market has a zonal configuration. As Figure 1 illustrates, there are 6 market zones: *North* (NORD, in Italian "Nord"), *Centre-North* (CNOR, in Italian "Centronord"), *Centre-South* (CSUD, in Italian "Centrosud"), *South* (SUD, in Italian "Sud)", *Sardinia* (SARD, in

Italian “Sardegna”) and *Sicily* (SICI, in Italian “Sicilia”). The six areas show different conditions in terms of capacity, prices and energy sources production; moreover, for each sub-market, each zone has its peculiar characteristics and, given this, the analysis will observe each case separately.

Fig. 1. Geographical Zones of Italian Transmission Network.

Source: GME, 2009.

Most of the electricity transactions are hosted in the MGP, where participants submit their asks/bids with the quantity and the maximum/minimum price at which they want to purchase/sell electricity. Bids/asks are accepted after the closure of the market based on the economic merit-order criterion, i.e. the energy sources are classified in a rank assembled on increasing prices, and taking into account transmission capacity limits between zones. Therefore, the MGP is an auction market and not a continuous-trading market. Indeed, the big difference between MGP and balancing markets is the pricing rule: as the first works with uniform auctions, the MSD and MB use a pay-as-you-bid-rule. The MGP fixes the system marginal price at each hour and at each zone, so the winning bidders receive that marginal price depending on which zone they belong to. Instead, the load pays a weighted average price, called PUN (Single National Price, in Italian “Prezzo Unico Nazionale"), weighted by the volumes of exchanges.

Instead, in the MSD and MB, generators receive the price they have offered/demanded if their offers to sale/purchase to/from TERNA have been accepted. More precisely, if the TSO forecasts an increase in electricity demand with respect to the forecasted MGP's quantity, it asks to power plants more energy; this is called Up-Regulation (in Italian, “chiamate a salire”). Viceversa, if there's lower energy's demand with respect to the volume's day-ahead forecast, power companies purchase electricity from the TSO, which sells it and makes earnings in the so-called Down-Regulation offers (in Italian, “chiamate a scendere”). Therefore, Up-Regulation is generally more costly than Down-Regulation: the first one should have its minimum at its related MGP value, whereas the second should range from 0 to the connected MGP price. The outcome is in balancing prices that are highly variable, sometimes skyrocketing, other times without any value, when there's not need to use them, i.e. when the forecast in the MGP market is good enough to maintain the market balanced.

1.1 The Costs of Balancing Markets

Balancing is fundamental in electricity systems, since energy is not a storable good (or rather it's too costly to be stored in large amounts) and because its demand highly depends on weather conditions, which are difficult to predict. Moreover, energy must be generated near the delivery time and often in a situation of demand's uncertainty; because of this, balancing markets are the last chances for TSO to procure resources and services to secure the system's stability. Italian suppliers are sometimes obliged to deliver electricity under some circumstances, especially in cases of “emergency” in which TERNA forces generators to deliver energy with determined conditions. These conditions could be very expensive for the system, since up-regulation prices are capped at €3000 (down-regulation market prices are instead usually limited up to MGP price) and day-ahead prices fluctuate between 0 and €250[2]; hence up-regulation may be much more expensive since MGP prices are very much closer to

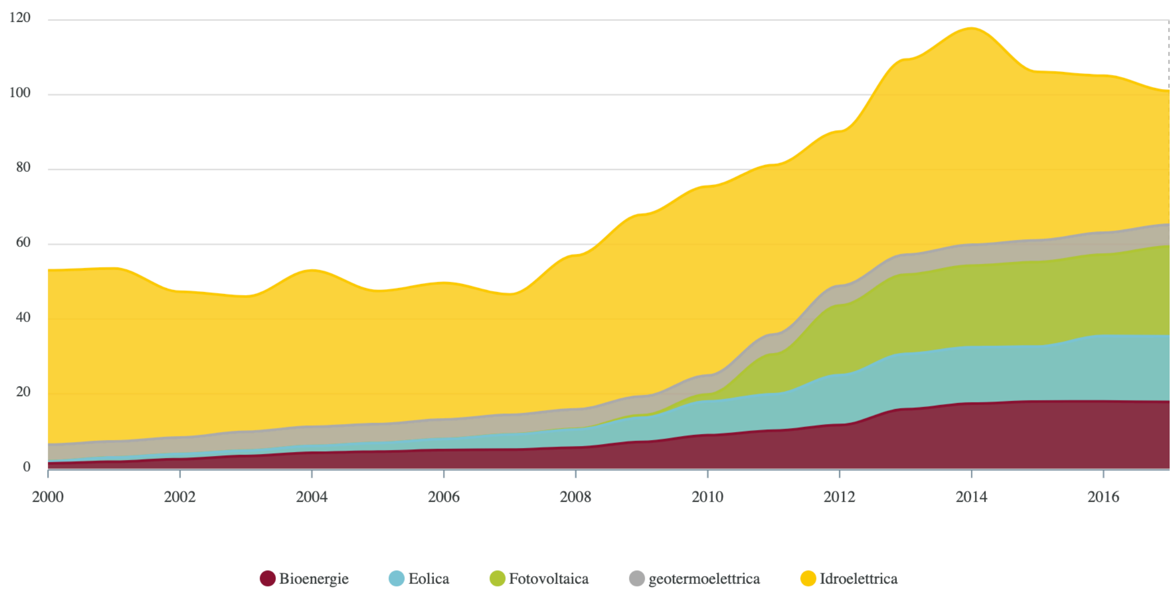
[2] These prices refer to years 2016, 2017 and 2018, and are available in Chapter 2;

0 than to 3000. The TSO bears itself the extra-cost in both phases, even though the real burden is passed to consumers on electricity bills.

1.2 Energy Sources

Italy in the last 10 years, trying to fulfill the goals of 20/20/20 European policy, has seen the rapid growth of a new kind of energy sources, the renewables ones. RES like photovoltaic, wind and biomass caused a substantial impact in electricity markets, especially in the balancing ones, as RES generators enjoy priority dispatch in the merit order because of their low prices, in contrast to conventional power plants. The high RES penetration in Italy (see Fig. 2) put to the test the operation of power exchanges, since the intermittent functioning of RES requires TSO asking for energy to flexible power plants, as gas-fired ones, if there's uncertainty close to delivery time. Hence, an electricity market with high share of RES - theoretically - heavily relies on balancing and could have also larger balancing prices and volatility. Instead, conventional power suppliers, as oil, coal and natural gas generators, although they may earn less in the day-ahead market (MGP) because of the unfavorable merit order, they might compensate their profits with the high premia earned from the available flexibility in balancing markets (MSD and MB).

Fig. 2. Electricity Production from Renewable Sources (TWh), years 2000 - 2017.



Source: Terna.it

It is highly likely that large electricity producers owning different production units (both RES and conventional power units) submit bids for RES units in the MGP market (exploiting the priority dispatch guaranteed to RES) and then place bids for conventional units later in the MI and balancing sessions (Gianfreda et al., 2016). This means that even though RES have priority dispatching because of their lower prices, not necessarily prices always decrease. Gullì and Lo Balbo found out that, despite PV power production rose incredibly fast during the last 10 years, it might not provide - in some periods - direct significant benefits in terms of decreasing spot prices. It means that power firms could push the prices up to offset the decreasing profits during low solar radiation. This could be real for every intermittent energy source, as PV and wind, maybe less true for controllable renewable energy sources such as hydroelectricity, geothermal or biomass. The transition to very large shares of renewable electricity production requires a careful planning to avoid creating instabilities in the supply, which may cause high volatility in electricity prices. The continued increase in *green* sources could change not just prices and their volatility, as the renewable sources are known to be irregular sources, but also quantities, as the thermal sources production market saw an increase in concentration and a decrease in capacity of the balancing system (Antonelli et al., 2017). Balancing volumes could be an additional and important factor to determine if electricity costs are increasing or not, because those costs could weight on consumers' bills, as Batalla-Bejerano and Trujillo-Baute highlight.

A recent literature has deeply studied the subject, in several countries with different market mechanisms. An important document that should be pointed out has been conducted by Hirth and Ziegenhagen in 2015, in which they analyzed the German electricity market. They found out that, despite variable renewable energy sources' capacity has tripled from 2008, balancing reserves have been reduced by 15% and balancing costs by 50%. This so-called "German paradox" was explained by Ocker and Ehrhart in 2017, who believe that the national and international Grid Control Cooperations for balancing power and two flexible trading options led to efficiency savings and not to a greater power reserve.

To verify if Italian electricity market has improved its stability since the boom of RES production and to check if and then why balancing prices have risen or not, it'll be studied how - in the last 3 years - balancing prices are related to MGP prices, to balancing volumes, to renewables sources and to fossil fuels' production and if there are relevant differences between zones and regulations.

Chapter 2

Data analysis

2.1 Preliminary Analysis

My analysis starts using hourly data of the Italian electricity market, covering the period from January 1st, 2016 up to December 31st, 2018, provided by the Italian Power Exchange. The whole dataset is available at GME website[3], both MGP, MSD, MB hourly prices and hourly quantities and RES and fossil fuels' hourly generation for MGP. Regarding MSD and MB *riserva secondaria* prices, I collect the hourly non-revoked[4] offers' prices and I compute a weighted price, weighted by the respective volumes asked by and to TERNA in the so-called up and down-regulation. By doing so, I create a hourly prices' series for each zone and each regulation which represents the average price of balancing, both the extra cost of TERNA when it buys more electricity and its earnings when the TSO sells energy in the event that forecasted supply exceeds real demand. With six zones and two types of regulation, the weighted balancing price series are 12.

2.2 Balancing Prices

What concerns balancing prices is about how often in a specific zone TERNA needs an extra amount of energy in up-regulating mechanism or, on the contrary, when TSO needs to sell power for an excess of supply. Table 1 and 2 report descriptive statistics for the weighted hourly prices of balancing markets, for down-regulation and up-regulation respectively; the column "*observation*" gives the number of hours when balancing is required. We can easily see which zones use it more: Sardinia and Sicily seem to resort to up-regulating more than down-regulating; instead, South zone uses few times both markets, while for North they are

[3] www.mercatoelettrico.org

[4] "A valid offer submitted by an operator may be revoked until the deadline of the market session in which the offer has been submitted. The revocation is active even for all other markets still open." GME, *Testo Integrato della Disciplina del Mercato Elettrico*, 2003.

extremely useful to balance demand and supply. The volatility in balancing markets is completely disharmonious: while down-regulation values sometimes seem to have a trend (in those cases in which there are at least 50% of prices: North, Centre-North and Centre-South), up-regulation reaches high prices in very few hours. Fig. 3 illustrates the graphs' differences between regulations in North zone; the other graphs can be seen in the Appendix.

Table 1. Descriptive Statistics of Down-Regulation Prices of balancing markets (in €)

Zone	Min	Q(5%)	Q(25%)	Median	Q(75%)	Q(95%)	Max	Mean	Std. Dev.	Obs.	% of values
NORD	0	5.04	15.36	23.30	30.20	43.14	77.22	23.17	10.98	26182	99,54%
CNOR	0	0	14.44	22.39	29.51	40.93	69.19	21.56	11.96	18589	70,67%
CSUD	0	0	5.07	15	25.03	45.02	100	17.29	14.38	13784	52,40%
SUD	0	0	0	0	0	0.53	10	0.08	0.49	1747	6,64%
SARD	0	0	0.95	23.20	52.24	71.26	104.67	29.42	28.38	555	2,11%
SICI	0	0	9.64	23.23	49.29	89.18	450.26	33.07	29.10	11491	43,69%

Table 2. Descriptive Statistics of Up-Regulation Prices of balancing markets (in €)

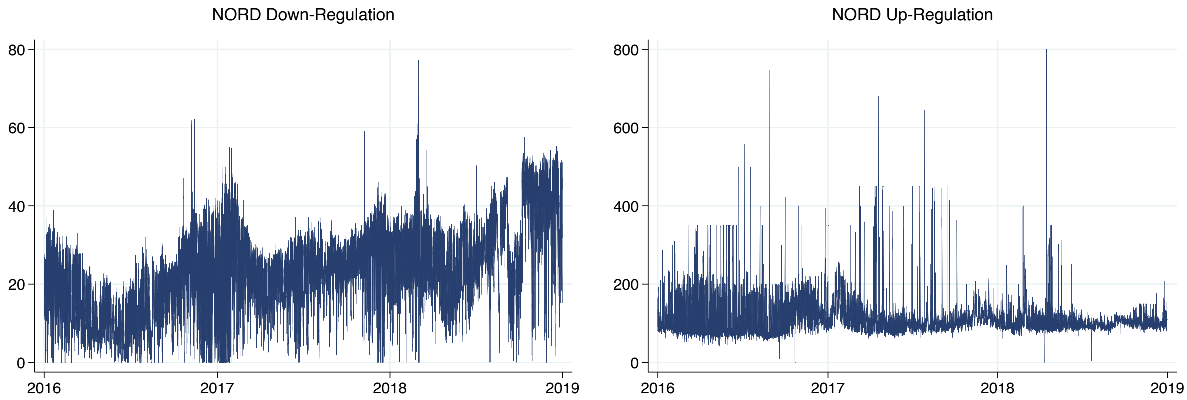
Zone	Min	Q(5%)	Q(25%)	Median	Q(75%)	Q(95%)	Max	Mean	Std. Dev.	Obs.	% of values
NORD	0	69.70	85.48	96.09	112.44	180.94	800	106.77	41.38	25085	95,37%
CNOR	34.99	70.31	84.99	98.01	109.18	151.84	418	101.92	30.90	16201	61,59%
CSUD	0	74.85	87.50	112.60	268.55	425	748	181.76	125.00	18179	69,11%
SUD	63	85	120	138	200	260	353	159.69	59.69	417	1,59%
SARD	46.41	63.30	80.92	89.24	118.75	284.77	500	124.82	76.12	16698	63,48%
SICI	0	51.95	89.82	102.96	121.72	171.52	650.42	107.05	37.86	25095	95,40%

The main characteristic of all the time series is that every one has *holes* in the three years of time considered[5]. The number of maximum observations in each zone and regulation is 26304 hours (3 years, considering a leap year): just Sicily in one regulation and North in both have almost all of the hourly values.

[5] This characteristic is not weird. It's in the nature of balancing prices series to have missing values, because if there's no need of regulation, there's no negotiation. To have a missing value is different than having a zero price.

The fact that three of the twelve series have very few values (South and Sardinia in the Down-Regulation, South in the Up-Regulation), actually it makes them unusable, since the non-existing values cannot be treated as zero prices. So, after having dropped out these three series, I start to analyze the others.

Fig. 3. North series' graphs in comparison.



2.2.1 Seasonality of Balancing Prices

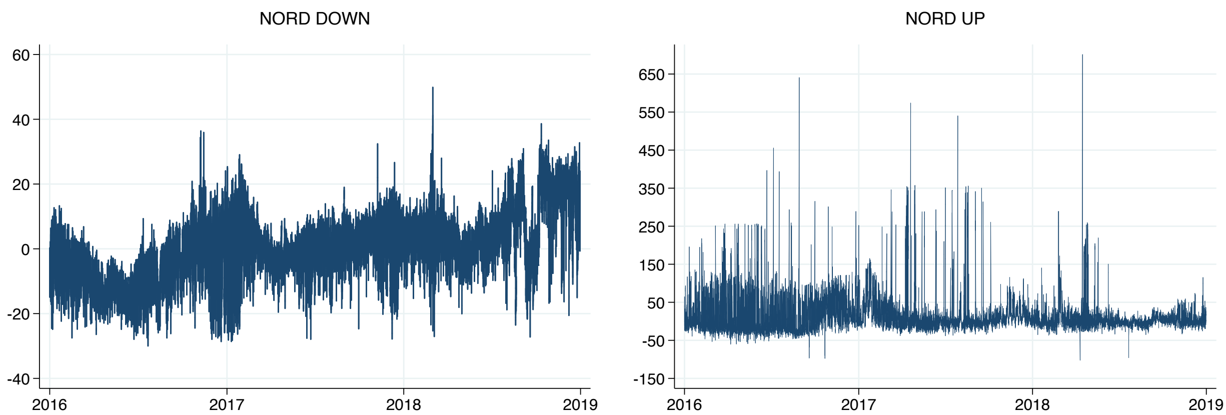
As it is well-known, electricity prices - generally speaking - exhibit specific characteristics like seasonality (on the annual, weekly and daily level), high volatility and spikes. These features derive from electricity demand that highly depends on work hours, weekends and weather conditions. The balancing prices in MSD and MB that I computed in the previous paragraph are not much different: in those cases in which there's need to balance, the seasonal characteristic of prices is on a daily and weekly level. The solution I adopt to avoid this problem is finding a median value for each hour of each day, starting from the 1st hour of Monday to the 24th of Sunday. By doing this, I find 168 medians and I can compute the difference between balancing prices and their associated median[6], trying to remove some of the seasonality present in the series. Indeed, my dependent variable will be the difference

[6] For example, if 01/01/2016 is a Friday, I subtract from its 1st hour's balancing price the median obtained from all the balancing prices of the Fridays' first hours present in the 3 years long dataset. The same for the second observation, the third and so on.

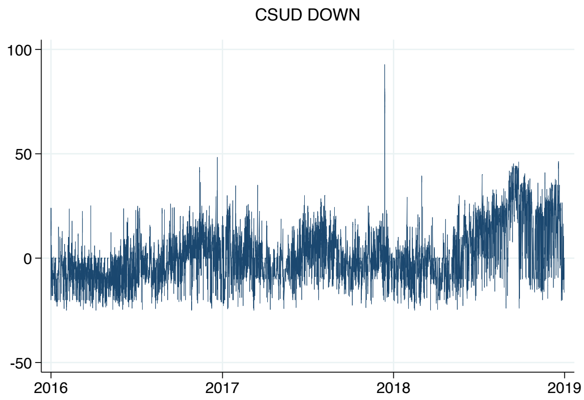
between balancing prices and their medians[7]. Figure 4 describes the series of balancing prices variation from their medians, based on zones and regulations.

All the series seem to behave similarly (except for Sardinia only series), floating around the zero value, sometimes having high spikes, above €400 in Sardinia Up-Regulation or Sicily Down-Regulation, or even above €650 in North Up-Regulation time series. The below graphs may still contain some seasonality that will be immediately faced firstly testing them in the autocorrelation tests and then - in the case values are autocorrelated - in the regression model. Below, in the Figure 5, I test the series watching if there's still presence of seasonality, showing the seasonal patterns of the series. As we can see from the autocorrelation graphs, the series of dependent variables see the existence of autocorrelation both in up and down-regulation; prices are affected by the past observations, particularly in the first and 24th past lags, except for Sardinia Up-Regulation ACF that show how its series is very high correlated even up to the 100th lag. Because of that, Sardinia won't be analyzed in the following chapters.

Fig. 4. Balancing prices variation from median values, 2016-2018; series from North, Centre-North, Centre-South, Sardinia and Sicily



[7] From now on, I will continue to call the dependent variable as "balancing prices variation" for simplicity.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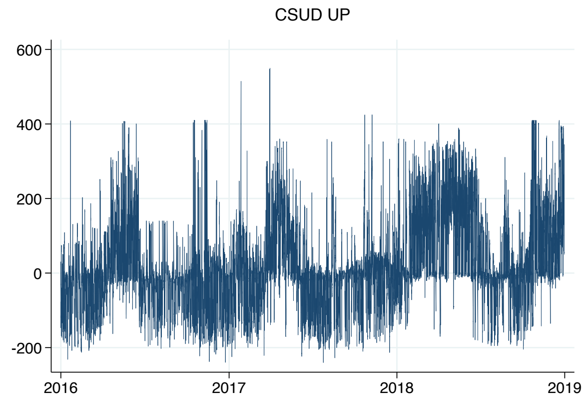
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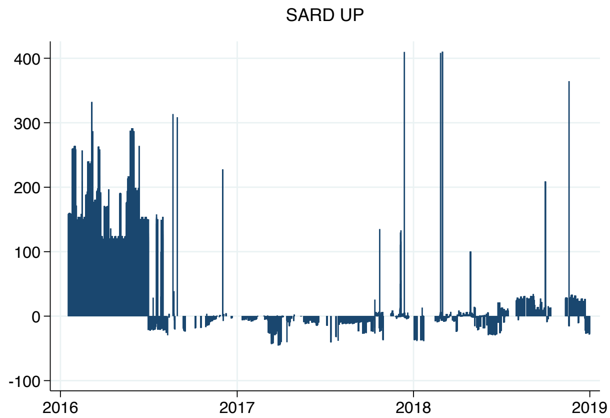
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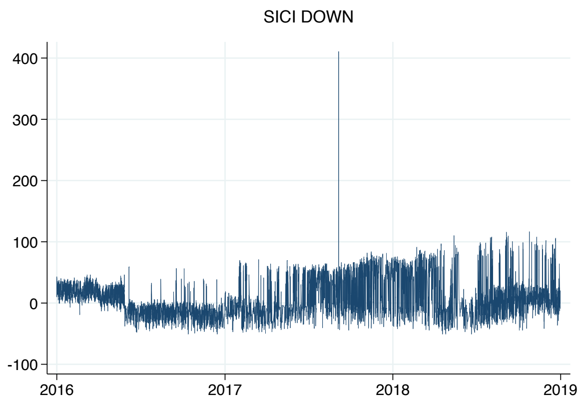
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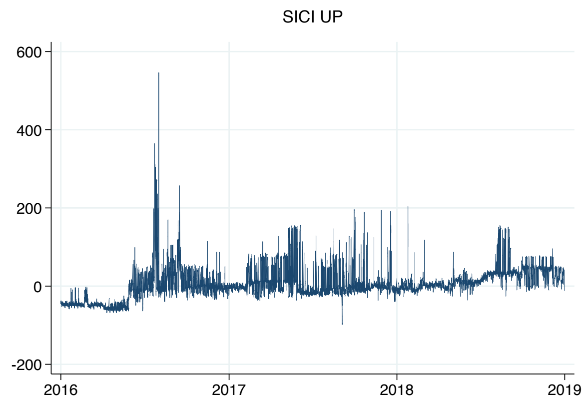
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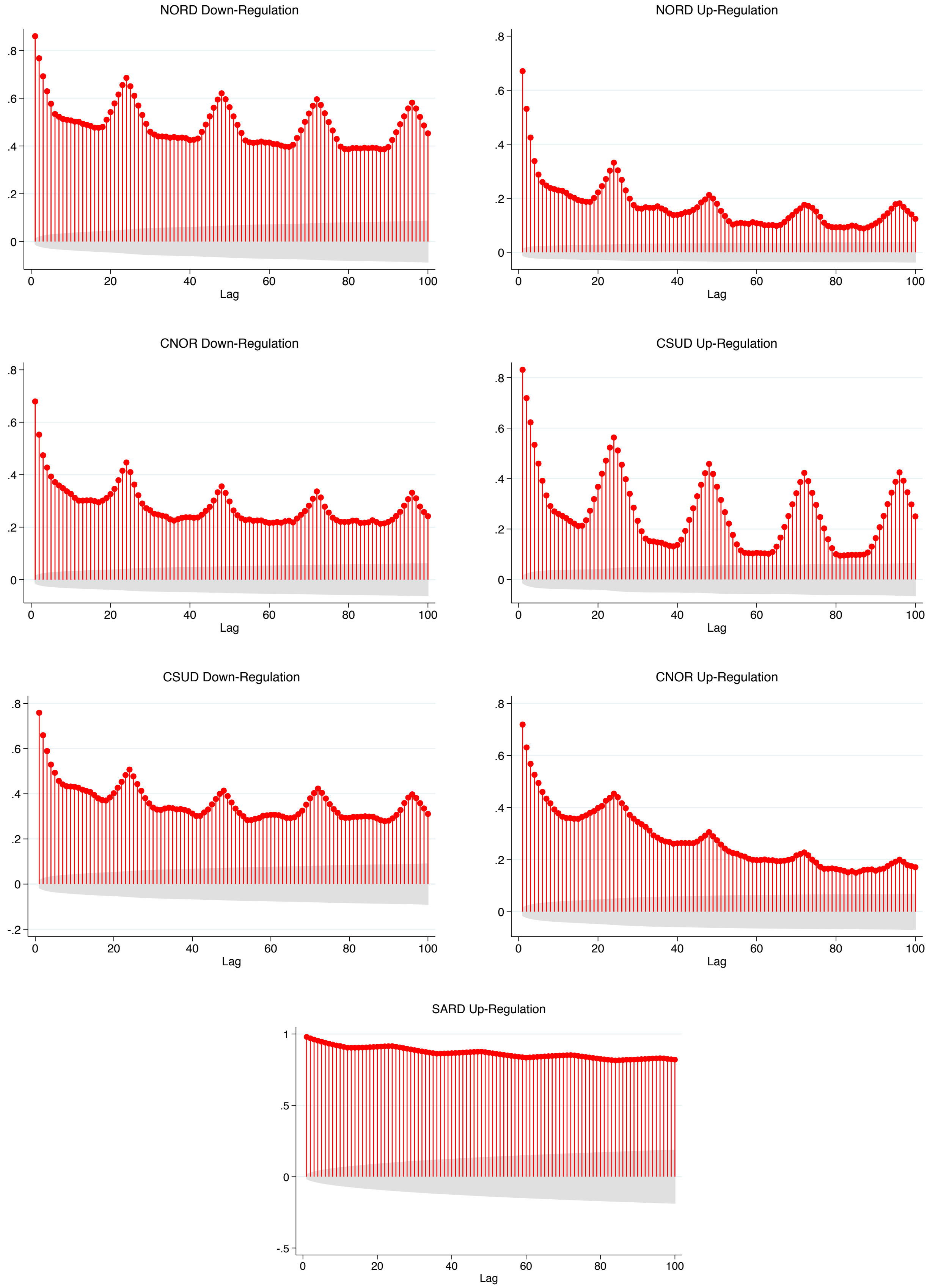
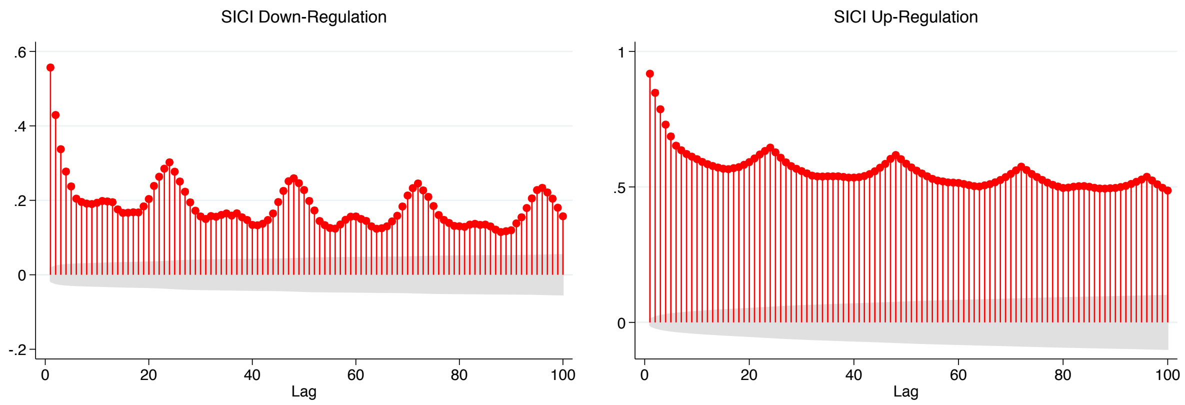
Fig. 5. ACF of balancing prices variation from median values; series from North, Centre-North, Centre-South, Sardinia and Sicily





2.3 MGP Prices

As mentioned before, down and up-regulation prices follow a general rule in which they should be, respectively, below and above the related MGP price. Table 3 describes the statistics of hourly MGP prices whereas Table 4 depicts statistics for PUN, the Single National Price, computed by GME using a weighted average of MGP prices. There are clear differences between markets and zones. In the MGP, each zone sees the presence of null prices, except North, even though the median and the mean are quite similar as well as the standard deviation, which has a little bump in Sicily. Those series are not taken into account as they are: there's a large literature focusing on MGP prices' seasonality (Caporin et al., 2012; Uniejewski et al., 2018; Weron, 2007). Therefore data have been treated in the same way as balancing prices, finding the median of the 168 hours of the week and subtracting them to the associated values. From here on out, MGP prices will be their variation from the medians.

These series of prices are fundamental in the understanding of balancing in electricity markets; as Caporin et al. (2019) found out, MGP and MSD have common dynamics within each zone in Italian electricity market even though some zones like Centre-North and Centre-South see a weaker evidence and can still improve their efficiency. It's easily understandable that MGP prices will provide interesting and significant informations to the model.

Table 3. Descriptive Statistics of Prices in MGP (in €)

Zone	Min	Q(5%)	Q(25%)	Median	Q(75%)	Q(95%)	Max	Mean	Std. Dev.
NORD	9.39	28.76	40	50	62.98	84.71	206.12	52.59	17.99
CNOR	0	29.73	40.33	49.96	62.36	83.30	175.75	52.55	17.39
CSUD	0	29.55	40.08	49.17	60.56	78.95	170	51.37	16.26
SUD	0	28.14	39.74	48.41	59.17	75.28	170	49.84	15.07
SARD	0	29.28	40	49.09	60.47	78.93	170	51.25	16.46
SICI	0	29.54	43	53.81	71.47	99.14	259.03	59.28	23.24

Note: South and Sardinia zones won't be used

Table 4. Descriptive Statistics of PUN (in €)

	Min	Q(5%)	Q(25%)	Median	Q(75%)	Q(95%)	Max	Mean	Std. Dev.
PUN	6.97	29.98	40.73	50.31	62.48	81.26	170	52.67	16.68

2.4 Balancing Volumes

What also could add something significant to the model are the balancing volumes, both the MSD and MB quantities, required by TERNA. Table 5 explains which are the zone with the highest request of balancing in the MSD, separated also by regulation. As expected, North has the greatest share of MSD quantities requested by TSO, both in the down and up-regulation; it means that TERNA has trouble to predict exactly the demand of electricity and it overestimates or underestimates it. All the areas present a relative high volatility: looking, for example, at Centre-South, we can see low values up to the median (even zero at the median) and then very high quantities to the maximum. The same happens for Centre-North and Sicily in down-regulation.

However, MSD is just the first phase of balancing: TERNA may even ask for an additional quantity of power or for selling an excess amount of it in MB. The result is more or less the same as we saw before: as we can see from Table 6, North can't be balanced by TERNA in the MGP and MSD most of the times and requires the MB to avoid some imbalances. The other zones behave similarly, with little means and zero medians, except for Centre-North in down-regulation.

The two balancing markets' quantities (MSD and MB) requested by TERNA to balance the system are then summed hour by hour between zones and regulations and treated as balancing prices and MGP prices have been transformed before. It means that the medians of the two balancing markets volumes summed together were computed and subtracted from each hour. From now on, balancing volumes are the variations of them from their median values.

Table 5. MSD volumes by area and regulation (in MWh)

		Min	Q(5%)	Q(25%)	Median	Q(75%)	Q(95%)	Max	Mean	Std. Dev.
NORD	Down	0	30	185	346.46	629.14	1268.9	3138.42	461.76	396.45
	Up	0	0	43.97	291.89	707	1466.54	3395.45	453.92	495.76
CNOR	Down	0	0	0	24.74	48.02	87	781.8	31.97	51.1
	Up	0	0	0	0	42	136.95	606.88	29.51	57.95
CSUD	Down	0	0	0	0	40	136	1177.09	34.09	81.1
	Up	0	0	0	29	163	414	1251.45	104.10	157.55
SICI	Down	0	0	0	0	4	60.11	523.5	10.94	29.51
	Up	0	0	156	214	328	491	864.36	237.52	137.65

Table 6. MB volumes by area and regulation (in MWh)

		Min	Q(5%)	Q(25%)	Median	Q(75%)	Q(95%)	Max	Mean	Std. Dev.
NORD	Down	0	0	26.6	93.89	189.24	361.70	790.39	124.86	119.08
	Up	0	0	0.56	26.43	104.09	265.34	927.04	68.07	92.48
CNOR	Down	0	0	0	2.74	14.76	38.41	98.14	9.42	13.41
	Up	0	0	0	0	4.51	23.67	78.71	4.36	8.93
CSUD	Down	0	0	0	0	12.20	50.42	251.45	10.09	19.79
	Up	0	0	0	0	1.23	25.06	180.52	4.07	11.31
SICI	Down	0	0	0	0	1.24	27.22	108	4.01	9.92
	Up	0	0	0	0	0.31	16.82	70	2.46	7.09

2.5 Renewable Energy Sources

The model aims to study the RESs' effect on Italian balancing market, looking if energy production from *green* sources has some implications in the two types of regulation and among the four remaining zones. Italy sees the presence of 6 big renewable sources' production in the electricity markets: Photovoltaic, Hydroelectric, Wind, Geothermal, Biomass and Waste productions. Hence, I collected the data of renewable energy sources for MGP from GME website, which provides hourly and zonal data. The only unconventional aspect is the usage of another type of RES: GME uses a seventh variable, which we can call "Micro", that includes all those non-relevant renewable energy sources that apparently cannot be encoded individually in a precise way and therefore are unified. All these Micro RES take into account the renewable energy production under the threshold of 10 MWh; reasonably, the micro PV and the micro hydroelectric production are the best candidates for being the biggest part of it, even though it depends on the zone they are related for. It cannot be ruled out that also biomass, geothermal, waste and wind are part of this category, in specific hours and/or physical zones. Watching the renewables sources' effect of balancing prices, it's important to note their special characteristics. The following tables describe renewable energy sources hourly production's statistics, in MWh:

- Table 7.1 describe Micro RESs production that, even if - at first glance - it may seem not very useful, actually it represents the first RES in the size, as it exceeds even hydroelectric production's volumes in the four zones. Its presence is prevailing in the North zone, while in the other three regions the median quantity is much lower, since almost whole micro hydroelectric is generated in the North of the country.

- PV source (Table 7.2) is available obviously only from the early morning to the late evening, approximately from 7 AM to 7 PM. The biggest production is made by the North and Centre-South zones, despite the favorable weather of Sicily. Its values are the smallest ones, maybe because the biggest part of its share is below 10 MWh (depending on the zone, it could be see from the correlation matrix) and, for this, PV source may represent large photovoltaic plants.

- Hydroelectric energy - in Table 7.3 - is the single most performing renewable source, as the technology has been developed long time before modern PV, wind and biomass methods; it's always active in the country and North zone holds the record for electricity generation.

Table 7.1. Descriptive Statistics of Energy Production from Micro RES by zone (in MWh)

	Micro								
	Min	Q(5%)	Q(25%)	Median	Q(75%)	Q(95%)	Max	Mean	Std. Dev.
NORD	1274.51	1817.11	2182.48	2685.58	3533.92	5250.22	7178.86	2999.33	1074.16
CNOR	127.19	168.9	216.79	299.82	660.46	1148.96	1636.69	461.19	323.48
CSUD	108.16	155.24	217.17	309.41	742.07	1252.94	1712.61	493.7	364.57
SICI	28.63	44.59	68.52	131.3	392.54	654.64	912.64	237.83	209.07
Total	1759.52	2332.79	2769.01	3426.36	5285.38	8186.66	11319.59	4192.05	1883.45

Note: Total production is computed without considering South and Sardinia zones.

Table 7.2. Descriptive Statistics of Energy Production from PV by zone (in MWh)

	PV								
	Min	Q(5%)	Q(25%)	Median	Q(75%)	Q(95%)	Max	Mean	Std. Dev.
NORD	0	0	0	10	70.45	189.71	263.16	44.06	64.38
CNOR	0	0	0	0.09	7	5.25	10.5	2.86	3.95
CSUD	0	0	0	10	76.74	148.57	204.00	40.35	52.26
SICI	0	0	0	0.19	7.76	15.27	19.37	4.02	5.45
Total	0	0	0	21.99	163.76	343.38	470.11	91.28	119.56

Note: Total production is computed without considering South and Sardinia zones.

Table 7.3. Descriptive Statistics of Energy Production from Hydro by zone (in MWh)

	Hydro								
	Min	Q(5%)	Q(25%)	Median	Q(75%)	Q(95%)	Max	Mean	Std. Dev.
NORD	353.47	599.67	1377.84	2586.55	4006.48	5845.62	8075.97	2811.16	1664.82
CNOR	6.01	27.11	105.91	177.52	300.07	494.08	724.78	213.86	141.81
CSUD	73.77	101.39	152.34	236.81	384.84	625.73	1761.48	287.25	170.64
SICI	0	0	0	1.48	11.27	36	58.5	8.22	12.03
Total	516.49	939.60	1854.32	3076.43	4572.50	6519.23	8791.58	3320.49	1753.33

Note: Total production is computed without considering South and Sardinia zones.

Table 7.4. Descriptive Statistics of Energy Production from Wind by zone (in MWh)

	Wind								
	Min	Q(5%)	Q(25%)	Median	Q(75%)	Q(95%)	Max	Mean	Std. Dev.
NORD	0	0.12	0.95	3.15	8.01	14.12	25.3	4.96	4.95
CNOR	0.02	1.52	5.41	12.47	26.91	52.09	80.04	18.18	16.17
CSUD	2.01	20.93	70.02	178.44	417.12	870.07	1203.27	279.76	267.44
SICI	5.21	40.07	110.26	231.1	471.6	922.52	1396.47	326.77	279.21
Total	13.01	88.53	235.13	476.30	912.03	1639.59	2415.70	629.67	494.12

Note: Total production is computed without considering South and Sardinia zones.

- Wind (Table 7.4) total production is also always active in the country, with high standard deviation values because of its nature of variable energy source. The biggest share of wind production are held by Sicily and Centre-South, because South and Sardinia zones - which creates the biggest shares of wind electricity production in Italy - are not relevant for the analysis.

- Biomass (Table 7.5) and waste (Table 7.6) sources produce less than wind with also less volatility. Biomass has its peaks production in North whereas waste energy generation is only exploited in North, Centre-South and Centre-South. Geothermal energy production (Table 7.7) is available only in Centre-North because it's exploited just in Tuscany region. Geothermal production is sometimes even larger than biomass and waste production together.

Non-programmable RES are clearly exogenous variables, as their production depends on weather conditions and they cannot bid strategically according to price dynamics (Clò et al., 2015). Hence, all the renewable energy sources are taken into account without analyzing their autocorrelation. The presence of Micro RES brings the attention to its correlation with the other renewable energy sources. If most of the Italian PV production is under 10 MWh, i.e. it is generated by small-scale photovoltaic plants, then it's included in the category of Micro RES. Since data can't say which of the energy sources mostly fall into this category, the correlation tables will later show if there's presence of multicollinearity between explanatory variables.

Table 7.5. Descriptive Statistics of Energy Production from Biomass by zone (in MWh)

	Biomass								
	Min	Q(5%)	Q(25%)	Median	Q(75%)	Q(95%)	Max	Mean	Std. Dev.
NORD	50.06	88.8	108.75	124.27	140.34	161.74	204.32	124.76	22.41
CNOR	0	0	8.5	9	9.4	31.35	54.3	10.87	9.29
CSUD	0	0	2.26	5.85	10.5	18.04	20.7	6.62	5.47
SICI	0	0	14.07	15.7	15.9	16	18.2	14.15	3.96
Total	78.96	118.88	138.59	154.56	174.12	198.77	248.40	156.40	24.62

Note: Total production is computed without considering South and Sardinia zones.

Table 7.6. Descriptive Statistics of Energy Production from Waste by zone (in MWh)

	Waste								
	Min	Q(5%)	Q(25%)	Median	Q(75%)	Q(95%)	Max	Mean	Std. Dev.
NORD	190.13	268.09	304.90	324.30	342.63	370.79	442.75	322.89	31.18
CNOR	0	3.22	4.75	5.73	9.70	15.77	24.62	7.30	4.44
CSUD	20	120.33	151.40	165.27	181.31	188.84	204.85	162.88	22.80
Total	315.7	427.51	470.83	495.9	517.92	547.98	614.08	493.07	36.68

Note: Total production is computed without considering South and Sardinia zones.

Table 7.7. Descriptive Statistics of Energy Production from Geothermal by zone (in MWh)

	Geothermal								
	Min	Q(5%)	Q(25%)	Median	Q(75%)	Q(95%)	Max	Mean	Std. Dev.
CNOR	581.3	627.3	651.8	663.5	673.9	687.3	708.5	661.76	17.57

2.6 Fossil Fuels

To control the model I also add the fossil fuels' hourly energy production in cases where they are used to provide energy in the MGP market. Italian energy markets are provided with power generated from Coal, Natural Gas and Oil. These three common fossil fuels are not exploited in every region of the country: as it can be seen in Table 8.1, oil and coal production are not used to foster North and Sicily electricity markets, respectively. Natural gas has been in the last decades the most exploited one (see Table 8.2), especially in North zone, whereas among the other regions the median value is similar. North zone and Centre-South also use coal consistently to provide energy to day-ahead market. Regarding oil's volumes, they are not really high; oil, which has once produced the biggest share of power, in the last years it has been replaced mostly by natural gas and renewable sources.

If RES are taken as exogenous variables, fossil fuels are treated in the same way, without considering the presence of seasonality and taken into account separately between each zone.

Table 8.1. Minimum, Median and Maximum of Fossil Fuels' Energy Production by zone (in MWh)

	Coal			Natural Gas			Oil		
	Min	Med	Max	Min	Med	Max	Min	Med	Max
NORD	0	1004.5	1761.5	1156.48	6425.18	15955.98	\	\	\
CNOR	0	0	130	75.39	755.05	1589.40	0	0	14
CSUD	0	1290	1845	0	823.32	3128.09	0	0	69
SICI	\	\	\	85.9	642.64	1937.00	0	0	818

Table 8.2. Descriptive Statistics of hourly Fossil Fuels' Total Energy Production (in MWh)

	Min	Q(5%)	Q(25%)	Median	Q(75%)	Q(95%)	Max	Mean	Std. Dev.
Coal	0	545	1768.63	2389.51	2839.5	3399.5	3584.5	2241.20	832.33
Natural Gas	1962.35	4399.76	6476.72	8731.41	11777.69	15623.46	19883.37	9247.29	3488.70
Oil	0	0	0	0	0	288	818	39.42	107.58

Note: South and Sardinia zones have not been considered in the computation

2.7 Correlation

After considering the energy sources' composition, I create the linear correlation matrices for each regression which later will be run. Table 9 is an example for correlation using North Up-Regulation series; the other linear correlation matrices can be found in the Appendix.
It's easy to check which variables are correlated in this example; in bold there are the values greater than 0.5 correlation[8]. As hypothesized before, Micro RES are high correlated with PV energy source, reaching even more than 0.9 correlation's coefficient in Centre-South (see Appendix). Also hydroelectric source is correlated with Micro RES but in less extent (0.49) with respect to PV. It's the norm - instead - that fossil fuels are often high correlated, since usually gas prices are based on oil indexation; here's mostly between coal and natural gas (in

[8] According to Verbeek (2008), in a regression, multicollinearity problems could exist with coefficients higher than 0.8. However, there's no a specific threshold above which there's surely multicollinearity; it depends on case by case basis. In this work, I selected the threshold of 0.5.

Table 9 the value between the two is 0.50), maybe because oil is not used as much as the other fossil fuels.

In the regressions all these aspects will be taken into account; sometimes variables will be omitted for probable multicollinearity and - in that case - the least present variable in volume terms will be removed. All correlations, even those taking very small values (in absolute terms) are statistically significant at the 1% confidence level given the large sample sizes.

Table 9. Linear correlation matrix in North Up-Regulation

	MSD/ MB price	MGP price	MSD/ MB vol	Micro	Biomass	Hydro	PV	Waste	Wind	Coal	NG
MSD/ MB price	1.00										
MGP price	0.22	1.00									
MSD/ MB vol	0.14	0.47	1.00								
Micro	-0.13	-0.25	-0.20	1.00							
Biomass	-0.08	0.09	0.00	-0.02	1.00						
Hydro	-0.08	-0.07	-0.08	0.49	0.04	1.00					
PV	-0.10	-0.13	-0.15	**0.85**	-0.04	0.18	1.00				
Waste	-0.03	-0.15	-0.08	-0.02	0.19	0.03	-0.08	1.00			
Wind	0.06	-0.09	-0.02	-0.04	-0.03	-0.14	-0.03	0.07	1.00		
Coal	0.13	0.30	0.19	-0.21	-0.18	-0.08	-0.11	-0.04	0.09	1.00	
NG	0.15	**0.54**	0.31	-0.10	-0.02	0.09	-0.03	-0.17	-0.05	**0.50**	1.00

Note: correlations are computed on 25085 observations; in bold the values higher 0.5;

2.8 Cointegration

The last step of the analysis consists in testing for unit roots all the series that appear in the model. To test it, I use the augmented Dickey-Fuller Test (Dickey and Fuller, 1979) which tests the null hypothesis that the series have a unit root against hypothesis H1 that the series are stationary. MacKinnon (1996) critical values for rejection of hypothesis of unit root are -2.570 for 10% confidence level, -2.860 for 5% confidence level, and -3.430 for 1% confidence level for the model with constant and no trend. Table 10.1 and Table 10.2 confirm that the dependent variable series present in the model are stationary at a 1% critical value.

Table 10.3, Table 10.4, Table 10.5 and Table 10.6 verify that also MGP prices, balancing volumes, RES and fossil fuels are stationary at 99% significance level.

Table 10.1. Augmented Dickey-Fuller Test on Balancing Prices for Down-Regulation

Down-Regulation

Variable	ADF
NORD	-44.593
CNOR	-45.094
CSUD	-26.463
SICI	-35.723

Table 10.2. Augmented Dickey-Fuller Test on Balancing Prices for Up-Regulation

Up-Regulation

Variable	ADF
NORD	-64.207
CNOR	-35.008
CSUD	-31.525
SICI	-30.455

Table 10.3. Augmented Dickey-Fuller Test on MGP Prices

Variable	ADF
NORD	-23.103
CNOR	-28.610
CSUD	-29.162
SICI	-38.927

Table 10.4. Augmented Dickey-Fuller Test on Balancing Volumes

Down-Regulation		***Up-Regulation***	
Variable	ADF	Variable	ADF
NORD	-47.645	NORD	-38.391
CNOR	-56.003	CNOR	-53.657
CSUD	-61.930	CSUD	-39.171
SICI	-74.482	SICI	-40.302

Table 10.5. Augmented Dickey-Fuller Test on RES

	Biomass	Geothermal	Hydro	Micro	PV	Wind	Waste
NORD	-33.953	\	-25.742	-21.756	-26.209	-28.913	-23.435
CNOR	-22.867	-13.477	-33.859	-25.710	-63.100	-15.823	-24.277
CSUD	-17.969	\	-39.225	-26.405	-26.354	-11.716	-20.886
SICI	-18.075	\	-11.318	-25.910	-30.167	-12.905	\

Table 10.6. Augmented Dickey-Fuller Test on Fossil Fuels

	Coal	Natural Gas	Oil
NORD	-26.415	-21.686	\
CNOR	-38.688	-35.911	-36.124
CSUD	-37.518	-26.814	-54.006
SICI	\	-35.407	-37.057

Chapter 3

Results

3.1 The Model

Given the autocorrelation still considerable in the series, I adapt to each one of them an AutoRegressive model with lags 1, 2 and 24, trying to remove the autocorrelation still present, namely, the previous two hours and one day before's contamination. Indeed, the model is an AR constructed using three different lags, with the variation of MGP prices from their medians, the variation of total balancing volumes from their medians, renewable energy sources production and fossil fuels production as explanatory variables; the model is as follows:

$$\begin{bmatrix} P_{t,z}^{DOWN} \\ P_{t,z}^{UP} \end{bmatrix} = \begin{bmatrix} \alpha_1 \\ \alpha_2 \end{bmatrix} + \phi_1 \begin{bmatrix} P_{t-1,z}^{DOWN} \\ P_{t-1,z}^{UP} \end{bmatrix} + \phi_2 \begin{bmatrix} P_{t-2,z}^{DOWN} \\ P_{t-2,z}^{UP} \end{bmatrix} + \phi_3 \begin{bmatrix} P_{t-24,z}^{DOWN} \\ P_{t-24,z}^{UP} \end{bmatrix} + \beta MGP_{t,z} + \gamma \begin{bmatrix} BV_{t,z}^{DOWN} \\ BV_{t,z}^{UP} \end{bmatrix} + \\ + \delta RES_{t,z}^{i} + \lambda FF_{t,z}^{j} + \begin{bmatrix} \varepsilon_t^{DOWN} \\ \varepsilon_t^{UP} \end{bmatrix}$$

where *P* represents balancing prices variation, *MGP* is MGP prices variation, *BV* is total balancing volumes variation, *RES* is renewable energy sources hourly production, *FF* is fossil fuels hourly production, ϵ is white noise ($\epsilon \sim$ iidN(0,σ^2)), with *t* representing hourly time, *i* = MicroRES, Biomass, Geothermal, Hydroelectric, PV, Waste and Wind, *j* = Coal, Natural Gas and Oil and *z* = North, Centre-North, Centre-South and Sicily. Table 11.1 briefly explains the variables of the model.

Each regression will be treated separately between zones and regulations, considering that in few series the significant lags could be different due to non-significant values, particularly in the second lag, and explanatory variable as RES and FF could be correlate to other variables of the same type and, because of multicollinearity, excluded. In the next paragraph, I start going from North to Sicily, with up-regulation and down-regulation.

Table 11.1. Variables, Unit of Measurement and Definition

Variable	Unit of measurement	Definition
P	€/MWh	Balancing prices variation from their median values
MGP	€/MWh	Day-ahead prices variation from their median values
BV	MWh	Total balancing volumes variation from their median values
RES	MWh	RES generation for the day-ahead market
FF	MWh	Fossil fuels generation for the day-ahead market

3.2 Results

3.2.1 North Up-Regulation

Table 11.2. Results for North Up-Regulation

North UP balancing price	Coef.	Std. Err.	z	P>|z|
North MGP price	.3357541	.0478448	7.02	0.000
North balancing volumes	.0092332	.0007218	12.79	0.000
Micro RES	- .0018883	.0006525	- 2.89	0.004
Biomass	- .0477743	.0200179	- 2.39	0.017
Hydro	- .0007375	.0003547	- 2.08	0.038
Waste	.0414846	.0148174	2.80	0.005
Wind	.178736	.0702136	2.55	0.011
Natural Gas	.0009176	.0002778	3.30	0.001
Constant	2.593655	5.456518	0.48	0.635
Lag 1	.6579334	.0015055	437.01	0.000
Lag 24	.1242114	.0023187	53.57	0.000

Number of observations: 25085

North in the up-regulation mechanism, represented in Table 11.2, is analyzed without considering the second lag, since its presence is non-significant, and without large PV source and coal production, for multicollinearity (see Table 9) respectively with microRES and natural gas[9].

A high upwards effect is given by MGP price variation: a relative variation of 1% of MGP prices changes positively - by around 0.33%, since they are both measured in €/MWh terms - the balancing prices variation. It's a positive coefficient and this was expected, but not as large as imagined; the two markets are relatively low correlated, given that day-ahead markets can't explain the most of what happens in balancing markets. Also positive is the sign of balancing volumes variation: more volumes and therefore more need to balance probably means more market power for energy firms which gain more money from the variation (~ 0.1 €/MWh) of balancing prices from their medians.

Some RES stabilize the market: microRES (~ -0.002 €/MWh), biomass (~ -0.048 €/MWh) and hydroelectric (-0.0007 €/MWh) productions have negative signs; these sources, widely used in this zone, may make fossil fuels be used less to regulate the system; this is confirmed by the positive sign of natural gas production. On the contrary, the remaining two renewable sources - waste and wind - have upwards effect on prices. A big impact (~ €0.18) characterizes wind energy source which, maybe due to its intermittent nature and its scarce presence in North, pushes upwards balancing prices variation and the extra cost for TERNA.

3.2.2 North Down-Regulation

About North zone in the down-regulation balancing market, watching the ACF of the series and the linear correlation matrix present in the Appendix, I opt for all the three lags considered in the model but with PV variable eliminated for multicollinearity with micro RES. Table 11.3 illustrates the results: first of all, it's fundamental to highlight that the meaning of signs is completely the opposite of up-regulation: a positive coefficient pushes the down-regulating price towards the MGP price, making firms pay more and TERNA earn more, whereas a negative one brings it closer to 0, making firms pay less and TERNA earn less. Secondly, all the three lags (1, 2 and 24) and most of the explanatory variables are highly

[9] Between the two variables, I omit the one with less weight.

significant with respect to the dependent variable: the only ones non-significant are waste and wind, respectively largely and poorly exploited in North.

Table 11.3. Results for North Down-Regulation

North DOWN balancing price	Coef.	Std. Err.	z	P>|z|
North MGP price	.0439033	.0051283	8.56	0.000
North balancing volumes	- .0048363	.0001037	- 46.65	0.000
Micro RES	- .0005235	.0001239	- 4.23	0.000
Biomass	.0118989	.0031447	3.78	0.000
Hydro	- .0008332	.0000695	- 11.98	0.000
Waste	.001479	.0030739	0.48	0.630
Wind	- .0078405	.014894	- 0.53	0.599
Coal	- .0004752	.0002082	- 2.28	0.022
Natural Gas	.0007716	.00004	19.28	0.000
Constant	-2.235911	1.178219	- 1.90	0.058
Lag 1	.6467306	.0040791	158.55	0.000
Lag 2	.1067543	.0037791	28.25	0.000
Lag 24	.168345	.0030226	55.70	0.000

Number of observations: 26182

MGP price variation has a positive impact (~0.044%) but much lower than the coefficient in the up-regulating mechanism. Probably in down-regulations, MGP is less correlated and the balancing prices depend on other information.

About balancing volumes variation, the coefficient is negative, so it pushes downwards the price: this verifies that, in North region, a greater use of balancing markets increases the market power of power plants and makes them profit more.

More odd is the fact that a contrast between variables is present in RES and fossil fuels, as micro RES, hydroelectric and coal have negative and very low effects while biomass and natural gas positive ones. Hence, in this case, biomass and natural gas are the only two energy sources that make TERNA earn more when selling power to stabilize demand and supply, with biomass increasing down-regulation price variation by more than €0.01 for each MWh produced. Even though one cent for one MWh seems a very low effect, it's fundamental to adapt the result to each series. North Down-Regulation's variation doesn't possess high volatility, as other series instead have, so the results - ceteris paribus - gain more strength.

3.2.3 Centre-North Up-Regulation

Table 11.4. Results for Centre-North Up-Regulation

Centre-North UP balancing price	Coef.	Std. Err.	z	P>|z|
Centre-North MGP price	.3314616	.0166932	19.86	0.000
Centre-North balancing volumes	- .0231273	.0024902	- 9.29	0.000
Micro RES	.002168	.0012454	1.74	0.082
Biomass	- .0877327	.0609324	- 1.44	0.150
Geothermal	.0304106	.0308034	0.99	0.324
Hydro	.0049298	.0021212	2.32	0.020
PV	- .056822	.0458403	- 1.24	0.215
Waste	- .154022	.1166678	- 1.32	0.187
Wind	- .0025137	.0213267	- 0.12	0.906
Coal	.0593387	.0325099	1.83	0.068
Natural Gas	.0040587	.0010915	3.72	0.000
Oil	- .042476	.1498728	- 0.28	0.777
Constant	- 20.73048	20.615	- 1.01	0.315
Lag 1	.6263538	.0025351	247.07	0.000
Lag 2	.1464108	.003072	47.66	0.000
Lag 24	.1303764	.0023752	54.89	0.000

Number of observations: 16201

Centre-North in the up-regulation (Table 11.4) shows many non-significant coefficients, as biomass, geothermal, PV, waste, wind and oil have high p-values. What I can extrapolate from the few significant values is that almost all the variables, with the exception of balancing volumes variation, have upwards consequences on prices. MGP prices have practically the same impact as North zone in the up-regulation (0.33), but balancing volumes behave differently, having a negative and a greater than up-regulation - in absolute value - effect.
This means that in Centre-North Up-Regulation, the more balancing markets are used, the more competitiveness increases in electricity markets. This results is counterbalanced by the use of microRES (significant at 90%), hydroelectric, coal (significant at 90%) and natural gas, which increase the costs of TSO.

3.2.4 Centre-North Down-Regulation

In Centre-North Down-Regulation (Table 11.5), it's been used an AR process with lag 1, 2 and 24 but there's no room for biomass, PV, coal and oil to be analyzed because of their non-significance characteristics, probably due to their almost absence in this zone (see Paragraphs 2.5 and 2.6). On the contrary to North Down-Regulation analysis, MGP prices variation and balancing volumes variation have the same sign, which is positive and both also with a greater coefficient than above, with ~€0.08/MWh and ~€0.02/MWh increase respectively. One prove more to confirm the fact that Centre-North and North energy markets behave differently: if in North zone, the use of balancing volumes raises the market power of firms, in Centre-North they enlarge the competitiveness between companies.
One thing in common is that, as it happened in North, down-regulation shows a lower impact of MGP prices than up-regulation.
MicroRES, hydroelectric, geothermal and wind power decrease the balancing prices variation, making the Italian TSO earn less when energy supply exceeds demand: this should be taken into account, not so much for microRES and wind which are intermittent sources, but particularly for hydroelectric and geothermal. What affect positively the balancing prices variation is waste and natural gas production, the first one, not widely used in Centre-North, with €0.08 per MWh and the second one with a 10 times higher coefficient with respect to natural gas in North.

Table 11.5. Results for Centre-North Down-Regulation

Centre-North DOWN balancing price	Coef.	Std. Err.	z	P>|z|
Centre-North MGP price	.079936	.0077668	10.29	0.000
Centre-North balancing volumes	.0218996	.0011698	18.72	0.000
Micro RES	- .0022964	.0004881	- 4.71	0.000
Biomass	- .00332	.0229841	- 0.14	0.885
Geothermal	- .0357766	.0104019	- 3.44	0.001
Hydro	- .0084055	.0008572	- 9.81	0.000
PV	.0261841	.0200593	1.31	0.192
Waste	.0884015	.0310839	2.84	0.004
Wind	- .014404	.0080729	- 1.78	0.074
Coal	- .009746	.0151604	- 0.64	0.520
Natural Gas	.0072105	.0003877	18.60	0.000
Oil	.0738669	.0684499	1.08	0.281
Constant	18.45628	6.920377	2.67	0.008
Lag 1	.5781584	.0054107	106.86	0.000
Lag 2	.1178896	.0051617	22.84	0.000
Lag 24	.1650275	.0039752	41.51	0.000

Number of observations: 18589

3.2.5 Centre-South Up-Regulation

The regression about Centre-South in the up-regulation market is the second and last time in which the second lag is non significant and, hence, not used. PV source's production is also omitted because of collinearity with microRES.

Here, in the below Table 11.6, almost all the explanatory variables are significant, except for biomass and oil, which are infrequently used in Centre-South to produce energy. MGP prices variation coefficient (~0.31) behaves similarly to the previous up-regulating systems, increasing the earnings of the companies, with the help of balancing volumes variation which has a positive coefficient of ~0.18€/MWh. These values make Centre-South companies more similar to North ones than the Centre-North firms (even though the geographical zone is much closer to Centre-North than to North), decreasing the market competitiveness.

Regarding the RES, waste has a high positive effect of €0.22 for each MWh added; also wind, natural gas and coal push upwards the prices, making TERNA pay much more. Those four sources - waste, wind, natural gas and coal - are extremely exploited in this region.

The cost of TSO in up-regulating is hardly contrasted by hydro and microRES, whose sign is negative but with relatively low coefficients.

Table 11.6. Results for Centre-South Up-Regulation

Centre-South UP balancing price	Coef.	Std. Err.	z	P>|z|
Centre-South MGP price	.309842	.0715596	4.33	0.000
Centre-South balancing volumes	.1810476	.002891	62.62	0.000
Micro RES	- .0075246	.0034532	- 2.18	0.029
Biomass	.3949206	.2564282	1.54	0.124
Hydro	- .0228417	.0042959	- 5.32	0.000
Waste	.2227511	.0510946	4.36	0.000
Wind	.0250982	.0049373	5.08	0.000
Coal	.0089171	.0014097	6.33	0.000
Natural Gas	.011866	.0009621	12.33	0.000
Oil	.1481667	.7514665	0.20	0.844
Constant	- 54.54476	10.6315	- 5.13	0.000
Lag 1	.7935355	.0027874	284.69	0.000
Lag 24	.1391163	.0026521	52.46	0.000

Number of observations: 18179

3.2.6 Centre-South Down-Regulation

Table 11.7. Results for Centre-South Down-Regulation

Centre-South DOWN balancing price	Coef.	Std. Err.	z	P>|z|
Centre-South MGP price	.0937968	.0064674	14.50	0.000
Centre-South balancing volumes	.0056811	.0005885	9.65	0.000
Micro RES	- .0050754	.0009639	- 5.27	0.000
Biomass	.0215626	.033783	0.64	0.523
Hydro	- .0036974	.0006668	- 5.55	0.000
PV	.0277257	.0064798	4.28	0.000
Waste	- .0233358	.0061086	- 3.82	0.000
Wind	- .0025423	.0006244	- 4.07	0.000
Coal	.0002814	.0002122	1.33	0.185
Natural Gas	- .0008343	.0001415	- 5.90	0.000
Oil	- .1443913	.0469966	- 3.07	0.002
Constant	8.115586	1.271686	6.38	0.000
Lag 1	.6465619	.004587	140.96	0.000
Lag 2	.1448827	.0048167	30.08	0.000
Lag 24	.1447218	.0032362	44.72	0.000

Number of observations: 13784

Table 11.7 describes the Centre-South Down-Regulation results. We can see some similarities with Centre-North: for example, biomass and coal have not significant coefficients and MGP prices variation and balancing volumes variation have positive coefficients - also almost of the same size - and they increase the firms' competitiveness as it happens in Centre-North Down-Regulation.

MicroRES, hydroelectric, waste and wind productions are affecting balancing prices variation negatively; microRES and hydro productions decrease TERNA earnings in all the down-regulating regression analyzed up to now, with wind source that, even if in North is not significant, in Centre-North and Centre-South behave as microRES and hydroelectric sources. Quite surprising is the double negative effect obtained from natural gas and oil, with a €0.14 impact per MWh for oil production, which decrease firms' costs.
Instead, PV, for the first time both present and significative, has a positive impact on balancing prices and in Centre-South is the only renewable source that raises the earnings of the TSO.

3.2.7 Sicily Up-Regulation

Table 11.8. Results for Sicily Up-Regulation

Sicily UP balancing price	Coef.	Std. Err.	z	P>|z|
Sicily MGP price	.0488657	.0082659	5.91	0.000
Sicily balancing volumes	.0201317	.0007413	27.16	0.000
Biomass	- .0793143	.0866306	- 0.92	0.360
Hydro	.0117941	.0308376	0.38	0.702
PV	- .117583	.0553447	- 2.12	0.034
Wind	- .0109164	.002067	- 5.28	0.000
Natural Gas	.0011014	.0006976	1.58	0.114
Oil	.0155503	.0015423	10.08	0.000
Constant	7.326786	3.028887	2.42	0.016
Lag 1	.8861626	.0018635	475.52	0.000
Lag 2	- .034716	.0019017	- 18.26	0.000
Lag 24	.1086828	.0012033	90.32	0.000

Number of observations: 25095

The next regression is run for Sicily in up-regulation market (see Table 11.8), without considering microRES for collinearity. The first thing to notice is the lower impact of MGP prices (~0.05), which in the other up-regulating regressions was always above 0.30. MGP here explains a lot less than the above results, even though its coefficient has the same sign of the balancing volumes variation, as it happens in North and in Centre-South, increasing market power for companies.

Even though biomass, hydroelectric and gas are non-significant, large PV (~-0.12€/MWh) and wind (~-0.01€/MWh) push downwards the price, with large PV production decreasing the costs of the Transmission System Operator.

About fossil fuels, only oil production is significant (it's significant only here) with coefficient around 0.02€/MWh, surprisingly raising balancing prices variation.

3.2.8 Sicily Down-Regulation

Table 11.9. Results for Sicily Down-Regulation

Sicily DOWN balancing price	Coef.	Std. Err.	z	P>|z|
Sicily MGP price	.1544144	.0145144	10.64	0.000
Sicily balancing volumes	- .0457866	.0047908	- 9.56	0.000
Micro RES	.0208343	.0039758	5.24	0.000
Biomass	.0845975	.1335804	0.63	0.527
Hydro	.0300689	.0443188	0.68	0.497
PV	- .287637	.1489369	- 1.93	0.053
Wind	.0010245	.0018438	0.56	0.578
Natural Gas	- .0050055	.0013024	- 3.84	0.000
Oil	.022036	.0027428	8.03	0.000
Constant	4.762762	2.575225	1.85	0.064
Lag 1	.5951434	.0032641	182.33	0.000
Lag 2	.1371598	.0056846	24.13	0.000
Lag 24	.1547195	.0044916	34.45	0.000

Number of observations: 11491

Sicily in down-regulation (Table 11.9) could be analyzed without considering biomass, hydroelectric and wind productions. MGP prices and balancing volumes have the same characteristics of North Down-Regulation, i.e. with different signs; it means that the more balancing markets are used, the more the companies have market power. Sicily is the only zone in which MGP prices have a greater effect in down-regulation than in up-regulation.
MicroRES for the first time in down-regulation regressions increase Terna earnings. Large PV production - significant at 90% - decreases the variation of balancing prices by more than €0.28 per MWh in a region which it's not largely exploited (see Table 7.2). Wind, that in Sicily is the most productive renewable source, unfortunately is not significant. The two fossil fuels present in the zone - natural gas and oil - are behaving oppositely.

Conclusions

The thesis aims to give an interpretation of the results obtained, looking for zonal or market characteristics that may help the understanding of electricity balancing markets in Italy and that may boost the efficiency improvement. This analysis differs from the other studies in that data are taken hourly and separately between zones and regulations at the same time. On a case by case basis analysis, the outcomes are more detailed and can discover distinctive traits of a single zone in a single market or they can find either similarities between distant regions or differences between close zones.

To detect those types of results, let's start observing the up-regulating mechanism. As a major finding, a greater use of up-regulating balancing markets usually increases firms' market power in North, Centre-South and Sicily, with the exception of Centre-North in which the more the market is used the more competitive it is. Watching the down-regulation results, it comes out that in North and in Sicily, confirming up-regulation outcomes, using the balancing market actually makes the market less competitive. The exception is still Centre-North, in which balancing markets are more competitive the more are used, and Centre-South, where in down-regulating balancing markets it reveals more competitiveness among firms.

With regard to renewable sources, microRES and hydroelectric energy productions, which always have the same sign (probably due to the high correlation between the two variables), have a downward effect on up-regulating balancing prices in North and Centre-South but an upward one in Centre-North, whose market still behaves differently from the others. In down-regulation, microRES and hydro tend to move closer to 0 the down-regulation price (except for microRES in Sicily), hence completely different from the previous regulation.

The behavior of almost all the renewable energy sources in up-regulation mechanism is pretty ambiguous; on the contrary, regarding fossil fuels, the situation is clear: every supplementary fossil fuel' energy production for day-ahead market always raises up-regulating prices and consequently the costs for TERNA to pay for increasing the electricity supply. This happens for all the significative values for fossil fuels: for natural gas in North, for natural gas and coal in Centre-North and Centre-South, and for oil in Sicily. A very unexpected result considering the conventional fuels' nature.

In down-regulation - instead - fossil fuels' effects are unclear: natural gas tend to increase the price in the two northern zones and tend to decrease it in the two southern ones. An ambiguous behavior is also that of oil, which in Centre-South has negative sign and in Sicily positive sign and - speaking about renewables - of PV production, which affects largely and negatively the price in Sicily: ~-€0.29/MWh in down-regulation market and ~-€0.11/MWh in up-regulation market, and less and positively in Centre-South Down-Regulation (~€0.03/MWh).

Combining all the results obtained, it's possible to say that fossil fuels generations make power firms earn more in balancing markets in almost all the country, mostly in up-regulation system. Instead, RES have ambiguous impacts on prices, depending on zones and regulations:

- MicroRES and hydroelectric production may make TERNA pay less in North and Centre-South in up-regulating mechanisms but not in down-regulating ones, in which its costs are more. Centre-North is different: microRES and hydro sources always increase TERNA costs.

- Large PV production has different effects in too few regressions, but, considering its high correlation, it can be compared to the microRES impact, which has significative and interesting effects in North and Centre-South, the two zones in which large PV production is greater.

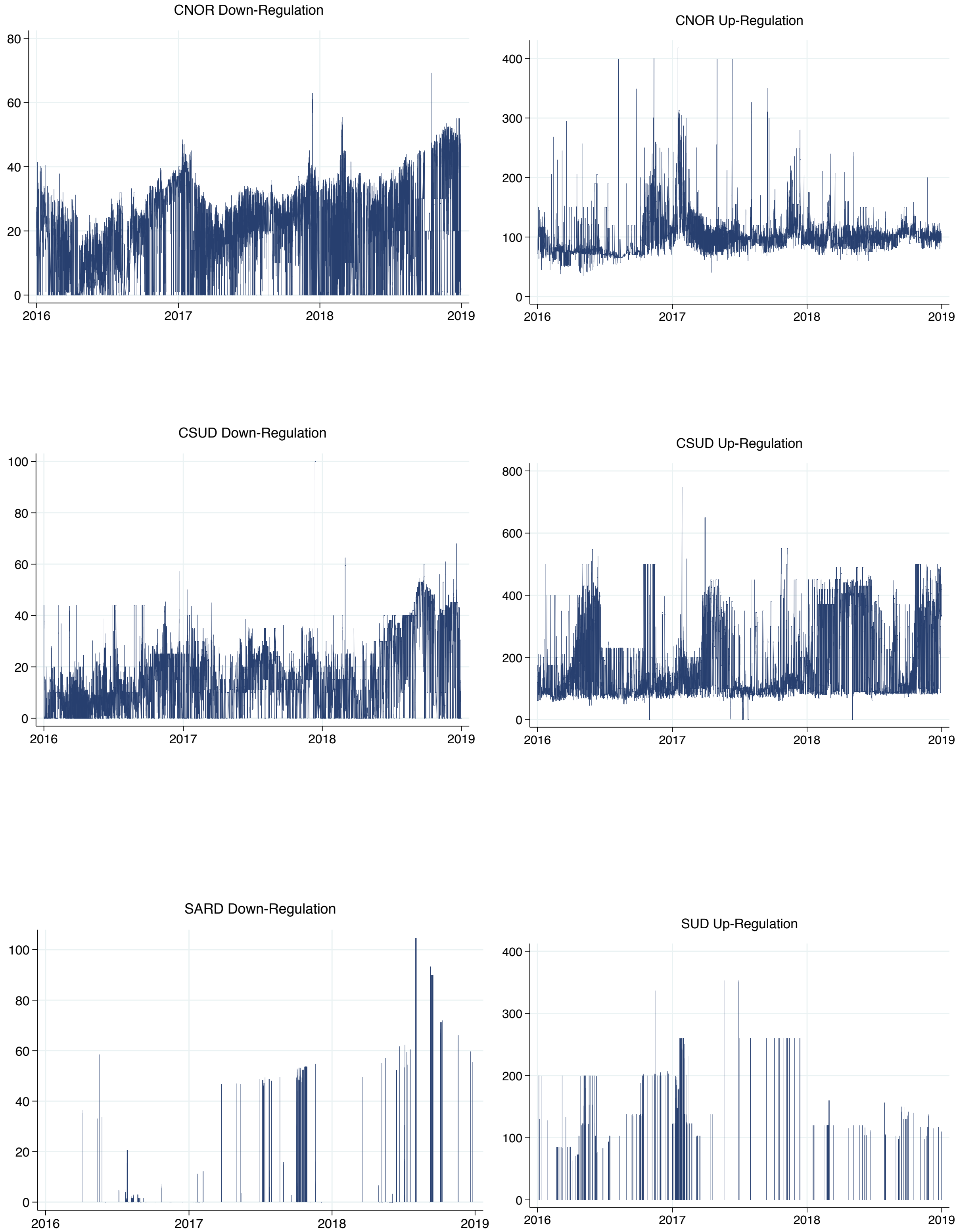
- Biomass, exploited practically only in North, has a positive effect in that zone on increasing competitiveness among firms in both regulations.

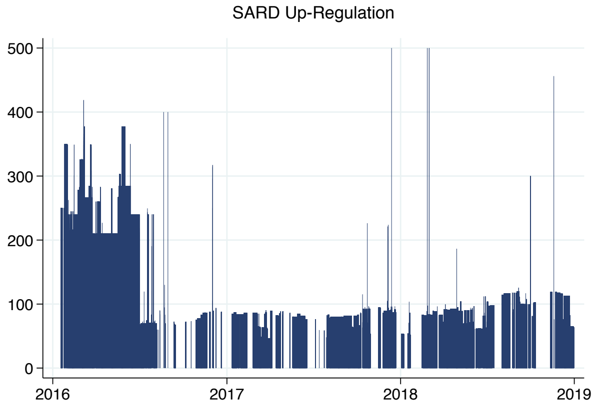
- Wind, which is more productive in Centre-South and in Sicily, has a pretty clear behavior in Centre-South, in which it increases the costs of TERNA and the earnings of firms, but it has a diminishing effect in Sicily Up-Regulation prices.

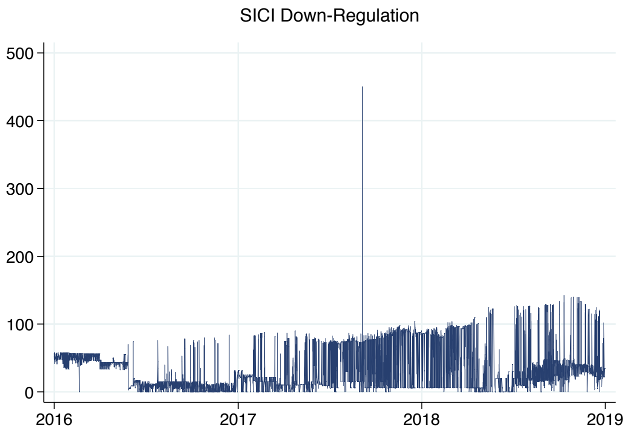
- Waste generation (used mostly in North and Centre-South) usually increases market power and TSO costs in these two zones. Particularly high is its effect in Centre-South Up-Regulation.

Appendix

Fig. A1. Graphs of each zone in comparison between regulations




SARD Up-Regulation
500
400
300
200
100
0
2016
2017
2018
2019


SICI Down-Regulation
500
400
300
200
100
0
2016
2017
2018
2019

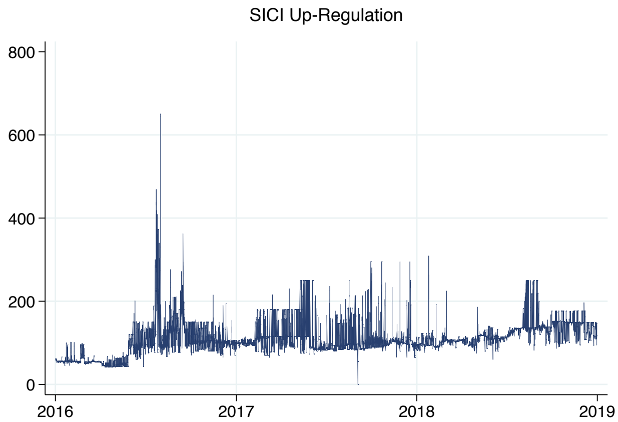

SICI Up-Regulation
800
600
400
200
0
2016
2017
2018
2019

Table A2. Correlation matrix in Nord Down-Regulation

	MSD/ MB price	MGP price	MSD/ MB vol	Micro	Biomass	Hydro	PV	Waste	Wind	Coal	NG
MSD/ MB price	1.00										
MGP price	0.48	1.00									
MSD/ MB vol	-0.10	0.04	1.00								
Micro	-0.20	-0.24	0.08	1.00							
Biomass	0.22	0.09	0.03	-0.02	1.00						
Hydro	-0.18	-0.07	0.06	0.49	0.05	1.00					
PV	-0.10	-0.13	0.06	**0.85**	-0.03	0.18	1.00				
Waste	-0.06	-0.16	-0.03	-0.03	0.19	0.02	-0.09	1.00			
Wind	-0.06	-0.10	0.03	-0.05	-0.04	-0.14	-0.03	0.08	1.00		
Coal	0.05	0.29	-0.15	-0.21	-0.18	-0.08	-0.11	-0.03	0.09	1.00	
NG	0.31	**0.54**	-0.04	-0.09	-0.02	0.09	-0.02	-0.18	-0.05	0.49	1.00

Note: correlations are computed on 26182 observations; in bold the values higher 0.5;

Table A3. Correlation matrix in Centre-North Up-Regulation

	MSD /MB price	MGP price	MSD /MB vol	Micro	Biom.	Geoth.	Hydro	PV	Waste	Wind	Coal	NG	Oil
MSD/ MB price	1.00												
MGP price	0.48	1.00											
MSD/ MB vol	0.14	0.17	1.00										
Micro	-0.09	-0.16	0.01	1.00									
Biomass	-0.14	-0.26	0.11	0.15	1.00								
Geother mal	0.01	-0.20	0.06	-0.10	0.24	1.00							
Hydro	0.04	0.05	0.08	-0.02	0.02	0.10	1.00						
PV	0.00	0.11	0.00	0.43	0.08	-0.08	-0.10	1.00					
Waste	0.00	0.22	0.01	0.00	-0.13	-0.15	0.27	-0.01	1.00				
Wind	0.15	0.05	0.12	-0.06	0.12	0.16	0.13	-0.07	0.08	1.00			
Coal	0.15	0.13	0.09	0.01	0.01	0.08	0.03	-0.02	-0.02	0.05	1.00		
NG	0.23	0.28	0.09	-0.07	-0.07	0.02	0.19	0.10	-0.03	0.03	0.11	1.00	
Oil	0.03	0.01	0.03	0.10	-0.01	0.01	0.10	0.05	0.00	-0.01	-0.02	0.07	1.00

Note: correlations are computed on 16201 observations; in bold the values higher 0.5;

Table A4. Correlation matrix in Centre-North Down-Regulation

	MSD /MB price	MGP price	MSD /MB vol	Micro	Biom.	Geoth.	Hydro	PV	Waste	Wind	Coal	NG	Oil
MSD/ MB price	1.00												
MGP price	0.39	1.00											
MSD/ MB vol	-0.02	-0.16	1.00										
Micro	-0.13	-0.13	0.05	1.00									
Biomass	-0.13	-0.22	0.04	0.08	1.00								
Geother mal	-0.15	-0.22	0.17	-0.11	0.22	1.00							
Hydro	-0.10	0.09	0.02	0.02	0.02	0.08	1.00						
PV	0.03	0.15	-0.03	0.44	0.03	-0.10	-0.07	1.00					
Waste	0.17	0.27	-0.09	0.02	-0.12	-0.18	0.25	0.01	1.00				
Wind	0.01	0.08	-0.03	-0.04	0.09	0.11	0.15	-0.05	0.12	1.00			
Coal	-0.01	0.11	-0.02	0.00	0.05	0.06	0.03	-0.02	-0.02	0.05	1.00		
NG	0.27	0.30	-0.04	-0.05	-0.06	0.01	0.21	0.11	-0.02	0.01	0.09	1.00	
Oil	0.00	0.04	-0.01	0.12	-0.01	-0.02	0.09	0.06	0.01	0.00	-0.02	0.06	1.00

Note: correlations are computed on 18589 observations; in bold the values higher 0.5;

Table A5. Correlation matrix in Centre-South Up-Regulation

	MSD /MB price	MGP price	MSD /MB vol	Micro	Biomass	Hydro	PV	Waste	Wind	Coal	NG	Oil
MSD/ MB price	1.00											
MGP price	0.10	1.00										
MSD/ MB vol	0.32	-0.07	1.00									
Micro	0.06	-0.06	-0.03	1.00								
Biomass	0.11	0.40	0.02	-0.03	1.00							
Hydro	0.24	0.03	0.19	0.01	0.02	1.00						
PV	0.04	0.04	-0.09	**0.93**	0.05	-0.09	1.00					
Waste	0.08	0.09	-0.03	-0.07	0.08	-0.02	-0.07	1.00				
Wind	0.04	-0.13	0.09	0.08	0.06	0.10	-0.02	0.05	1.00			
Coal	-0.16	0.04	-0.21	-0.08	-0.18	-0.06	-0.08	0.06	-0.15	1.00		
NG	-0.14	0.29	-0.30	0.11	0.05	0.00	0.16	-0.06	-0.15	0.37	1.00	
Oil	0.04	0.03	-0.01	0.06	0.01	-0.03	0.06	0.01	0.03	0.01	0.06	1.00

Note: correlations are computed on 18179 observations; in bold the values higher 0.5;

Table A6. Correlation matrix in Centre-South Down-Regulation

	MSD /MB price	MGP price	MSD /MB vol	Micro	Biomass	Hydro	PV	Waste	Wind	Coal	NG	Oil
MSD/ MB price	1.00											
MGP price	**0.53**	1.00										
MSD/ MB vol	-0.13	-0.14	1.00									
Micro	-0.06	-0.06	0.03	1.00								
Biomass	0.34	0.44	-0.19	0.01	1.00							
Hydro	-0.18	0.04	0.05	-0.02	0.01	1.00						
PV	0.08	0.05	0.00	**0.93**	0.11	-0.11	1.00					
Waste	-0.01	0.13	-0.09	-0.04	0.13	0.01	-0.05	1.00				
Wind	-0.18	-0.16	-0.03	0.12	0.02	0.12	0.01	0.07	1.00			
Coal	-0.05	0.02	-0.05	-0.12	-0.18	-0.12	-0.12	0.04	-0.18	1.00		
NG	0.29	0.38	-0.19	0.06	0.18	-0.03	0.14	0.02	-0.20	0.31	1.00	
Oil	-0.03	0.02	-0.01	0.03	0.03	-0.01	0.03	0.02	0.03	0.00	0.05	1.00

Note: correlations are computed on 13784 observations; in bold the values higher 0.5;

Table A7. Correlation matrix in Sicily Up-Regulation

	MSD/ MB price	MGP price	MSD/ MB vol	Micro	Biomass	Hydro	PV	Wind	NG	Oil
MSD/MB price	1.00									
MGP price	0.38	1.00								
MSD/MB vol	-0.08	0.00	1.00							
Micro	-0.13	-0.09	0.04	1.00						
Biomass	-0.03	0.10	0.05	-0.08	1.00					
Hydro	-0.05	-0.06	0.14	0.11	-0.06	1.00				
PV	-0.07	-0.11	0.04	**0.87**	-0.11	0.08	1.00			
Wind	-0.30	-0.34	-0.03	0.15	0.06	0.03	0.07	1.00		
NG	0.04	0.20	0.10	-0.16	0.00	0.06	-0.11	-0.18	1.00	
Oil	-0.19	-0.07	-0.01	-0.01	-0.02	0.02	-0.05	0.02	0.13	1.00

Note: correlations are computed on 25095 observations; in bold the values higher 0.5;

Table A8. Correlation matrix in Sicily Down-Regulation

	MSD/ MB price	MGP price	MSD/ MB vol	Micro	Biomass	Hydro	PV	Wind	NG	Oil
MSD/MB price	1.00									
MGP price	0.15	1.00								
MSD/MB vol	-0.18	-0.01	1.00							
Micro	0.03	-0.04	0.09	1.00						
Biomass	0.11	0.13	0.00	-0.09	1.00					
Hydro	0.00	-0.05	0.01	0.10	-0.06	1.00				
PV	-0.08	-0.08	0.11	**0.86**	-0.12	0.09	1.00			
Wind	0.05	-0.34	0.00	0.09	0.04	0.00	0.03	1.00		
NG	-0.15	0.11	0.20	-0.16	0.00	0.10	-0.09	-0.22	1.00	
Oil	0.14	-0.15	0.10	-0.03	0.03	0.07	-0.11	0.07	0.10	1.00

Note: correlations are computed on 11491 observations; in bold the values higher 0.5;

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