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Ronald Huisman, Elisa Trujillo-Baute

Energy Sustainability

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Postal Address:
Chair in Energy Sustainability
Institut d'Economia de Barcelona
Facultat d'Economia i Empresa
Universitat de Barcelona
C/ Tinent Coronel Valenzuela, 1-11
(08034) Barcelona, Spain
Tel.: + 34 93 403 46 46
Fax: + 34 93 403 98 32
ieb@ub.edu
http://www.ieb.ub.edu

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ABSTRACT: The increase in the share of supply from intermittent power sources changes the demand for power from traditional power plants. The power system demands more volume flexibility from traditional plants. Our goal is to better understand the impact of a reduction of flexibility in power supply on the costs of volume adjustments. We define flexibility as the capacity with which nominated power plants can adjust their output to unexpected changed in residual demand. We exploit a policy change in Spain that affected the power market. The policy, implemented in 2010, aims to provide a stimulus for producing power with domestic coal. The policy, in combination with a year with scant rainfall in the year after the policy was implemented, decreased the amount of flexibility in power supply and we use this to examine the effect of a change in flexibility on the costs of the power system. We find that a decrease in flexibility resulted in an increase in the costs of adjustments as those flexible plants driven out of the spot market by the coal fired plants compensated themselves by charging higher prices in the adjustment market. Policies as the one evaluated in this paper oriented to stimulate generation from less flexible and more pollutant conventional plants should therefore in any case be abandoned. In contrast to the Spanish coal policy, more flexible power plants should remain online and be prioritised against less flexible power plants.

JEL Codes: Q48, L11, L52, G14

Keywords: Sustainable energy policy, power supply flexibility, imbalance costs

Ronald Huisman
Erasmus School of Economics & IEB
P.O. Box 1738
3000 DR, Rotterdam, The Netherlands
E-mail: rhuisman@ese.eur.nl

Elisa Trujillo-Baute
Chair on Energy and Environmental Sustainability & IEB
University of Barcelona
Av. Diagonal, 690
08034 Barcelona (Spain)
Email: elisatrujillo@ub.edu

1 Introduction

The increase in the share of supply from intermittent power sources changes the demand for power from traditional power plants. As those plants supplied the total demand for power in the past, they more and more supply the demand for power that cannot be met by renewable sources. As a result, the power system demands more volume flexibility from traditional plants. Our goal is to better understand the impact of a reduction of flexibility in power supply on the costs of volume adjustments. We define flexibility as the capacity with which nominated power plants can adjust their output to unexpected changed in residual demand. We define residual demand as total demand minus production from intermittent power sources[1]. An unexpected change in residual demand, due to an unexpected increase in supply from renewable sources or to a sudden decrease in consumer demand, can more easily be offset by changing production volume when power supply is flexible than when it is not.

Within the electricity power system the flexibility from power supply[2] - in the terms above defined - is provided through the adjustment processes that takes place after the day-ahead market closed. With the increased penetration of renewables the relevance of the adjustment markets has increased and has attracted higher research and policy interest. Most research has been devoted to analyse adjustments needed and its markets design in context with high wind generation penetration. While Weber [2010] analysed the design in terms of the intraday market, Vandezande et al. [2010] and Bueno-Lorenzo et al. [2013] focused on the design of the balancing market and of imbalance prices scheme. Pérez-Arriaga and Batlle [2012] evaluated the impact of intermittent renewables on electricity generation system operation.

Our paper contributes to the existing knowledge on the costs of adjustments in the power system by examining a natural experiment that happened in Spain in 2011. At that time, a policy change was implemented to provide a stimulus to the domestic coal industry. A direct effect, as we will discuss in more detail later, was that this policy increased the amount of electricity supply from coal fired power plants and this increase was offset by a reduction in power from combined cycled units that can adjust their output volumes more flexibly. In addition, Spain faced a year with low rainfall in the year after the policy change, resulting in reduced capacity from hydro power plants. Meanwhile, the share of production from intermittent power did not differ much before and after the policy. The total effect of the policy change and the low rainfall was a reduction in power supply from flexible plants. Hence, we argue that the policy change and the low rainfall provide a natural experiment to analyse the potential change in costs of power supply due to a decrease in supply flexibility.

[1] We apply a wider definition of residual demand that that Wagner [2012] applies. The latter defines residual demand as total demand minus supply from renewables; we replaced renewables by intermittent power sources. The intermittent power sources include renewables but also potentially other must-run power supply sources.

[2] Ecofys [2014] mentions as other options to enhance flexibility: increasing demand price elasticity, energy storage and network expansion.

2 The policy

In Spain, the demand for national coal for electricity generation has decreased in recent years as a consequence (among others) of the contraction of electricity demand, the high price of national coal relative to international coal, and the development of other production technologies (such as renewable). By 2009, the combination of these elements generated an important excess of national coal production that was not absorbed in production of energy, becoming a source of major concern for the coal sector. As in many other countries, the Spanish coal sector has always been a source of political distress. This sector has high negotiation power because it represents the main source of income in some regions and its unions are generally very strong. Hence, economic policies related to the coal sector are not always solely based on economic foundations but also on important social and political components.

2.1 Policy design

The conceived solution to the problem was announced in February 2010 and implemented in February 2011. It is a preferential dispatch mechanism for national coal power plants; i.e. to compel a number of plants to generate a mandate volume of electricity with national coal. Electricity generated by these plants is remunerated at regulated prices. The coal consumption, the volume of electricity to be generated, and prices are set by mandate at the plant level (this is the so-called restrictions of guarantee of supply[3]). This scheme modifies the energy market functioning by setting up an adjustment that takes place immediately after the daily market match. The adjustment implies the alteration of the market result by removing volume offered by the last units matched in the market and to replace them with units that produce using national coal[4]. To maintain the market volume equilibrium, the volume of retired electricity must equal the mandate volume generated with national coal. The electricity generated by plants using national coal is remunerated at a regulated price that is (usually) higher than the market price.

There are two types of announcements under this scheme. First, an annual announcement (by the State Secretary of Energy) informs about the maximum (target) volume of electricity production to be generated by plants subject to the policy and the regulated price to remunerate these plants. Both volumes and prices are set for each plant specifically. Second, a weekly announcement (by the System Operator) of electricity volume to be generated by each regulated plant during the next week.

[3]This preferential dispatch policy it is covered within the European framework (2003/59/CE) on the guarantee of a 15% domestic demand coverage with native production.

[4]The last units matched in the Spanish market are also usually the more pollutant among the matched in terms of CO2 emissions, but always less pollutant than national coal power plants.

3 Changes in the flexibility of power supply in Spain

The policy change became effective in January and February 2011. Firstly in January, the policy was implemented partially as the government commenced charging regulated costs to compensate for the costs of the policy. Like most of the regulated parts of the system, this costs component is set once a year in December, enters into place the next year, and does not change until the next year. The policy then became fully operational in February 2011.

To examine the impact of the policy, we distinguish two periods. The first period covers the 12 months period before the policy change, from 1 January 2010 through 31 December 2010. The second period covers the 12 months after the policy change became effective, from 1 March 2011 through 28 February 2012. We choose for one-year periods to minimise the probability that seasonal patterns (think about demand or supply from renewable sources such as wind, solar and hydro) explain results that we may find. We gathered information about other related policy changes in both periods that could affect our research, but we were not able to identify any (to our best knowledge). Hence, we feel certain that the policy change under consideration is the single policy event in our sample.

The policy's impact is likely to be a change the way power is produced in the Spanish market as the aim of the policy is to stimulate the use of domestic coal. We obtained daily actual production volumes from different power sources to see how power was supplied before and after the policy change. Table 1 shows the average share of production from different power sources. For example, the share of wind before the policy change is 0.158 which is measured as the total output (MWh) from wind power sources divided by the total amount of produced power in the period before the policy change. This share equals 0.160 for the period after the policy. Table 1 shows that the policy has its impact on power from coal production as the share of power production with domestic coal more than doubled: 5.4% of total supply was produced with domestic coal before the policy change and this share increased to 11.8% after introducing the policy. The share of coal production (domestic plus non-domestic) increased from 8.1% to 18.6%. This increase of 10.5% is offset by a decrease in the share of hydro production (6.2%) and combined cycle production (5.3%). The share of production with wind, solar, nuclear did not differ much before and after the policy change. The share of power supply from combined heat and power (chp) units increased by 1.4%.

We argue that the Spanish power market became less flexible after the policy change as the share of coal production increased and the share of power from hydro and combined cycle plants decreased. Combined cycle plants are considered to be more flexible than coal steam turbines as they can ramp their output up and down more easily, and their start-up and shutdown procedures involve less time and expenses (IEA [2013]). The increase in power from coal and the decrease in production from combined cycle plants is a direct result from the policy change as the policy replaces the last units in the merit order, mostly likely expensive gas fired combined cycled plants, with (domestic) coal burning plants. The decrease in hydro production was not

Table 1: **Shares of total supply** before and after the policy change. We only list the supply factors with a share of more than 10%.

	before	after
wind	0.158	0.160
solar	0.025	0.035
- wind + solar	0.183	0.195
hydro	0.166	0.104
nuclear	0.227	0.221
coal	0.081	0.186
- domestic	0.054	0.118
combined cycle	0.237	0.184
chp	0.124	0.138

related to the policy change, but was caused by a lower amount of rainfall in the period after the policy change than before. The annual report of the Spanish transmission system operator (REE) on power demand supplied by different technologies mentions that the decrease in share of supply from hydro power plants is due to the scant rainfall in 2011, against 2010 which was a year that stood out for its high rainfall (REE [2011]).

The overall picture is that power supply was less flexible in the period after the policy change than before due to an increase in power production with coal and a decrease in power production with combined cycle and hydro plants.

4 Flexibility and the costs of adjustments

Our research goal is to better understand the impact of a reduction of flexibility in power supply on the costs of volume adjustments. The previous section shows that the policy change in January and February 2010 resulted in less flexible power supply due to the policy itself and scant rainfall. We exploit this policy event to compare the costs of adjustments during the periods before and after the policy change. To do so, we use daily wholesale and final wholesale power prices from the Spanish market.

4.1 Data

We obtained Spanish wholesale prices, being daily average day-ahead power prices, from the market operator (OMEL). We obtained Spanish final wholesale prices from national regulatory agency, the National Commission of Markets and Competition (by its acronym in Spanish CNMC). The final wholesale price on a day consists of the day-ahead market price on that day, plus a component for the cost of the policy, plus the intraday and imbalance markets price premium over the day-ahead price[5]. We define the variable 'spread' as the difference between the final wholesale price and the wholesale (day-ahead) price. The spread therefore measures the additional costs for delivering one MWh of electricity on top of the wholesale price. Table 2 shows summary statistics of the spread variable observed during the periods before and after the policy change.

Table 2: **Summary statistics** of the spread before and after the policy change.

	before	after
mean	8.458	12.260
median	8.090	12.060
minimum	4.220	9.590
maximum	17.730	22.710
standard deviation	1.677	1.711
skewness	1.684	1.693
excess kurtosis	5.135	5.647

The increase in the mean spread after the policy change is clearly observable in table 2. The mean spread is 8.5 €/MWh in the period before the policy change and 12.3 €/MWh in the period after; an increase of 3.8 €/ MWh or approximately 45% on average. The shape of the spread empirical probability distribution does not change much as we observe no dramatic change in the standard deviation, skewness and kurtosis. The policy change resulted in higher spreads; an increase in the difference between the final price and the wholesale price. This increase comes from a change of the regulated component affecting the spread, which is used (among others) to finance the coal policy. Like most of the regulated parts of the system, this component is set once a year in December, enters into place the next year, and doesnt change until the next year. Anticipating that in the coal policy was to be implemented in 2011 (but not knowing exactly when), the change was made in December 2010 and started in January 2011. This is why the spread change is observable since January 2011.

4.2 The indirect effect of a decrease in supply flexibility

At first glance, this direct effect of the policy change, i.e. the increase in spread, seems to be a constant increase over all days as the shape parameters of the empirical distributions do not change. However, we think that potential indirect effects might be observable. Our interest is in observing potential indirect effects in the spread that are related to the reduction in supply flexibility. Think of the role of flexible but more expensive suppliers (such as gas fired combined cycle producers for example) in the after spot market adjustments. Although the policy replaces those suppliers by domestic coal producers and thereby take them out of the day-ahead spot

[5] After the intraday market, deviations between scheduled and measured energy are addressed through market procedures, such as secondary reserve, tertiary reserve and imbalances management process.

market, the flexible suppliers can participate in the adjustment markets after the spot market cleared. Especially, it is more likely that flexible power plant participate in the market for after spot adjustments when residual demand is low as fewer other plants are operating in the market because of lower demand levels. These flexible plants then have more market power in the adjustment market. We hypothesise that those flexible (gas) plants, in order to recover their cost, bid at higher prices in the adjustments markets, leading to a higher spread, especially when residual demand is low.

To examine whether the relation between the spread and residual demand is different during the period after the policy change than before, we need to measure residual demand. To do so, we have obtained daily total demand data in Spain for both periods[6]. For every day, we calculate residual demand by subtracting wind and solar production volumes from total demand. Figures 1, 2, and 3 show the relation between demand, residual demand and the spread for both periods.

Figure 1 shows the relation between daily total demand for power in the Spanish market and the spread. The left graph shows this relation before the policy change, the right graph is the relation after the policy change. The points indicate the daily observations on demand and spread and the line is the linear least squares fit. We clearly observe the higher average size of the spread in the period after the policy change (the y-axis have the sample scale in all graphs to make them comparable). This increase in spread is what we have seen before and is explained, at least partly, by a component for financing the policy costs. The best fit line changes too. It had a negative slope before and a positive one after. Table 3 shows the parameter estimates for these lines. The top panel in table 3 shows that the slope between spread and demand is 0.064 before the policy change and -0.101 after the policy change, that these slopes differ significantly from zero with 95% confidence and that the change in slope (-0.165) is significant as well. The conclusion from this is that spreads are more higher after the policy change than before when demand is low. The relation discussed here is between spread and total demand. This result is indicative but not what we are interested in as we want to observe this relation for residual demand as residual demand is what needs to be produced by non-intermittent power plants. Figures 2 and 3 show this relationship.

Figure 2 shows the relation between spread and residual demand. The slope is negative before (-0.047 but not significant, see table 3) and is more negative after (-0.183 and significant). The slope is significantly (the change is -0.136) more negative after the policy change and according to figure 2 the pattern especially changes when residual demand is low. This is what we hypothesised, i.e. that we expect higher spreads at low residual demand levels as flexible power plants have more market power and charge more for adjustments to compensate for their costs. The change is clearly observable in figure 2; the relation shows a hockey-stick pattern.

In figure 3 the change in the slope is confirmed with the same relationship but for relative residual demand instead of residual demand levels. Relative residual demand measures the residual

[6]We have obtained that data from the transmission system operator (REE)

Figure 1: **Spread versus demand.** This figure shows the relation between the spread (y-axis) and demand (x-axis) before (left graph) and after (right graph) the policy change.

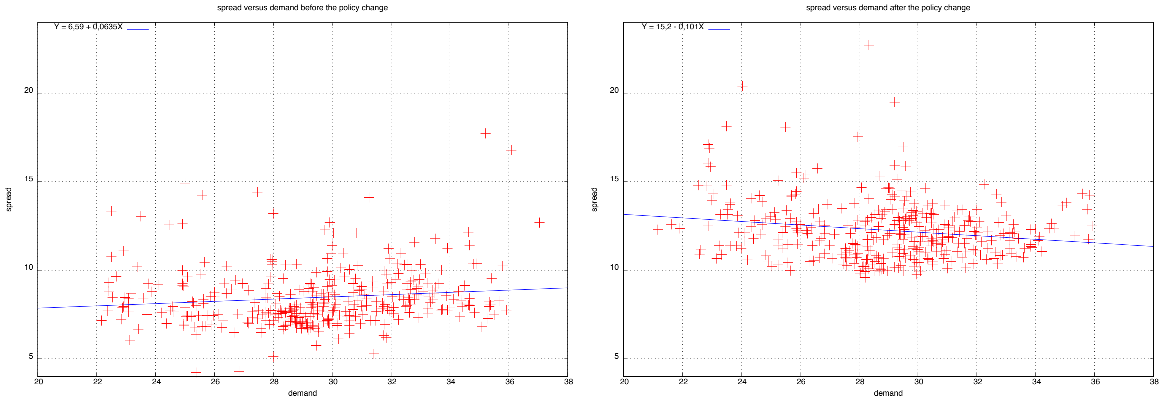
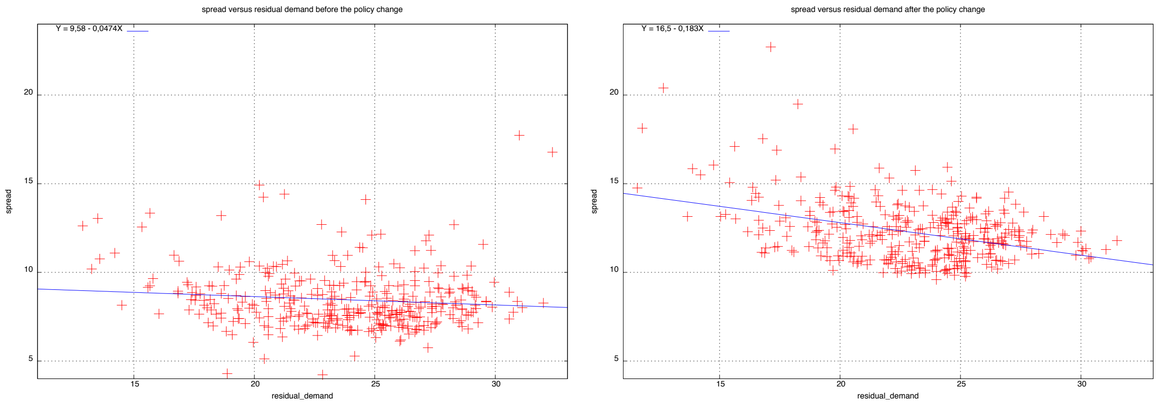


Figure 2: **Spread versus residual demand.** This figure shows the relation between the spread (y-axis) and residual demand (x-axis) before (left graph) and after (right graph) the policy change.



demand as a fraction of total demand. For instance, relative residual demand is 0.5 when half of total demand is produced by intermittent sources such as wind and solar. The hockey-stick pattern becomes more obvious, i.e. the higher costs of adjustments at lower relative residual demand levels. From this we conclude that costs of adjustments are higher on days when wind and solar serve a relatively high amount of total demand. We explain this result in terms of flexible power plants having more competitive power in the adjustments market as fewer other power plants are operational during low residual demand days.

The above analysis showed the spread as a function of residual demand. Table 4 presents these results in a more detailed way. We selected the days with the 20% lowest residual demands from the combined sample of days before and after the policy change. We call this group 'low'. We then measured the average spreads and the standard deviation of the spreads for those days in the 'low' group that occurred before the policy change and as we did the same for those days in the sample 'low' that occurred after the policy change. We repeated the same procedure for the

Figure 3: **Spread versus relative residual demand.** This figure shows the relation between the spread (y-axis) and residual demand divided by demand (x-axis) before (left graph) and after (right graph) the policy change.

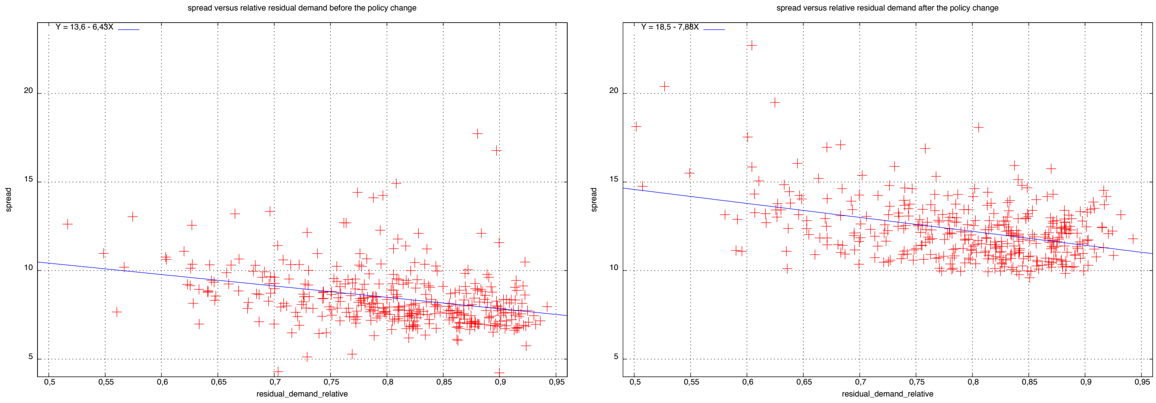


Table 3: **Ordinary least squares parameter estimates** for a model that linearly relates the spread observed on a day to a measure for demand during that day.

	before	after	difference
	demand		
intercept	6.590*	15.171*	8.581*
	(0.135)	(1.244)	(1.251)
demand	0.064*	-0.101*	-0.165*
	(0.045)	(0.040)	(0.060)
R^2	0.015	0.031	
σ	1.666	1.687	
	residual demand		
intercept	9.582*	16.474*	6.892*
	(0.935)	(1.039)	(1.398)
demand	-0.047	-0.183*	-0.136*
	(0.039)	(0.040)	(0.056)
R^2	0.011	0.144	
σ	1.669	1.585	
	relative residual demand		
4 intercept	13.632*	18.517*	4.885*
	(0.954)	(1.475)	(1.757)
demand	-6.432*	-7.759*	-1.327
	(1.143)	(1.759)	(2.098)
R^2	0.103	0.157	
σ	1.591	1.573	

*: significantly different from zero with 95% confidence

20% days with highest residual demands. The 20% is arbitrary, but taking a somewhat different number does not change the qualitative results. Table 4 shows that average spreads during the days with highest and lowest residual demand were almost equal in the period before the policy change (8.949 before versus 8.603 after). The average spread is higher in the period after the policy change, but it is clear from the table that spread during the days with lowest residual demand increased more than during the days with high residual demand (an increase of 48.8% instead of 38.6). In terms of standard deviation, the dispersion of spreads was more or less equal during periods with high and low residual demand before the policy, but differs clearly in the period after the policy change. The dispersion increased during those days with low demand and decreased during days with high residual demand.

Table 4: **Spread characteristics** within different groups before and after the policy change.

	average spread	
	residual demand	
	low	high
before	8.949	8.603
after	13.408	11.928
% change	49.8%	38.6%
	standard deviation of spreads	
	residual demand	
	low	high
before	1.820	1.818
after	2.309	0.926

5 Conclusion

We exploit a policy change in Spain that affected the power market. The policy, implemented in 2010 and still active, aims to provide a stimulus for producing power with domestic coal. The effect was an increase in the share of coal fired production at the cost of a reduction in power from combined cycle plants. The year after the policy change was also one with scant rainfall, resulting in lower supply of hydro power. In total, the amount of flexibility in power supply decreased and we use this to examine the effect of a change in flexibility on the costs of the power system. We find that a decrease in flexibility resulted in an increase in the costs of adjustments as those flexible plants driven out of the spot market by the coal fired plants compensated themselves by charging higher prices in the adjustment market.

6 Discussion

A wise use of available resources, markets, and policy tools is needed to better benefit from sustainable and reliable electricity systems as billions of euros are spent annually to promote generation from renewables. We focus on flexibility of supply and show that a reduction of supply flexibility results in an increase of adjustment costs. Policies as the one evaluated in this paper oriented to stimulate generation from less flexible and more pollutant plants should therefore in any case be abandoned. Actually, high penetration levels of intermittent renewable power sources increases the need for flexibility in the system, while simultaneously displaces traditional flexibility resources. This calls for a revising of the system operation, to ensure the provision of sufficient flexibility resources needed to maintain system stability and security. Therefore, in contrast to the Spanish coal policy, more flexible power plants should remain online and be prioritised against less flexible power plants.

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