Institut de Recerca en Economia Aplicada Regional i Pública
Research Institute of Applied Economics

Document de Treball 2021/17 1/22 pág.
Working Paper 2021/17 1/22 pag.

“A note on the relationship between electricity and natural gas prices across European markets in times of distress”

Jorge M. Uribe and Stephania Mosquera-López

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Aplicada Regional i Pública
UNIVERSITAT DE BARCELONA

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Abstract

We study the transmission of natural gas price shocks to electricity prices across different scenarios of electricity generation for thirteen European electricity markets. To this end, we propose a statistic based on the estimation of conditional quantile regression models, which allows us to identify the most vulnerable countries in the region to variations in the global price of natural gas, under scenarios of generation distress. We point out to market integration and different electricity generation mixes as the main factors underlying our results. Our main contribution is the analysis of the proposed static for the case of European markets from a comparative perspective, which helps to guide and support timely policy responses in European countries, aiming to isolate the most vulnerable consumers and firms from dramatic electricity price increments as those observed in the first three quarters of 2021. The most vulnerable countries according to our indicator are Portugal and Spain, while the most resilient are Italy and Finland.

JEL classification: Q40, L94, L95, C22.

Keywords: Quantile regression, Power markets, Energy crises, Energy shortages, Gas markets.

Jorge M. Uribe: Faculty of Economics and Business, Universitat Oberta de Catalunya, Spain; Riskcenter, University of Barcelona, Spain. Email: juribeg@uoc.edu. Av. Tibidabo 39-43.

Stephania Mosquera-López: Department of Finance, Universidad EAFIT, Colombia. Email: smosqueral@eafit.edu.co

1. Introduction

The recent surges in electricity prices around the world, and particularly in European countries during the first three quarters of 2021, put at risk the incipient and fragile economic recovery observed in the continent after the negative shock derived from the Covid19 pandemic and the public health measures implemented in the last two years. It also threatens the ambitious policy plans regarding the transition to a more sustainable, green and energy-efficient production scheme that the European Union has committed recently with renovated urgency[1]. Europe risks that vulnerable households, at the bridge of energy poverty, and small business, already very affected by the pandemic- both of which dramatically depend on electricity prices- may perceive such energy transition as a policy enemy to oppose in the urns, because they may (erroneously) perceive that the transition inevitably carries out a deterioration of their immediate wellbeing, by drastically forcing them to reduce their energy consumption, which is already at minimum values. These historically high rises may be even a symptom of the system's inability to comply with energy demand by all agents, at all times, and could be an early warning indication of energy crisis and energy shortages foreseeable in the not very distant future. Finally, electricity prices are a main component of core inflation, and any dramatic increment in the price of power is also expected to reflect on a similar increment in the general price indexes of any economy, both for consumption and production. Hence, the recently observed price surges in the European power markets also menace with destabilizing general price dynamics and resurrecting ancient fears of inflation, which has been the least of the concerns for Europe in the most recent decade.

These electricity price high records are mainly due to parallel historically high increments in the price of natural gas on a global basis. The price of natural gas has increased more than 200% from October 2020 to September 2021, which can be observed when examining recent dynamics of the Henry Hub natural gas reference index. In this period, developed countries around the world have increased their demand on natural gas above the pace of increment in the gas supply, while facing a faster than expected economic recovery after the pandemic. In Europe, the higher demand of natural gas has not been met by a higher imported supply, particularly from Russia, resulting in a new record of natural gas prices.

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[1] See all recent statements and news in the Energy Strategy web page of the European Commission which emphasize the increasing political commitment of the European Union with the energy transition to renewable sources. https://ec.europa.eu/info/news_en?department=880#news-block

The relationship between natural gas and electricity is complex, since both goods are substitutes and complements. On the one hand, natural gas is an input for electricity generation by combined-cycle power plants, while on the other hand natural gas and electricity are substitutes for heating and other activities in households and commercial outlets. Thus, at a first glance, it might seem difficult to predict the response of electricity prices to natural gas price shocks. Nevertheless, as it has been shown by Uribe et al. (2018), in times of scarcity, that its, when power generation is costly and both power and gas are close to their maxima price levels, the relationship between the price of gas and the price of power is not only positive, but it is also dramatically stronger than in other times when both goods are relatively abundant (i.e. when the prices are close to the center of their respective price distributions).

Here we provide a new tool to measure the transmission of price shocks from natural gas to electricity markets, which is crucial to inform the recent efforts by the European Commission (EC) to contain the electricity price climbing in the subcontinent (European Commission, 2021). The EC acknowledges the convenience of the current price setting mechanism by auctions in which the last generator in the merit order curve - and hence the less efficient-determines the price to be paid to all market participants by their generation. Nevertheless, it also opens the door for a new debate about novel pricing and regulatory mechanisms that could make the system more robust to the kind of shocks observed during 2021. In particular, it highlights the necessity to isolate the European system, and the most vulnerable agents, from the great uncertainty implied by the large variability that characterizes global fossil fuel markets, including natural gas. In this respect, our results recall the necessity to transit to a more integrated (across countries) and more diversified (across energy sources) wholesale European electricity market, which is in line with the EC goals. We provide some quantitative evidence necessary to support such an approach for policy making.

The new tools that we provide can be used to measure how stronger is the transmission from natural gas to electricity prices in times of “generation scarcity” (i.e. at the highest quantiles of the price distribution of electricity) than in times of “abundance” (i.e. at the lowest quantiles of the electricity price distribution). It consists of a ratio of the quantile-slope coefficients that measure the shock transmission from natural gas to electricity markets under different market scenarios, that is, at different quantiles of the electricity price distribution. Its simplicity means that the information uncovered by our indicators can be easily transmitted within different policy circles and from them to the general public, ensuring that more information can be used to support timely policy actions as those compromised by the Commission and several European Union countries so far, notably Spain and France, to mitigate the adverse consequences of the dramatic increases of energy prices. Such policy actions will be likely followed by governments in other geographies if the current situation persists (for instance, due to larger pressures on the natural gas price inflation, coming from a larger demand for heating during the winter), or in the medium-term, when the world energy transition to renewables is in a more advanced stage, so that the generation relying on fossil fuels becomes infeasible due to prohibitively high costs imposed by the Emission Trading System (ETS) on C02 certificates.

Our calculations are carried out for 13 European countries including: Belgium, Denmark, Finland, France, Germany, Italy, Norway, Portugal, Spain, Sweden, Switzerland, the Netherlands, and the United Kingdom and use daily data from January 1 2010 to September 3 2021. We show that the shock's transmission is remarkably different across countries, although in all of them the price setting mechanism is roughly the same. Hence, our results call for a deeper exploration of the determinants of such heterogeneity which is likely rooted on the fact that European countries face different electricity generation mixes (i.e. renewables, hydroelectric, nuclear, fossil-fuels) and different levels of market integration, both physical and economical. We point out to these two factors, market integration and the generation mix, as the main factors responsible for the sort of heterogeneity that we document here for the first time. In this way, we contribute to set priorities in the European energy transition agenda, and develop intuition about the most urgent tasks to be addressed from a policy perspective, regarding market integration, its benefits and challenges, especially for Spain and Portugal.

Lastly, our results also directly call for more urgent and drastic policy actions needed in Portugal, Spain and to some extent France than in other countries such as Italy, Finland or Sweden. That is, although the surge in electricity prices is rotted in global factors (i.e. the increment in global natural gas prices), which are common to all markets, idiosyncratic market responses of countries are greatly different and make the former Iberian markets more vulnerable to the risk described in the first paragraph of this introduction. This means that, for instance, temporary reduction in taxes to electricity transmission and consumption, and direct subsidies to vulnerable households, must be complemented with other market regulatory measures that include a closer examination of the marginal costs of production of nuclear and hydroelectric generators, which in the current setting are likely harvesting benefits that should be kept for vulnerable consumers and small firms. Our statistic sheds new light from a quantitative perspective to understand the differences between European markets and the price formation process that takes place in each of them.

2. Related literature

Our contribution enhances both the literature that explores the relationship between natural gas and electricity prices (see, Woo et al. 2006; Brown and Yucel, 2008; Chae et al., 2012; Nakajima and Hamori, 2013; Alexopoulos, 2017; Xia et al., 2020; Dign et al. 2020; Scarcioffolo and Etienne, 2021; Yang, 2021) and the literature that document the nonlinear nature of price dynamics and price formation in electricity markets (see Bunn et al., 2016; Hagfors et al., 2016; Mosquera-López et al., 2017; Xia et al., 2020; Dign et al. 2020; Scarcioffolo and Etienne, 2021). The former studies have analyzed the way in which natural gas prices affect price formation and market clearing in electricity markets, which is very complex. First, natural-gas-fired power plants are almost invariantly the last to be included in the merit-order curve and, as such, they determine the wholesale electricity rates, and hence the retail electricity rates, when electricity demand is not met with the generation from the cheaper sources. Second, load-serving entities are frequently the owners of natural-gas-fired power stations; and they can implement a direct pass through from natural gas to electricity rates, via automatic mechanisms, of their unexpected fuel costs to electricity consumers. Third, as emphasized by Woo et al. (2006), there exists a demand-pull effect that derives from a wider spread between electricity price and the fuel natural gas cost, when electricity is costly, which will increment the demand for natural gas by increasing the generators' willingness-to-pay, and by inducing less efficient plants to generate. In turn, this will be translated to larger bids for spot gas in bilateral trading and larger observed natural gas prices. As it has been emphasized by the past literature, these mechanisms may persist in a way that may even endanger the operation of the whole system and, in the worst scenario, the feedback effects between natural gas and electricity prices may open the door for an energy crisis and for energy shortages. Such feedback effects between different marketes, which are well studied in the recent literature on systemic risk (see Adrian and Brunnermeir, 2016) have been insufficiently explored in the energy field and are likely related to the great nonlinearities that share the two types of markets. In the latter case, such nonlinearities are likely related to the fact that electricity markets depend on weather, policy and economic systems, all of them plagued by high uncertainties and complexities that make forecasting and understanding extremely challenging. We aim to contribute to such understanding. Our novelty with respect to the extant literature is two folded: we are the first to propose the quantile-slopes ratios as a measure of resilience of the electricity markets to fuel markets shocks, and we focus our empirical implementation in European countries which have not been compared under the way proposed by the extant literature. Our results shed new light on a current relevant topic for the European energy policy agenda, particularly regarding the energy transition and the contention of the negative impact of such transition on the most vulnerable, which needs to be adequately addressed with new tools and new methodological perspectives as the ones advanced here.

3. Methodology and Data

3.1. Data

We use data from Bloomberg for a set of 13 European markets, consisting of Belgium, Denmark, Finland, France, Germany, Italy, Norway, Portugal, Spain, Sweden, Switzerland, the Netherlands, and the United Kingdom, from January 01 2010 to September 3 2021. Our set of variables includes: the Henry Hub index to track the global dynamics of natural gas prices, whole-sale electricity prices in each country, weather-related variables that are included in the control group to avoid imprecise or spurious estimates, including temperature, wind speed, precipitation, and irradiance. The latter is the only variable that we retrieved outside Bloomberg, from SoDa (solar radiation data) Service. We use daily data, so that we rely on 3046 transaction days in our sample period to conduct our estimations. When there is available information for the prices of more than one zone in a given country (as it is the case of Norway or Sweden) we used the biggest zone in our estimations.

In Table 1 we present the summary statistics and the ADF tests of our sample variables. As can be seen, there is a great variability across countries in terms of both weather and electricity prices. Variability in weather translates to variability in prices, not only because it pushes demand in asymmetric ways (i.e. different heating or cooling necessities in different geographies), but also because weather directly impacts generation by variable renewable energy sources, such as solar cells and wind turbines. Hence, different levels of penetration of these technologies in the power markets imply different energy supply structures, alongside the set of analyzed countries. We also conduct unit root ADF tests in all our variables to ensure stationarity before estimation of the quantile regressions models in the next section.

Table 1. Descriptive Statistics and ADF test

Statistic	Electricity Prices	Temperature	Wind Speed	Precipitation	Irradiance	Natural Gas Prices	Electricity Prices	Temperature	Wind Speed	Precipitation	Irradiance	Natural Gas Prices
			Belgium						*Denmark*			
Min	-133.56	-9.02	1.72	0.00	8,856,521.00	1.33	-38.38	-8.14	2.37	0.00	5,256,553.00	1.33
Mean	46.27	11.38	7.18	235.05	47,353,298.96	3.05	38.00	10.01	9.90	253.77	43,564,811.14	3.05
Max	207.92	29.32	23.01	6,366.18	88,072,490.00	16.35	109.04	25.18	24.88	3,349.65	86,809,717.00	16.35
Sds	16.32	6.24	3.33	435.56	25,471,294.01	0.91	14.35	6.38	3.78	390.48	27,046,271.25	0.91
Skewness	1.15	-0.08	1.00	4.68	-0.04	2.95	0.91	-0.05	0.67	2.80	0.03	2.95
Kurtosis	14.69	-0.44	1.10	37.83	-1.50	33.29	2.56	-0.86	0.17	10.92	-1.51	33.29
t-ADF	-5.38	-4.15	-11.12	-13.14	-5.82	-4.41	-4.73	-3.44	-11.38	-12.82	-6.53	-4.41
			Finland						*France*			
Min	2.99	-25.87	2.07	0.00	2,165,654.00	1.33	3.68	-4.73	2.40	0.00	11,772,859.00	1.33
Mean	39.00	5.91	7.13	286.47	39,946,630.38	3.05	44.49	13.40	7.04	301.38	49,446,796.46	3.05
Max	108.47	25.15	17.48	3,813.50	87,113,574.00	16.35	367.60	30.12	17.34	3,663.87	87,698,076.00	16.35
Sds	12.72	8.91	2.59	390.16	28,214,452.65	0.91	16.69	6.26	2.17	404.74	24,745,775.40	0.91
Skewness	0.86	-0.28	0.73	2.78	0.09	2.95	3.37	-0.04	0.81	2.91	-0.07	2.95
Kurtosis	2.79	-0.33	0.45	11.50	-1.51	33.29	52.81	-0.79	0.80	12.28	-1.50	33.29
t-ADF	-5.80	-3.91	-11.50	-13.25	-6.47	-4.41	-5.76	-3.43	-11.65	-12.28	-5.57	-4.41
			Germany						*Italy*			
Min	-56.87	-13.16	2.40	0.00	8,224,387.00	1.33	10.66	-0.66	2.35	0.00	16,390,555.00	1.33
Mean	40.13	10.58	6.92	225.75	46,060,810.58	3.05	58.58	16.08	5.51	289.19	55,260,416.69	3.05
Max	109.04	28.14	20.72	2,719.73	86,571,641.00	16.35	136.67	29.59	14.94	13,799.70	88,635,488.00	16.35
Sds	14.10	7.06	2.57	273.26	25,785,450.41	0.91	15.99	6.73	1.55	534.37	21,786,693.89	0.91
Skewness	0.49	-0.09	1.27	2.35	-0.02	2.95	0.54	0.03	1.25	8.77	-0.13	2.95
Kurtosis	3.70	-0.72	2.13	9.25	-1.50	33.29	1.05	-1.13	2.40	168.50	-1.47	33.29
t-ADF	-4.36	-3.82	-10.93	-11.44	-5.43	-4.41	-2.55	-2.92	-12.22	-11.88	-3.70	-4.41
			Norway						*Portugal*			
Min	0.94	-12.03	2.43	0.00	2,138,721.00	1.33	0.00	4.74	2.56	0.00	22,624,080.00	1.33
Mean	31.38	6.90	7.24	457.22	40,708,304.81	3.05	48.86	16.32	7.62	239.95	58,392,043.34	3.05
Max	98.53	23.81	18.82	3,274.94	87,368,359.00	16.35	117.29	30.67	20.30	5,731.00	90,331,035.00	16.35
Sds	13.78	6.75	2.42	440.10	28,491,668.71	0.91	14.93	4.52	2.48	568.46	20,986,519.00	0.91
Skewness	0.17	-0.17	1.07	1.78	0.08	2.95	0.05	0.09	0.99	3.81	-0.16	2.95
Kurtosis	0.60	-0.71	1.37	4.35	-1.51	33.29	2.14	-0.69	1.41	18.90	-1.46	33.29
t-ADF	-3.68	-3.75	-11.48	-11.37	-6.72	-4.41	-4.14	-3.73	-11.10	-10.26	-4.12	-4.41
			Spain						*Sweden*			
Min	0.00	2.06	2.30	0.00	22,199,280.00	1.33	1.64	-14.63	2.40	0.00	5,370,404.00	1.33
Mean	48.84	16.39	6.00	166.83	58,738,439.50	3.05	36.43	7.40	8.11	225.52	43,785,574.45	3.05
Max	117.29	29.42	17.14	2,791.85	91,477,109.00	16.35	106.26	24.81	19.50	3,481.76	87,049,658.00	16.35
Sds	14.84	6.32	1.91	280.65	21,994,798.54	0.91	13.93	7.52	2.62	314.22	27,106,022.20	0.91
Skewness	0.09	0.07	1.41	3.48	-0.15	2.95	0.80	-0.11	0.82	2.87	0.02	2.95
Kurtosis	2.18	-1.18	2.85	17.70	-1.46	33.29	2.26	-0.73	0.74	12.33	-1.51	33.29
t-ADF	-4.20	-2.79	-11.23	-10.47	-4.30	-4.41	-5.14	-3.64	-11.48	-12.41	-6.55	-4.41
			Switzerland						*The Netherlands*			
Min	-133.56	-11.52	1.22	0.00	14,982,347.00	1.33	5.15	-8.46	2.37	0.00	7,520,509.00	1.33
Mean	46.27	10.86	4.16	475.10	52,272,122.34	3.05	45.10	11.18	8.45	270.33	46,129,918.41	3.05
Max	207.92	27.69	16.06	25,225.00	90,100,586.00	16.35	106.56	29.29	24.47	5,167.85	87,107,070.00	16.35
Sds	16.32	7.40	1.77	862.88	24,359,758.83	0.91	12.19	6.04	3.66	407.56	25,875,725.63	0.91
Skewness	1.15	-0.04	1.60	10.19	-0.10	2.95	0.78	-0.09	1.02	2.95	-0.02	2.95
Kurtosis	14.69	-0.89	3.84	252.80	-1.49	33.29	2.03	-0.45	1.13	15.28	-1.50	33.29
t-ADF	-5.38	-3.36	-11.60	-12.87	-6.02	-4.41	-2.58	-4.04	-11.48	-13.50	-5.97	-4.41
			The United Kingdom									
Min	-10.13	-3.86	2.22	0.00	12,488,658.00	1.33						
Mean	46.55	11.05	8.06	262.97	50,569,231.38	3.05						
Max	198.13	25.83	21.34	2,773.34	89,432,666.00	16.35						
Sds	12.56	5.12	2.92	325.21	24,277,396.42	0.91						
Skewness	2.69	-0.02	0.92	2.33	-0.07	2.95						
Kurtosis	18.31	-0.64	1.01	7.76	-1.48	33.29						
t-ADF	-2.90	-3.97	-12.14	-12.62	-4.16	-4.41						

Note: the units of electricity prices are EUR/Mwh, except for the United Kingdom for which the units are GPB/Mwh. The units of the weather variables are: temperature in degrees Celsius; wind spee in m/s; precipitationin an integer in 100th mm; irradiance in Wh/m^2. Lastly, the Henry Hub natural gas prices is in USD/MMBtu. For all the variables the null hypothesis of the ADF test is rejected and stationarity at 1% confidence level is found.

3.2. Quantile Regression and proposed statistic

Conditional quantile regression is a method to estimate the quantiles of the cumulative distribution of a response variable, in our case electricity prices, given some covariates, in our case natural gas prices (alongside other potential controls, remarkably weather variables). In these models, mainly due to Koenker and Bassett (1978), and recently revisited by Uribe and Guillen (2020) in the context of energy markets, a quantile of the response variable is expressed as a linear combination of right-hand-side variables and estimating the model implies finding the coefficients for that linear combination. This method focuses on the conditional distribution of the response variable, and therefore the parameters describing the relationship between the variables of interest are estimated for given fixed values of the covariates. The objective of quantile regression differs from this of classical linear regression, which is mainly concerned with average realizations of the response variable. Instead, quantile regression may be used to change the focus from the average to the extreme realizations (i.e. the tails of the distribution) of the dependent variable. In our case, it allows us to compare the effect of natural gas price changes on electricity prices, when electricity prices are relatively high (high quantiles) or relatively low (low quantiles). Such different quantiles correspond to abnormally high or low prices of electricity and therefore can be naturally related with different market scenarios, of scarcity and abundance in electricity generation, respectively.

More formally, let X_{t-1} be the vector containing the observations of explanatory variables in a given market day $t-1$ and let Y_t be the price of electricity one day after, t. Our objective is to estimate a parameter vector β with the same dimension as the vector of covariates. We express the linear combination as $X_{t-1}{}'\beta$, where $'$, denotes the transposed vector. Finally, ε_t is a random vector that corresponds to the t-th error term. In a linear regression setting:

$$Y_t = X'_{t-1}\beta + \varepsilon_t \, , \tag{1}$$

and assuming that $E(\varepsilon_i) = 0$, then $E(Y_i|X_i) = X_i{}'\beta$. We regress the electricity price on the one day lagged explanatory variables because today's electricity spot wholesale prices are formed by the bids of market participants the day before. On the other hand, in a quantile regression setting we have that:

$$Q_\theta(dY_t|\mathrm{X}_{\mathrm{t-1}}) = \mathrm{X}_{\mathrm{t-1}}\beta(\theta), \tag{2}$$

where $0 < \theta < 1$ and $Q_\theta(.|.)$ denotes the conditional quantile function for the θ-th quantile of the response variable Y_t . $\beta(\theta)$ is a vector that contains the slope coefficients of the quantiles regression, associated to the effect of each explanatory variable on the variable Y_t. These slope coefficients can be interpreted as rates of change, as in any ordinary linear models. Thus, the scalar $\beta_k(\theta)$ corresponds to the rate of variation of the θ-th quantile of the dependent variable distribution per unit of change in the value of the k-th regressor such that: $\beta_k = \frac{\partial Q_\theta(dY_t|X_{t-1})}{\partial x_{kt-1}}$.

We are particularly interested in the case when k corresponds to natural gas, hence β_{gas} at different quantiles of the electricity prices, i.e. when electricity is relatively expensive, for instance $\beta_{gas}(\theta = 0.9)$ or relatively low-priced, for instance $\beta_{gas}(\theta = 0.1)$. We can then construct our main indicator as the ratio between the two of these slopes, as follows:

$$R = \frac{\beta_{gas}(\theta=0.9)}{\beta_{gas}(\theta=0.1)}, \tag{3}$$

A ratio, R , greater than one indicates that the price of natural gas is transmitted to the price of electricity in a greater proportion when electricity is expensive than when it is cheap. For example, if R =10, this indicates that the price is more transmitted when prices are high than when prices are low. In fact, it means that it is transmitted 10 times more. The uncertainty in the estimation of R will be a function of the uncertainty in the estimates of the quantile coefficients. In our empirical implementation we use the point estimates of the method proposed by Koenker and Bassett (1978), which roughly consists on solving a nonlinear problem given by:

$$\beta_{(\theta)} = argmin_\beta E[\rho_\theta(Y - X_i{}'\beta)], \tag{4}$$

with an asymmetric loss given by the fact that:

$$\rho_\theta(u) = (1-\theta)I_{\{u<0\}}|u| + \theta I_{\{u>0\}}|u|. \tag{5}$$

4. Results

Our main results are presented in Table 2 and Figure 1. In Table 2 we show the slope coefficients associated with the effect of natural gas prices on electricity prices alongside different quantiles of the conditional distribution of electricity prices, joint with their respective standard errors. We estimate the ratios of transmission described in equation 3 for each country in our sample, setting θ = 0.9 for the high quantiles and θ = 0.1 for the low quantiles. We consider two specifications of the model expressed in equation 2, namely a first model in which X_{t-1} includes natural gas prices and weather covariates, and a second model which only consists of the explanatory variable natural gas prices. In the two cases we have lagged one day the right-hand-side variables in equation 2 to acknowledge the fact that in electricity auctions the bids that agents make today determine tomorrow's price, so the price is set with the information of the explanatory variables one day lagged.

R statistics are plotted in Figure 1 for our two specifications. A number greater than one indicates that the price of natural gas is transmitted to the price of electricity in a greater proportion when electricity is expensive than when it is cheap. For example, the data for Spain is equal to 6.1, which results from dividing the effect of natural gas on electricity, when the price of electricity is high (i.e. 4.90), over the effect when electricity has a low price (i.e.0.80), in the first model, or 12.4, according to the second model, which results from dividing the effect of natural gas on electricity, when the price of electricity is high (i.e. 7.35), over the effect when electricity has a low price (i.e. 0.59). In both cases this ratio clearly indicates that the price is transmitted more upwards (when prices tend to be high) than downwards (when prices tend to be low). In fact, it means that it is transmitted 6.1 (12.4) times more.

Analogously, an alternative interpretation will be that, when natural gas prices drop, the reduction in electricity prices may be 6.1(12.4) times smaller than when they increase. In other words, the increases observed in "scarcity" markets for generation -i.e. expensive electricity- is never offset by subsequent similar reductions in "abundance" markets for power generation – i.e. low-priced electricity-. This under the assumption that low quantiles are generally found in market scenarios with decreasing prices of electricity which are persistent.

Notice that the effect of the control weather covariates is attenuating the magnitude of the quantile slope coefficients associated with natural gas, alongside the distribution of electricity prices, but especially in times of system's distress, when electricity is relatively expensive. This is due to the fact that colder seasons are also associated with higher prices of electricity, regardless of the price of natural gas. Nevertheless, even the attenuated difference between the transmissions of shocks from natural gas prices in the two tails of the distribution of electricity prices, for countries such as Spain or Portugal is astonishing.

Table 2. Quantile Effect of Natural Gas on Electricity Markets

Panel A. Regression including weather covariates

	Belgium	Denmark	Finland	France	Germany	Italy	Netherlands
θ=0.05	2.814	2.860	2.888	1.543	1.969	4.175	3.882
s.e.	0.673	0.420	0.526	0.537	0.439	0.470	0.441
θ=0.10	3.676	2.882	3.094	1.545	1.844	4.781	4.381
s.e.	0.450	0.396	0.396	0.472	0.380	0.426	0.332
θ=0.90	5.964	4.535	2.022	4.572	5.935	1.078	7.791
s.e.	0.783	0.703	0.442	0.535	0.720	0.687	0.679
θ=0.95	16.262	8.926	4.392	11.547	10.451	4.387	11.433
s.e.	2.439	1.044	1.047	1.698	1.177	0.960	1.044

	Norway	Portugal	Spain	Sweden	Switzerland	United Kindgdom
θ=0.05	4.560	-0.450	-0.348	3.378	2.129	2.964
s.e.	0.405	0.844	0.846	0.600	0.732	0.326
θ=0.10	5.145	0.461	0.802	3.511	3.403	3.325
s.e.	0.296	0.716	0.746	0.412	0.533	0.192
θ=0.90	6.613	5.816	4.901	5.142	5.883	6.466
s.e.	0.576	0.793	0.895	0.527	0.839	0.897
θ=0.95	6.428	12.257	13.637	6.930	15.720	10.567
s.e.	0.234	1.166	1.233	1.056	1.654	1.146

Panel B. Regression without weather covariates

	Belgium	Denmark	Finland	France	Germany	Italy	Netherlands
θ=0.05	3.433	3.019	3.480	1.909	1.924	4.815	4.084
s.e.	0.784	0.454	0.674	0.734	0.627	0.595	0.382
θ=0.10	3.452	2.876	3.142	1.712	2.003	4.800	4.372
s.e.	0.435	0.474	0.366	0.324	0.392	0.425	0.320
θ=0.90	9.088	5.316	2.386	8.578	7.067	5.050	7.990
s.e.	1.080	0.935	0.560	1.106	0.860	0.825	0.809
θ=0.95	17.245	12.967	7.121	14.233	13.454	12.813	15.625
s.e.	0.927	1.994	0.838	1.202	2.756	2.282	2.023

	Norway	Portugal	Spain	Sweden	Switzerland	United Kindgdom
θ=0.05	5.138	-1.488	-1.331	4.233	2.391	2.900
s.e.	0.445	1.449	1.531	0.911	0.428	0.271
θ=0.10	5.820	0.387	0.592	4.855	2.490	3.140
s.e.	0.569	1.146	1.130	0.523	0.298	0.351
θ=0.90	8.573	7.200	7.353	5.867	6.638	8.571
s.e.	0.581	1.800	1.882	0.314	0.929	0.826
θ=0.95	7.989	17.422	17.583	4.780	10.350	19.167
s.e.	0.842	1.297	1.312	0.802	0.929	1.600

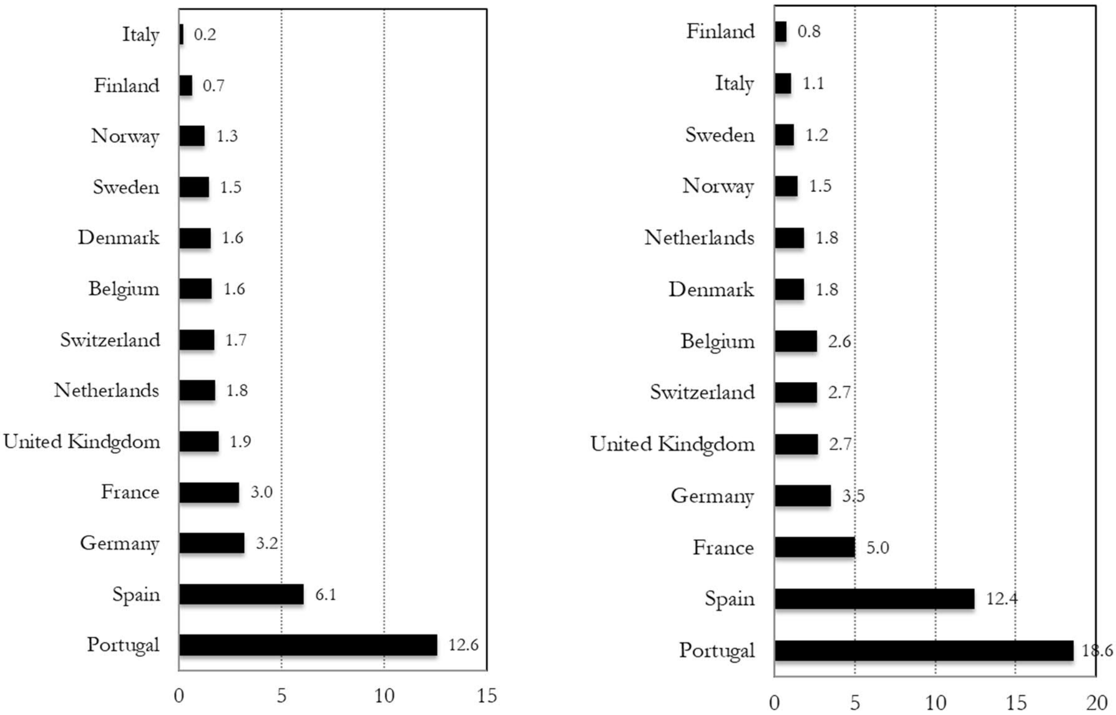
Note: the table shows the quantile slopes, and associated bootstrapping standard errors of the transmissions from gas prices to electricity prices at high quantiles ($\theta = 0.9; 9.5$) over low quantiles ($\theta = 0.1; 0.05$), respectively. All the coefficients are statistically significant at a 99% confidence level, except for the low quantiles of Portugal and Spain in both regressions.

This ratio is greater than one for almost all the countries in the sample, but shows significant variations, between 0.2 in the case of Italy and a maximum of 12.5 in the case of Portugal for the first model specification, which include weather controls, while these numbers vary between 0.8 for Finland and 18.6 for Portugal, in the second model specification. The ranking presents only small variations between the two models, and in both case Iberian countries lead the ration of transmissions.

Numbers lower that 1, like in Italy, mean that the cost-push from natural gas to electricity is indeed smaller for the higher quantiles of electricity prices, than for the lower quantiles and, point out to very different policy responses in these countries, compared to Spain and Portugal. Any policy action designed to safeguard vulnerable consumers from dramatic increments of electricity prices (like reduction of taxes and increments of subsidies) would be more urgent in the latter countries than in the former. That is, the pass-through from gas to electricity in Spain and Portugal is stronger, precisely, when the system is more vulnerable, which is signaled by high electricity prices. In contrast, when the system is more solid, that is, when demand is met to a great extent by cheaper power sources, and the price of electricity is relatively low, Italy faces a greater pass-through from gas to electricity, but in such a case the system is better prepared to absorb the shock.

Most of the countries within the Nord Pool present a relatively stable transmission effect from natural gas to electricity, across the quantiles of the distribution of electricity prices, which is reflected in a R statistic between 1 and 2, in all the cases, in the two model specifications.

Figure 1. Ratio R between Transmissions from Natural Gas Prices to Electricity Prices


Model 1. Including weather controls
Model 2. Excluding Weather controls

Note: the figure shows the ratio, R, between the transmissions from gas prices to electricity prices at high quantiles ($\theta = 0.9$) over low quantiles ($\theta = 0.1$). A number greater than one means that the shock transmits more when electricity prices are higher.

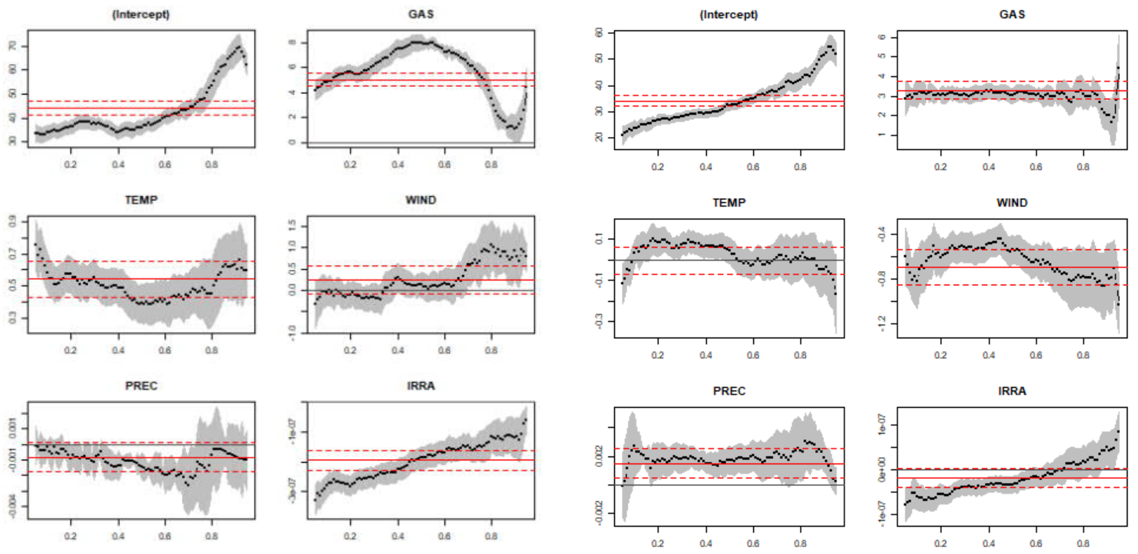
In general lines, our two specifications emphasize the nonlinear transmission of natural gas prices to electricity prices, which affect in a very diverse way national European markets. In all our specifications Portugal and Spain present the higher ratios and are therefore the most vulnerable to natural gas price shocks as the ones observed during the first quarter of 2021.

We present in Figure 2 the effect of natural gas prices on the whole distribution of electricity prices and the effect of the weather variables for the two countries that exhibit the lowest transmission of natural gas price shocks (Italy and Finland) and the two countries with the highest ratios of transmission (Spain and Portugal). Although Italy and Finland have a similar small value of R (0.2 against 0.7 in model one, and 0.8 against 1.1. in the second model), the effect of natural gas prices on electricity is quite different across the rest of the distribution of electricity prices. In the case of Italy, the impact of natural gas on electricity prices is very similar for extreme quantiles on both tails of the distribution, but the effect is nonlinear and increasing from the left tail of the distribution until the center of it. For Finland, a different dynamics is observed, according to which natural gas has a linear effect on the different quantiles of the distribution of electricity prices.

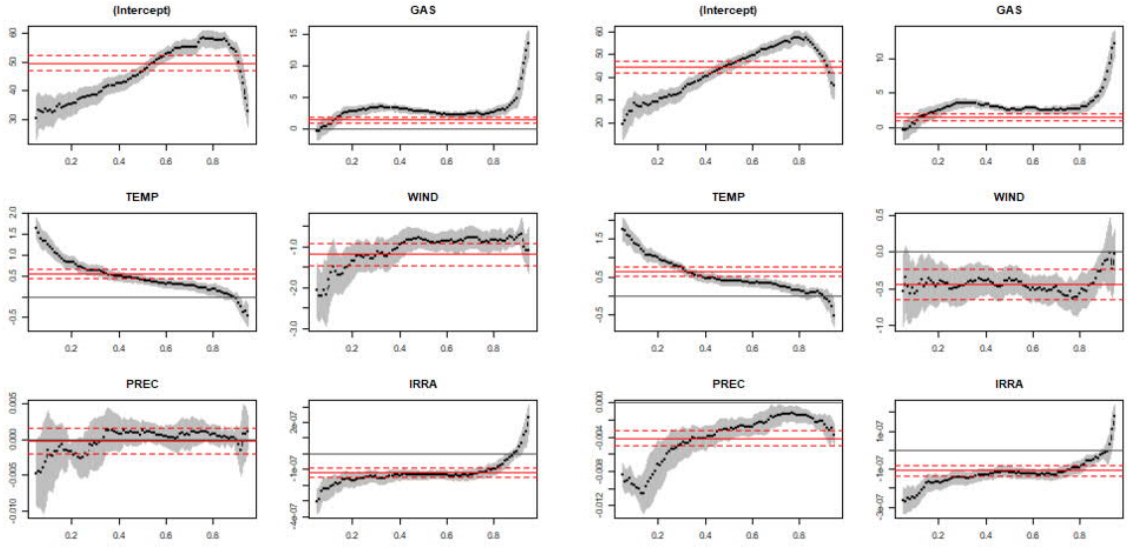
In the case of Spain and Portugal, the impact of natural gas on electricity shows a very similar pattern: the effect is mostly linear while electricity prices increase from the lowest quantiles up to the 80th percentile to, but once the extreme high quantiles are reached the effect magnifies nonlinearly.

Regarding the weather covariates, all of them tend to have a nonlinear effect on electricity prices, and in most scenarios the impact has the expected sign. Nevertheless, the impact of weather is also heterogeneous across countries. For instance, in Portugal and Spain, an increment in the temperature translates into lower prices of electricity when electricity is relatively expensive (negative effects above $\theta = 0.9$), but and increment of temperature increases the prices of electricity, when electricity is relatively cheap. The same occurs in Portugal. In contrast, the effect of the temperature on electricity prices is mostly linear for Italy and Finland.

Figure 2. Effects of Natural Gas Prices and Weather Covariates on Electricity Prices at Different Quantiles of the Price Distribution for Italy, Finland, Spain and Portugal


Italy

Finland


Spain

Portugal

Note: the horizontal axis in each subplot corresponds to a quantile of electricity prices, from the 5th to the 95th percentile, while the vertical axis corresponds to the effect of the explanatory variable on the electricity prices of the four countries. The dotted black lines show the varying effects across percentiles, with their respective confidence intervals displayed as shadowed areas. The red solid line is the effect at the mean of the price distribution, which has associated confidence intervals shown as red dotted lines. All the confidence intervals were constructed with 95% confidence. The explanatory variables are defined as follows: GAS is the Henry Hub natural gas prices; TEMP is the average temperature; WIND is the average wind speed; PREC is the average precipitation; IRRA is the irradiance of the capital of the respective country.

5. Conclusions and policy implications

Our results alert us to the need to enhance our current understanding of the price formation mechanisms in electricity markets. That is, even when the auction mechanism is in general the same across the various European markets, considerable variations are presented in terms of system transmission from natural gas to electricity prices. Portugal and Spain depict the highest ratios of transmission from natural gas to electricity prices, from 6 to 18, depending on the model specification, but always significantly larger than the rest of the markets in our sample, all of them below 5 for both model specifications.

Countries such as Finland, Italy, Sweden or Norway present the lower ratios, below 1.5 in any case, meaning that price increments of natural gas, occurring when electricity price is high, can be offset by future natural gas price reductions, when electricity is less expensive to generate. And overall, indicating a more stable transmission under different market scenarios of the natural gas price movements to electricity prices.

These results emphasize the need to advance public policies that allow isolating the most vulnerable electricity consumers, particularly in Iberian countries, from the unintended economic consequences that a surge in natural gas prices carries out. This is crucial, especially when considering that in fact, upward pressures on the price of electricity will tend to intensify in the future, due to the energy transition towards greener generation sources, in which European countries are immersed. Such pressures will come in the future from the restrictions in the common European regulatory framework on CO2 emissions, which will intensify as the energy transition progresses. Indeed, such pressures have been already noticed in ETS markets, which have recorded historical maxima prices in 2021, after being stagnant for decades, since their inception more than a decade ago. Such extra costs will affect precisely, to a greater extent, the thermal generation plants that require such rights in order to operate, and which set the wholesale electricity prices in times of scarcity.

Our results give a precise empirical context to the recent policy actions advocated by the European Commission (2021) aiming to safeguard the wellbeing of vulnerable electricity consumers facing the recent climbing of electricity prices. The recommended toolkit of policy measures include emergency income support and preventing disconnections via social payments to the most vulnerable electricity consumers, tax exemptions and reductions for vulnerable households, financial aid to companies and households in the way of direct support for a defined minimum consumption per household or inhabitant, or targeted support measures to help industries, and enhanced cooperation and EU level monitoring (to prevent anti-competitive behavior in electricity markets). The main policy implication of our study is visualizing the different levels of urgency of such measures across European countries. That is, although the problem is general, and rooted in the increment of global natural gas prices, not all European countries are equally impacted by the surge in the cost of electricity. Any of such policy measures is more urgent in the most fragile systems, which are precisely those in which the cost-push becomes stronger when the prices of electricity are already high, and therefore the provision of electricity is more vulnerable, which is the case of Spain and Portugal.

Our research results also invite us to explore other forms of market organization, for example, more physically and economically interconnected forms at the international and regional level. Note, for example, that the price transmission ratio for the countries belonging to the Nord Pool, which is the most deeply integrated market in Europe, consisting of Denmark, Sweden, Norway, Latvia, Lithuania, Estonia and Finland tend to be lower, than for the rest of the countries. Market integration is something that has been analyzed by Uribe et al. (2020) and it promises to be a fundamental topic for understanding price formation mechanisms in the electricity market and the design of public policies to protect vulnerable consumers for suffering during the energy transition.

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UBIREA

Institut de Recerca en Economia Aplicada Regional i Pública
Research Institute of Applied Economics

Universitat de Barcelona
Av. Diagonal, 690 • 08034 Barcelona

WEBSITE: www.ub.edu/irea/ • **CONTACT:** irea@ub.edu