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Estimating temperature effects on the Italian electricity market

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ABSTRACT

This paper provides empirical evidence of the effects that weather conditions exert on the electricity market, offering a new contribution to the understanding of hourly regional price formation in the day ahead market in Italy. The empirical estimation uses a new data set of hourly data on both market variables and temperature variables.

There is a vast body of literature on the effect of temperature on final consumers and on wholesale electricity market equilibrium. However, the influence of temperature on the behavior of the wholesale electricity market has not been studied at the hourly level. A new econometric estimation shows some evidence of different effects of temperature and provides a more accurate estimation of the hourly prices. Forecasting out-of-sample performance of the model is satisfactory.

The present results have welfare-improving policy implications, because appropriate policy strategies can help public decision-makers promote regulation, such as issuing public weather alert and designing contingent plans to face extreme weather conditions, which improves production efficiency, network management, and consumer saving behavior, taking specific weather conditions into account.

1. Introduction

The analysis of the dynamic pattern of electricity prices has developed extensively with the liberalization of electricity markets, exploiting the rich data made available from the organized wholesale markets. In particular, the European market design, as framed by the EU Directive (EU, 2009) and implemented by Member States, explicitly envisions the public release of the relevant market data in accordance with the principles of transparency and promotion of efficiency. In this respect, the Italian Power Exchange market (IPEX) is no exception. Data on prices, quantities, and relevant structural conditions are released by the market operator, GME spa, at an hourly frequency, almost in real time.

There is a large amount of empirical literature investigating several aspects of the liberalized electricity markets. This paper analyzes the stochastic properties of the spot prices, like mean reversion, seasonality, and extreme values, and assess the influence of the weather variables, such as temperature, on the pattern of electricity consumption. While a large amount of literature has addressed the issue of temperature effects by looking at the final consumer behavior at the structural level of monthly or annual data, as argued more in detail in the next Section, there has not been any explicit analysis of the nexus between market prices and temperature effects at the hourly level.

The aim of this paper is to fill this gap, providing empirical evidence of the effects of temperature conditions on the electricity market at the hourly frequency, specifically investigating whether forecasting the temperature effect is a relevant additional variable in the day-ahead price determination at the hourly frequency. In this paper, this aim has been broken down to the following three new research questions:

First, the hourly price forecast is explicitly modeled, both taking into account and testing the specific effect of a function of the hourly temperature. Second, the empirical analysis considers simultaneously regional and hourly data for the longest period available. Data are for six regions and 101,520 h from January 2005 to July 2016. There are no studies of the Italian market that analyze such a long range of data. Third, the estimation is carried out via a comprehensive model of hourly price determination using data on both market variables and weather forecast variables. In particular, a new hourly measure of heat degree-hours (HDH) and cooling degree-hours (CDH) is computed and used, together with a new measure of extreme weather conditions for six Italian regions.

Results can offer a more accurate forecast of electricity market prices, which can be useful for both private business and public policymakers. Generation companies can use a more accurate price forecast to improve their profitability strategies and their short-term technical and operational decisions, as well as their long-term investment decisions.

Policy-makers and public agencies (like the Energy Authority and the Renewable Incentive Program Agency) can use more accurate price forecasts to implement better regulation to promote competition and enhance consumer welfare. Consumers will have better choice

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opportunities. Specific consumer categories can be better protected, like in the case of linking, in a systematic way, the issuance of public weather alerts to real time measures to helping the elderly in extreme weather conditions.

The paper proceeds as follows. Section 2 presents a brief literature review. Section 3 describes the model. Section 4 discusses the methodology applied and the data. Section 5 presents the results. Section 6 concludes and discusses the policy implications.

2. Literature review

The introduction of weather variables in the analysis of electricity consumption and price patterns dates back to the pioneering works of Le Comte and Warren (1981), Engle et al. (1986), and Peirson and Henley (1994), who estimated models with monthly data. Since then, there have been three main lines of research on the weather–electricity market variables' nexus.

The first line of research deals with the impact of temperature on residential demand and prices. The data are generally at a monthly frequency (Miller et al., 2017; Son and Kim, 2017), with a breakdown of monthly sectorial electricity demand and complex functions of the density of temperatures (Chang et al., 2016). Analysis of the sectorial firms' electricity demand with temperature effects has been conducted at the daily frequency in the case of Spain (Moral-Carcedo and Pérez-García, 2015). Also using daily temperature data, Graff Zivin and Novan (2015) assess the impact of temperature on the individual response to the residential weatherization programs designed to encourage conservation. A specific interest in the analysis of demand response in urban areas is provided by Papakostas and Kyriakis (2005), who use HDH and CDH in Greece, with daily data; Véliz et al. (2017), who estimate the effect of climate change on electricity prices in the US, with monthly data; Luiz and Afshari (2015), who measure several hourly weather variables to model and forecast the electricity load within the UAE, using a transfer function method, with daily data; Jovanović et al. (2015), who analyze the impact of temperature conditions on the consumption of electricity in East Europe, with daily data.

The second line of research analyzes the supply side. Yu et al. (2009) use a data envelope analysis to investigate the impact of weather on the overall efficiency of network utilities, measured with costs and quality of service. Herrerias and Girardin (2013) use temperature to analyze the seasonal character of electricity production across Chinese regions, at the monthly frequency.

The third line of research deals with dynamic modeling and forecasting the electricity price with temperature variables at a higher frequency, generally either daily or weekly. The electricity price is modeled using the stochastic time change method, with the temperature being used as a proxy for the demand (Borovkova and Schmeck, 2017). Figueiredo et al. (2016) provide an updated literature review of the analysis of daily electricity prices and the weather variables, analyzing the Central–West European market with vector auto regressions (VARs), showing that there are also spillover effects across all countries.

The day-ahead spot price dynamics in the German electricity spot market is analyzed with a dynamic structural VAR model by Paschen (2016), who finds that load and spot prices are stationary. Several price variables, peak hours, and daily averages, are analyzed by Huurman et al. (2012) at the daily frequency, who show that temperature information demonstrates predictive power in forecasting electricity prices. Evidence that electricity load and prices are temperature sensitive is reported also in Forbes and Zampelli (2014). Bosco et al. (2010) justify the use of weekly medians of the original hourly time series to avoid intra-day seasonality. A mean reversion of electricity prices in wholesale markets is found in Bosco et al. (2010), and Yang et al. (2017). The latter authors estimate a general model combining wavelet transformation, a kernel extreme learning machine, and an auto regressive moving average (ARMA), using daily data.

A specific interest in the effects of extreme temperature events on the electricity prices in Latin America is provided by Santágata et al. (2017). Evidence of extreme weather with daily data is provided by Moral-Carcedo and Pérez-García (2015), who analyze the impact on firms' electricity demand in Spain, and by Mansanet-Bataller et al. (2007), who analyze the EUA price levels.

Raviv et al. (2015) challenge the view that hourly prices are independent, because, as they point out, the market process is based on simultaneous bids submitted for the prices of all the hours of the next day in the day-ahead market.

They posit that prices are determined simultaneously and that it is not appropriate to model the hourly prices as single time series. Their line of analysis is geared toward the question of whether hourly electricity prices can be used to predict the daily average price.

In summary, the existing literature does not contain an explicit estimation of the hourly frequency of the electricity price determination with temperature effect. This paper intends to fill this gap.

3. The model

The general model specification is grounded on the simple textbook supply equation, which can be identified (Fisher, 1966) as a price-quantity relation that excludes a priori specific demand determinants (such as income). In this context, the supply function is specified as follows: price P is a function of quantity Q and possibly market structure M (as defined in the next section) plus an error term u.

$$P = f(Q, M) + u \tag{1}$$

The main interest of this paper is to investigate the additional explanatory content of the temperature T, assuming that the supply function includes also the temperature T:

$$P = f(Q, M, T) + u \tag{2}$$

Note that Eq. (2) allows us to test empirically whether temperature is an additional significant regressor, together with load, that explains day-ahead prices.[1] In this paper, three specifications of Eq. (2), both parametric and non-parametric, are used to assess the impact of temperature on electricity day-ahead prices in the six regions of the Italian electricity market (as explained in detail in the next section).

First, a non-parametric regression is conducted to compute a kernel estimator of the relation price-quantity and price:

$$E(P|X = x) = f(x) \tag{3}$$

where $X = \{Q, T\}$ and $f(x)$ is a kernel estimator with a Gaussian function.

Second, a simple ARMA(p,q) model is used for each regional price:

$$P_t = \sum_{j=1}^{k} a_j P_{t-j} + \sum_{j=0}^{k-1} b_j u_{t-j} \tag{4}$$

where $b_0 = 1$, $b_j = 0$ for $j > q$, $a_j = 0$ for $j > p$ and the innovations u_t are independent and identically distributed, with $E[u_t] = 0$.

Third, a VAR(p) model is specified for the six regional prices, or a p-th order VAR, with exogenous variables X:

$$P_t = c + A_1 P_{t-1} + \ldots + A_p P_{t-p} + B_0 X_t + B_1 X_{t-1} + \ldots + B_s X_{t-s} + u_t \tag{5}$$

where P_t is a vector of the six regional prices, with p lags of these variables, c A_j B_j are parameters, and $X_t = \{Q_t, T_t, M_t\}$ are exogenous variables, which include functions of contemporaneous and lagged quantities, market structure, and temperatures. The usual assumption holds:

$$E(u_t) = 0, \quad E(u_t, u_t') = \Sigma, \quad and E(u_t, u_s') = 0, \forall \quad t \neq s.$$

[1] This is an empirical question, because it cannot be taken for granted that the load incorporates all the relevant information at the time of the day-ahead price formulation. So, adding the temperature forecast in the equation allows its significance to be tested.