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The role of renewable energy sources on electricity prices in Spain. A maximum entropy econometric model*

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The liberalization of electricity markets in Europe aims to increase competition, thus decreasing electricity prices for the consumers, including households. Moreover, the electricity generated from renewable energies (RES-E) is physically integrated into the electricity market and can influence electricity prices. This paper presents the impact of the liberalization process in the Spanish electricity market and the impact of RES-E on household electricity prices.
However, as the electricity market liberalization is relatively recent, the related data is limited, and even when trying to estimate the electricity price models through regression procedures a dimensionality problem presents itself. Therefore, in this paper a Maximum Entropy Econometric approach is used that allows for the estimation of models when information is limited. The obtained results suggest that the use of wind energy in electricity generation can contribute to the reduction of electricity prices. However, the electricity generated from hard coal increases the electricity prices. Results also reveal that energy dependence also has an important effect on electricity prices.

Keywords

Electricity price
Renewable energy
Market liberalization
Entropy measure
Information Theory

Ključne riječi

Cijena električne energije
Obnovljivi izvori energije
Liberalizacija tržišta
Mjerenje entropije
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*** Uloga obnovljivih izvora energije na određivanje cijene električne energije u Španjolskoj. Ekonometrički pristup maksimalne entropije**

Izvorni znanstveni članak

Cilj liberalizacije tržišta električne energije u Europi je povećanje konkurencije čime bi se smanjila cijena električne energije za potrošače, uključujući i kućanstva. Štoviše, električna energija dobivena iz obnovljivih izvora energije (OIE-E) je fizički integrirana u tržište te može utjecati na cijenu. Ovaj članak prikazuje utjecaj procesa liberalizacije na španjolsko tržište električne energije i utjecaj OIE-E na cijenu električne energije u kućanstvima.
Pošto je liberalizacija tržišta električne energije relativno nov pojam, relevantni podatci su ograničeni i kad se pokušavaju koristiti modeli procijene cijena električne energije regresijom, javlja se problem veličine. Zbog toga je u ovom članku primijenjen ekonometrički pristup maksimalne entropije koji dozvoljava korištenje modela procijene čak i kad su podatci ograničeni. Dobiveni rezultati ukazuju na to da bi korištenje energije vjetra moglo doprinijeti smanjenju cijene električne energije dok ju korištenje antracita povećava. Rezultati također otkrivaju da ovisnost o uvozu energije također ima značajan utjecaj na cijenu.

1. Introduction to the Article Layout

Following the EU Directives [1] and [2], the electricity markets in Europe were fully liberalized on the 1st of July, 2007. Within this legal framework, the implementation of electricity liberalization at the national level in Spain is conducted by laws [3] and [4].
Moreover, according to the Kyoto protocol of the United Nations Framework Convention on Climate Change (UNFCCC, Kyoto, 11 December 1997), the European Union has made the commitment to reduce their emissions. The European Union aims to cut greenhouse gas emissions at least 20% below 1990 levels by 2020 (8% below 1990 levels by 2008-2012).
In this context, each European Union member is working on its energy strategy to guarantee security of the energy supply and competitiveness – see [5] for the case of Croatia – and also to control climate change through the implementation of energy efficiency measures (as in the building sector [6]) and the use of renewable energies. Therefore, special arrangements and other directives are made to promote electricity generation from renewable energies (RES-E) ([7] and [8]).

Regarding the aspects of electricity market liberalization, they act to introduce competition into electricity wholesale generation and supply activities, the unbundling of transmission and distribution activities and retail market competition for all customers.

Symbols/Oznake

n	- number of explanatory variables/ broj nezavisnih varijabli
T	- number of years/ broj godina
y	- electricity price/ cijena električne energije
X	- matrix of explanatory variables/ matrica nezavisnih varijabli
p	- regression parameter's probability distribution/ distribucija vjerojatnosti regresijskog parametra
w	- error's probability distribution/ distribucija vjerojatnosti greške
u	- random error/ nasumična greška
v	- support space for regression's parameters/ pomoćno mjesto za regresijske paramatre
z	- Support space for random error/ pomoćno mjesto nasumične greške
H(P)	- entropy measure/ mjera entropije
S(P)	- normalized entropy/ normalizirana entropija
R	- information index/ indeks informacije

Greek letters/Grčka slova

β	- regression parameter/ parametar regresije

Subscripts/Indeksi

i	- Explanatory variable i=1,…,n/ nezavisne varijable i=1,…,n
t	- year t=1,…,T/ godina t=1,…,T
k	- variable's point support k=1,…,K/ pomoćna točka varijable k=1,…,K
j	- error's point support j=1,…,J/ pomoćna točka greške j=1,…,J

Theoretically, competitive markets should lead to efficiency gains in the economy, thus reducing electricity prices.

However, the real benefits from increasing the competition are an object of debate because the opening up of the market does not necessary imply market efficiency [9] and competitive prices.

Some experiences of many liberalized electricity markets ([10], [11]) show that, in most cases, prices for household consumers rise, as has also happened in Spain mainly beginning in 2002 (Figure 1).

The obtaining of competitive prices depends on the characteristics of the electricity supply and the electricity demand as for instance, the disaggregation of traditional electricity generation monopolies, the number of enterprises in the electricity generation and retailing activities or the nature of consumers to switch from one retail supplier to another.

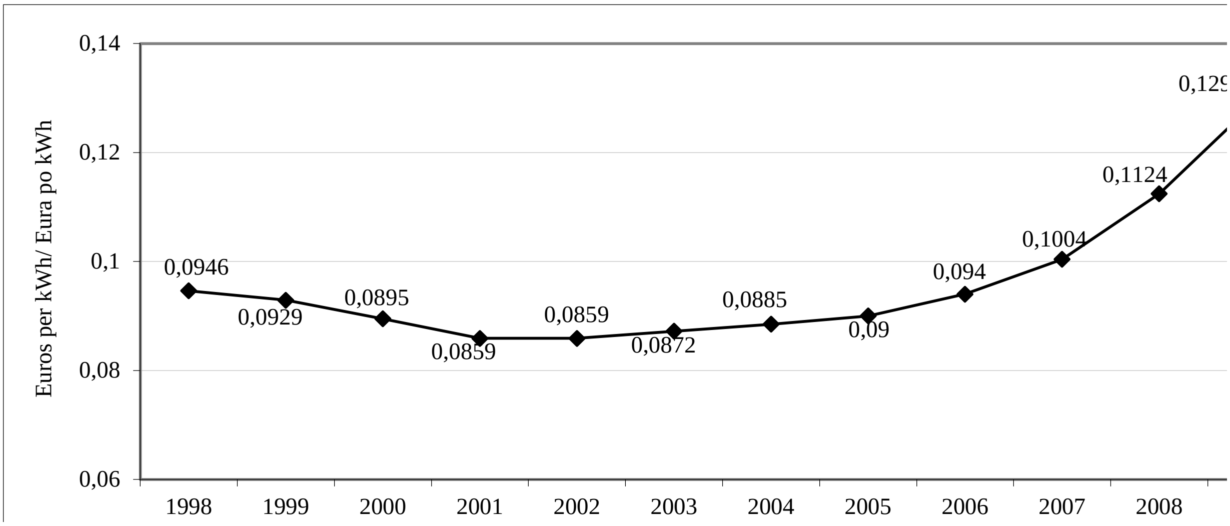

Figure. 1. Electricity prices for Spanish household consumers €/kWh.1998-2009 (Eurostat).
Slika 1. Cijena električne energije za kućanstva u Španjolskoj €/kWh.1998-2009 (Eurostat).

Regarding the generation market structure in Spain, the liberalization of the generation sector has provided a less concentrated market structure. The market share of the largest generator in the Spanish electricity market did have a significant decrease from 51.8% in 1999 to 22.2% in 2008.

In this context, one of the key concepts in the Spanish electricity industry is the creation of a wholesale electricity market. In the daily market (which sets 89% of the final electricity price in Spain), electricity generation selling companies determine, for every generation unit, the offered amount and price according to their short-term marginal cost (STMC), which is the variable cost of producing one extra unit of electricity (including the fuel, the emissions, and the operation and maintenance costs). In parallel, electricity consumers establish the demanded amount. Finally, supply and demand (which is fairly inelastic in the short run) settle at the same marginal kWh cost of electricity. Thus, in this wholesale market, all of the electricity producers get the same price although they have different short-term marginal costs. The production units with the lowest STMC are wind turbines, hydro plants and nuclear plants and the production units with the highest STMC are condensing power plants based on coal. Moreover, Spain has a high dependence (around 80% levels) on imported resources such as crude oil and natural gas. Therefore, Spanish electricity prices are linked to such international energy raw material prices as they can increase the STMC of technologies based on those products.

Regarding the participation of RES-E into this wholesale electricity market, a controversial debate has arisen about its effects on wholesale and household electricity prices. These production technologies are characterized by having a lower STMC than fossil conventional technologies – [12] and [13]. Therefore, their entrance into the electricity markets can allow the reduction of the wholesale electricity prices because they displace the marginal technology based on fossil fuel.

In Spain, the Renewable Energy Development Plan 2005-2010 and the Renewable Energy Plan 2011-2020, which is concurrently being drafted, processed by the Industry and Energy Council of the Spanish government and the Spanish Institute for Energy Diversification and Saving-IDEA, set the policies and strategies to its deployment of renewable energies (RES). As a result of the design of policies to promote renewable energies, Spain has registered an increase in the share of electricity from RES from 17.2% in 1990 to 29.4% in 2009 as we can see in Figure 2. Therefore, its effect on wholesale electricity prices becomes very important.

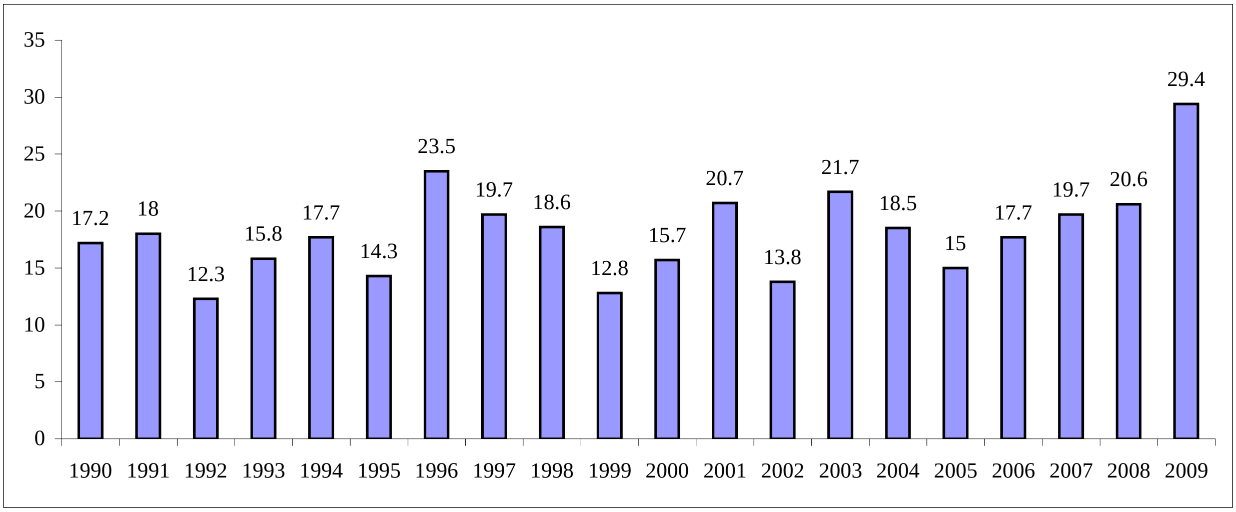

Figure. 2. Electricity generated from renewable sources, % of gross electricity consumption (Eurostat)
Slika 2. Električna energija iz obnovljivih izvora, % ukupne bruto potrošnje električne energije (Eurostat)

However, there is not clear evidence about the effect the development of renewable energies entails on the final electricity prices.

A large share of RES-E power generally gives lower electricity prices, reducing the profitability of investing in new electricity capacity. If RES-E generators are exposed to market prices, it directly affects their market revenues.

Therefore, as the majority of renewable energy technologies are not profitable at current energy prices, their development is mainly driven by several public renewable support schemes. A feed-in tariff system is used in Spain. Under a feed-in tariff, renewable electricity generators are paid a premium price for any renewable electricity they produce. Most RES-E support systems are financed via the electricity market, which could increase the household electricity prices. [14] shows that Feed-in tariff systems create an artificial market and cause policy costs (¼ additional costs are usually paid by electricity customers) and [15] points out that although the additional costs of the feed-in tariff are passed to the consumers, the exposition of RES-E to the market risks may also give an incentive to RES-E generators to make efficient use of the respective market and act in a cost-reflective way, thus limiting the indirect costs to society. However [16], by considering the cost-saving potential for electricity produced by wind, a net reduction in the retail electricity price for Spain has been detected.

In addition, environmental costs related to CO2 emissions in electricity generation usually have a significant negative effect on electricity price as a CO2 emission trading scheme (ETS) exists. The substitution of conventional electricity generation by renewable energies could reduce the costs derived from environmental emissions and the electricity price. Additional RES-E provides substitute electricity from fossil fuels, and thus CO_2-emissions are reduced. The demand for emission reductions is lowered; as a result the CO_2 price is also reduced and consequently the wholesale price for electricity decreases [17].

Therefore, the progress made towards electricity market liberalization and the increased participation of RES-E into the market are important factors in explaining the final electricity price paid by consumers.

Significant econometric evidence about the effect of electricity market reforms is not easy to find at the national level. Traditional parametric methods require an elevated sample size for the efficient estimation of the coefficients in the models. However, as the electricity market liberalization process is relatively recent, the sample data is limited and when trying to estimate the electricity price models through regression procedures a dimensionality problem arises. In order to increase the degrees of freedom, the majority of studies focus on panel data techniques (see [18] for a review of more of them).

As an alternative to estimate the model, when a dimensionality problem arises, a Maximum Entropy Econometric approach is proposed. It has been defined [19] as “a sub-discipline of processing information from limited and noisy data with minimal a priori information on the data-generating process”. This approach has its roots in Information Theory and builds on the entropy-information measure [20], the classical maximum entropy principle [21],[22], which was developed to recover information from underdetermined models, and the Generalized Maximum Entropy Theory [23].

The concept of maximization of entropies was introduced by Jaynes ([21],[22]) in the physics field, and has been successfully applied in other fields such as econometrics ([24], [23], [25], [26]), biology [27] or psychology [28], among others disciplines.

Therefore, this paper investigates the possibilities of the maximum entropy Econometric approach in the estimation of household electricity price models.

This paper is divided into two more sections. The next section (Section II) assesses the problem of the electricity price model estimation through regression-based procedures when a dimensionality problem arises. The Maximum Entropy Econometric procedure is also described in order to estimate the model. Moreover, an empirical application of the proposed method to Spanish household electricity prices over the period 2002-2007 is presented. Some concluding remarks complete the paper.

2. Maximum entropy econometric approach

The goal of this paper is to estimate the effect of several variables (*n*) related with electricity generation and electricity market liberalization on electricity prices (*y*) by using data of several years (*T*) such that:

$$y = X\beta + u \tag{1}$$

with *X* being a matrix Txn, *y* a matrix $Tx1$, β the vector of coefficients to be estimated (vector $nx1$) and *u* the vector of disturbances.

The estimation of β by regression techniques requires that the number of observations was superior to the number of independent variables ($T>n$).

Nevertheless, information related to the electricity market liberalization process is limited and when trying to estimate the electricity price models through regression procedures a dimensionality problem arises. Therefore, in a situation of limited sample data the estimation of the model by regression procedures (OLS) is not possible as the problem is undetermined or ill-posed.

However, when these circumstances of a small amount of information available make it unfeasible to combine forecasts through OLS procedures, the Maximum Entropy Econometric approach allows for the recovery of the estimates of $\beta_1, \beta_2,\dots,\beta_n$ in the corresponding parameterized model without making distributional assumptions. The approach consists of developing a non-linear inversion procedure [23] which requires the application of the tools provided by the Information Theory ([20], [21], [22]).

Consider a regression-based method:

$$y = X\beta + u \tag{1}$$

in a situation of limited sample data where $n>T$. A probability distribution should be used in order to represent partial and limited information regarding the individual observations so they are consistent with the observed sample data. Therefore, following [23] it is possible to define an inverse general problem for recovering β defined as:

$$y = X\beta + u = XP + u \tag{2}$$

where $P=(p_1, p_2,\dots, p_n)'$ is a *n*-dimensional vector of unknown terms related to the probability distribution. The main objective is to estimate a probability distribution *P* given the limited information and minimal distributional assumptions and therefore recover β as

$$\hat{P} = \hat{\beta}\ \cdot \tag{3}$$

However, as the number of observations (*T*) is smaller than the number of independent variables (*n*), in order to recover *P* by using traditional procedures of mathematical inversion, there is more than one vector *P* making the solution feasible. Therefore the problem is ill-posed and there is no basis for picking a particular solution vector for *P* from the feasible set. Thus, by asking for a particular set of probabilities considered as most likely, it seems reasonable to favour the one that could have been generated in the greatest number of ways given the available data.

The definition of the entropy measure *H(P)* and the formulation of the Entropy Maximization problem can help to estimate a unique *P* distribution since the principle of Maximum Entropy provides a basis for transforming the sample information into a probability distribution that reflects the uncertainty about the individual outcomes.

The measures of entropy *H(P)* quantify the uncertainty associated with a random experiment. In particular, given a random variable *X* with values x_i and probability distribution $P=(p_1,\dots, p_n)$ with $p_i \geq 0$ (i=1..., n) and

$$\sum_{i=1}^{n} p_i = 1 \tag{4}$$

Shannon's measure of entropy [20] is defined as:

$$H_S(P) = H_S(p_1,\dots, p_n) = -\sum_{i=1}^{n} p_i \log p_i \tag{5}$$

The value of the entropy is maximum when all the values x_i have the same probability (and then *P* is a uniform distribution). This situation would be justified by the Laplace Indifference Principle, according to which the uniform distribution is the most suitable representation of the knowledge when the random variable is completely unknown. Nevertheless, sometimes the ignorance of the probability distribution of *X* is not absolute and there is some partial information on the distribution such as the mean, variance, moments or some characteristics which can be formulated as equality constraints. In such a case, it is possible to estimate the probability distribution through the application of the Maximum Entropy principle ([21], [22]) choosing the distribution for which the available information is just sufficient to obtain the probability assignment.

Thus, if certain values a_r (r=1…,s) associated with functions $g_r(X)$ of the values of *X* are known but its distribution is unknown, the problem consists of estimating a nonnegative distribution that fulfils the conditions $p_i \geq 0$ for *i* =1..., n and

$$\sum_{i=1}^{n} p_i = 1 \tag{4}$$

maximizing the value of the entropy.

By solving the maximization problem it is possible to obtain the estimated probabilities $\widehat{P}=\{\widehat{p}_1,...,\widehat{p}_n\}$. The maximum entropy distribution does not have a closed-form solution and therefore numerical optimization techniques must be used to compute the probabilities.

Working towards a criterion for recovering the parameters of the regression model related to electricity price in the general inverse problem

$$y = X\beta + u = XP + u \quad (2)$$

if there is no evidence that a specific independent variable is more significant than others, the related probability distribution (*P*) would be the uniform variable (according to Laplace Indifference Principle). However, the principle of maximum entropy provides a basis for using the sample information in a probability distribution *P* that reflects the uncertainty about the individual independent variable. Therefore, the problem consists of estimating a nonnegative distribution *P* by maximizing the value of the entropy *H(P)* subject to the available information. By solving the optimization problem, the estimated probability distribution $\widehat{P}$ is obtained.

In the general inverse problem $y = X\beta + u = XP + u$ it is considered where the goal is to determine the unknown and unobservable frequencies $P=(p_1, p_2,\ldots, p_n)'$, representing the data generating process. Then, within the possible sets of probabilities fulfilling

$$\sum_{i=1}^{n} p_i = 1,\ p_i \geq 0,$$

a single vector must be chosen. Through the application of the principle of maximum entropy *H(P)* is maximized under the restrictions of information consistency $y = X\beta + u$, and the adding up-normalization constraint for *P:* $P'\ell = 1$.

If the vector of disturbances, *u*, is assumed to be a random vector with finite location and scale parameters ($v_{tj}, j=1,\ldots J$) it is possible to represent the uncertainty about it by treating each u_t $(t=1,\ldots,T)$ as a finite and discrete random variable with $2 \leq J \leq \infty$ possible outcomes.

Thus, it is assumed that each u_t is limited by an interval (v_{t1}, v_{tJ}), whose probability, $Pr(v_{t1},<u_t<v_{tJ})$, can become as small as necessary. For example, for $J=2$, the error can be defined as: $u_t=w_t v_{t1}+(1-w_t)v_{tJ}$ where each $w_t \in [0,1]$ is a vector of error weights. Furthermore, $J \geq 2$ can be used to assume certain characteristics of symmetry and kurtosis about the error distribution.

Because there may be different levels of uncertainty underlying each β_i, for more general inferential purposes, point estimates may be limiting and unrealistic. Consequently, it is possible to generalize the maximum entropy problem to permit a discrete probability distribution to be specified and obtained for each β_i. Rather than search for the point estimates of β, each β_i is viewed as the mean value of some well defined random variable *z*.

Then, for each β_i, it is assumed there exists a discrete probability distribution that is defined over a parameter space $\square^K$ by a set of equally distanced discrete points $z_i=[z_1,\ldots,z_K]'$ with corresponding probabilities $p_i=[p_{i1},\ldots,p_{iK}]'$ and with $K \geq 2$. Therefore: $\beta_i = E_{P_i}[z_i]$ or $\beta = E_P[z]$.

Using the Maximum entropy econometric approach, one investigates how “far” the data pull the estimates away from a state of complete ignorance (uniform distribution). In order to measure the reduction in the initial uncertainty, the information index entropy measure *R* is defined ([23], [29], [30]) and where $R \in [0,1]$. The higher the value of *R* is, the better the estimated model is.

Moreover, some measures are defined to evaluate the information in each one of the variables $i = 1, 2,...,m$ as the normalized entropy: $S(\widehat{p}_i)$. These variable-specific information measures reflect the relative contribution (of explaining the dependent variable) to the independent variable. Where $S(\widehat{p}_i) \in [0,1]$, zero reflects no uncertainty while one reflects total uncertainty in the sense that *P* is uniformly distributed.

3. The impact of RES-E and electricity market liberalization on electricity prices in Spain

In this section, the effect of several variables on household electricity prices in Spain is explored. The used data set are provided by Eurostat during the period 2002-2007 (available at the web site http://epp.eurostat.ec.europa.eu)

The considered dependent variable is *Electricity prices for Household consumers* (*y*). This indicator measures electricity prices charged to final consumers, which are defined as follows: Average national price in Euro per kWh without taxes applicable for the first semester of each year for consumers of the medium size household category (Consumption Band Dc with annual consumption between 2,500 and 5,000 kWh).

The following explanatory variables (*n*) are proposed:

- Variables related to the market’s opening in electricity generation:

  Number of enterprises dedicated to generation of electricity. A negative effect of this variable on electricity prices is expected by holding all the other relevant factors constant, since an increase in the number of enterprises leads to lower electricity prices.

  Market share of the largest generator in the electricity market. Ceteris paribus, a positive effect of this variable on electricity prices is expected, since an increase in market share leads to higher electricity prices.

Table 1. Number of enterprises dedicated to generation of electricity and Market share (%) of the largest generator in the electricity market in Spain

Tablica 1. Broj poduzeća koja se bave proizvodnjom električne energije te tržišni udio (%) najvećeg, na španjolskom tržištu

Year/ Godina	Enterprises of Generation/ Broj poduzeća	Market share/ Tržišni udio
2002	1.358	41.2
2003	1.715	39.1
2004	1.887	36
2005	2.042	35
2006	4.728	31
2007	7.426	31
2008	11.386	22.2

– A variable related to the market's opening in electricity distribution and retailing activities: *Number of enterprises dedicated to distribution and trade of electricity*. A negative effect of this variable on electricity prices is expected by holding all the other relevant factors constant, since an increase in the number of enterprises leads to lower electricity prices.

– Variables related to the participation of different energies in the electricity generation and thus in the wholesale electricity market.

Electricity generated from renewable sources- % Total gross electricity generation: There is a controversy about its effects on household electricity prices as it depends on several circumstances such as the amount of public renewable support, the promoted renewable energy, etc. Thus, a positive or negative effect on prices could be expected by holding all the other relevant factors constant.

Electricity generated from nuclear- % Total gross electricity generation

Electricity generated from natural gas- % Total gross electricity generation

Electricity generated from petroleum - % Total gross electricity generation

Electricity generated from hard coal- % Total gross electricity generation.

– Moreover, the following variables are also used:

Greenhouse gas emissions by Energy industries as a total of Greenhouse gas emissions. The emission trading schemes affect the short-term marginal cost of energy industries, increasing the wholesale electricity prices and thus, the household electricity price. Ceteris paribus, a positive effect of this variable on electricity prices is expected.

Gross Domestic Product per capita, GDP per capita: This variable aims to study the effect of the general economic activity on electricity prices. A positive effect of this variable on electricity prices is expected by keeping constant both known and unknown factors that may also influence the relationship between household electricity price and the GDP independent variables.

Energy dependency: Spain has a high dependence (around 80% levels) on imported resources such as crude oil and natural gas, therefore electricity prices are linked to such international energy commodities prices. The brent crude petroleum price by barrel (in dollars) is also used.

For the solution of the optimization, the GAMS program (*General Algebraic Modeling System*) is used. This is a programming language which allows diverse optimization problems to be solved.

A general maximum entropy model with a reparametrized error is considered. Firstly, it is necessary to establish an a priori range for the possible values that may be assumed by u error in the model, which may be employed to assume certain characteristics of its distribution: V. Since this decision is arbitrary, a support vector for the errors $(-v, -v/2, 0, v/2, v)$ for $v>0$ is assigned. It guarantees the error's symmetry around zero.

The decision regarding the amplitude of the range of values which it may assume is arbitrary. According to [31] support vector v it can be assessed if the variability presented on y was known and it would be possible to use the three standard deviation rule as the estimation for v. In fact, the proposal of [31] which uses the sample variance of y as an estimate for v is used. In the sample data used, the variance of y is 5.38 thousands of euros and then v=16.15. However, with a widening of the error bound by increasing v the estimated weights converge on the uniform distribution (the difference between the weights of the variables is reduced), the most reduced v that makes the solution feasible (v=7) is used.

Moreover, a priori range for the possible values that may be assumed by β in the model is also established. Thus, the support space Z has to be chosen, and then use the data to estimate the P which in turn yields β. The restrictions imposed on the parameter space through Z should reflect the prior knowledge about the unknown parameters. However, such knowledge is not available as the estimated models are scarce, and a variety plausible bound on β may want to be entertained.

However, a vector support symmetrical and centered on zero is considered according with the value ranking that the independent variables may take.

Moreover, as an initial approximation, a covariate matrix was calculated and negative values in β were found. So, *Z=(-z, 0, z)* was considered (*z* >0 which guarantees its symmetry around zero). The same *z* for all coefficients (*z*=0,7) was located. It is pertinent to be very cautious in the interpretation of the estimated $\hat{\beta}$. As $S(\hat{p}_i)$ is reported and $S(\hat{p}_i) \cong 1$ implies $\hat{\beta}_i \cong 0$, a natural criterion for the identification of the information content of a given x_i is just the normalized entropy.

Table 2 shows the estimated weights for the electricity price (*β*) under the reparametrized system. The reported estimated coefficients for the model correspond with the highest *R* obtained. The results are those obtained under the narrowest *V* vector.

Table 2. Estimated Household electricity price model by Maximum entropy econometric approach

Tablica 2. Model procijene cijene električne energije u kućanstvima koristeći ekonometrički pristup maksimalne entropije

Variables/ Varijable	$\hat{\beta}_i$	$S(\hat{p}_i)$
Electricity generated from RES/ Električna energija iz OIE	0.193	0,833
Electricity generated from nuclear/ Električna energija iz nuklearnih elektrana	0.388	0,127
Electricity generated from natural gas/ Električna energija iz prirodnog plina	-0.398	0,021
Electricity generated from petroleum/ Električna energija iz nafte	-0.396	0,048
Electricity generated from hard coal/ Električna energija iz antracita	0.399	0,443
Nº enterprises electricity generation/ Broj poduzeća za proizvodnju električne energije	-0.007	1,000
Nº enterprises distribution and trade of electricity/ Broj poduzeća za distribuciju i trgovanje električnom energijom	0.399	0,014
GDP per capita/ BDP po stanovniku	-0.307	0,537
Energy dependency/ Ovisnost o uvozu energije	0.399	0,014
Petroleum price/ Cijena nafte	0.331	0,113
Support vector for the errors/ Pomoćni vektor za greške *(-v, -v/2, 0, v/2, v)*	*v*=7	
Support space for coefficients/ Pomoćno mjesto za koeficijente *(-z, 0, z)*	*z*=0.7	
Estimated information index/ Procijenjeni indeks informacija	*R*=0.722	

The estimated information index *R*=0.722 indicates a reduction of the uncertainty by using the maximization entropy approach, however, the findings yield that the variable Electricity generated from renewable energies (RES) does not have the sense to explain electricity prices as $S(\hat{p}_i) \cong 1$.

In Spain, the largest part of the electricity generation by RES is devoted to wind power and hydro, so a second model is estimated by using *Electricity generated from wind power* and *Electricity generated from hydroelectricity* as independent variables (both as a percentage of total gross electricity generation). Table 3 shows new estimated weights for the electricity price (*β*).

Table 3. Estimated Household electricity price model by Maximum entropy econometric approach

Tablica 3. Model procijene cijene električne energije u kućanstvima koristeći ekonometrički pristup maksimalne entropije

Variables/ Varijable	$\hat{\beta}_i$	$S(\hat{p}_i)$
Electricity generated from wind/ Električna energija iz vjetra	-0.391	0,095
Electricity generated from hydro/ Električna energija iz hidroelektrana	0.116	0,942
Electricity generated from nuclear/ Električna energija iz nuklearnih elektrana	0.380	0,183
Electricity generated from natural gas/ Električna energija iz prirodnog plina	-0.372	0,234
Electricity generated from petroleum/ Električna energija iz nafte	-0.306	0,540
Electricity generated from hard coal/ Električna energija iz antracita	0.397	0,035
Nº enterprises electricity generation/ Broj poduzeća za proizvodnju električne energije	-0.006	1,000
Nº enterprises distribution and trade of electricity/ Broj poduzeća za distribuciju i trgovanje električnom energijom	0.361	0,298
GDP per capita/ BDP po stanovniku	0.062	0,984
Energy dependency/ Ovisnost o uvozu energije	0.399	0,014
Petroleum price/ Cijena nafte	0.361	0,299
Support vector for the errors/ Pomoćni vektor za greške *(-v, -v/2, 0, v/2, v)*	*v*=7	
Support space for coefficients/ Pomoćno mjesto za koeficijente *(-z, 0, z)*	*z*=0.7	
Estimated information index / Procijenjeni indeks informacija	*R*= 0.58	

The results give additional information about the direction in which the RES affect the electricity prices. *Electricity generated from wind* is a very important variable ($S(\hat{p}_i) = 0.095$) which contributes to reduce electricity prices. Moreover, *when electricity generated from hard coal* increases the electricity prices, these increases could be in part due to the cost of the GHG emissions which have to be paid by hard coal based energy industries.

Energy dependence has also an important effect. Spain has a high dependence (see Table 4) on imported resources such as crude oil and natural gas (100%), therefore electricity prices are linked to such international energy commodities prices and this introduces some risk to energy generation related to volatility of international market prices.

Table 4. Spanish Energy dependence (% of net imports in gross inland consumption)

Tablica 4. Španjolska ovisnost o uvozu energije (% neto uvoza u bruto domaćoj potrošnji)

Year/ Godina	Energy Dependence/ Ovisnost o uvozu energije
1998	74.3
1999	76.57
2000	76.62
2001	74.73
2002	78.46
2003	76.66
2004	77.62
2005	81.47
2006	81.2
2007	79.65
2008	81.27

Regarding the electricity market liberalization variables, the *Number of enterprises dedicated to distribution and trade of electricity* gives information to explain *y* as $S(\hat{p}_i) = 0.298$, nevertheless it has a positive effect on electricity prices. This result does not fulfill the initial expectations as it is generally expected that an increase in the number of enterprises (as is shown in Table 5) increases market competition, thus reducing electricity prices.

Table 5. Number of enterprises dedicated to distribution and trade of electricity in Spain

Tablica 5. Broj poduzeća koja se bave distribucijom i trgovanjem električnom energijom u Španjolskoj

Year/ Godina	Distribution and trade/ Distribucija i trgovanje
2002	96
2003	99
2004	122
2005	107
2006	194
2007	209
2008	392
2006	81.2
2007	79.65
2008	81.27

However, the obtaining of competitive prices depends on the characteristics of the electricity demand as for instance, the nature of consumers to switch from one retail supplier to another. With respect to those characteristics, some objectives of the reforms have not been fully achieved, producing deviation from competitive prices. For example, consumers are averse to change from their traditional retail electricity company as if they were to do so, they would have to face significant switching costs.

4. Main findings and concluding remarks

Spanish electricity market liberalization aims to introduce competition into electricity wholesale generation and supply activities, the unbundling of transmission and distribution activities and retail market competition for all customers. The liberalization of electricity markets in Europe aims to increase competition, thus decreasing electricity prices for the consumers, including households.

However, the real benefits from increasing the competition are an object of debate because the opening up of the market does not necessary imply market efficiency and competitive prices.

Moreover, the electricity generated from renewable energies is physically integrated into the electricity market and can influence electricity prices.

There is a controversial debate about the impact of RES-E on household electricity prices. A higher use of renewable energies could reduce the wholesale electricity prices as they are characterized by lower variable costs than fossil conventional technologies. However, the development of RES-E is mainly driven by public renewable support schemes which are financed via the electricity market by increasing the final price paid by consumers.

This paper explores the impact of the liberalization process in the Spanish electricity market and the impact of RES-E on household electricity prices by applying a General Maximum Entropy Estimation Approach.

The electricity market liberalization is relatively recent, so the related data is limited and when trying to estimate the electricity price models through regression procedures this presents a dimensionality problem.

The General Maximum Entropy Estimation procedure makes it possible to estimate a model with limited information available, which would not be possible with more traditional estimation methods.

Although there are some techniques in trying to extract relevant information from a large number of explained variables such as the subset selection, ridge regression, factor-based methods and the LASSO model [33], the proposed technique allows the use of all the available data without making distributional assumptions.

We would like to point out that there are more estimation methods to solve ill-posed linear inverse problems under the information theory approach. Their objective is to extract all of the available information from the data, but with minimal assumptions on the underlying distribution generating the data. These kinds of methods include the Empirical Likelihood, the Generalized Empirical Likelihood and the Generalized Method of Moments, as well as the Bayesian Method of Moments. Basically, the general maximum entropy estimation approach has several advantages over these methods: Firstly, the maximum estimator has several desirable properties [23]. Secondly, the approach uses all the data points and requires neither restrictive moment nor distributional error assumptions. As no assumptions about the error structure need be made and because it uses all the data, the obtained estimator is more robust and efficient than are the others. Thirdly, the maximum entropy approach performs well in both well-posed and ill-posed (small data sets, underdetermined problems, high levels of collinearity, and so forth) problems. Fourthly, the procedure is easier to implement than the above models, which are often computationally more complex.

Regarding the obtained results, they show that electricity generated from wind contributes to a reduction in electricity prices. Moreover, electricity generated from hard coal increases the electricity prices.

In that sense, as a European Union Emission trading system exists, CO_2 prices have an impact on Spanish electricity prices. Production technologies will tend to incorporate their emission allowance costs in their sale offers in the wholesale electricity market. Therefore, it entails an increase in the marginal costs of the contaminant production technologies (basically those using hard coal) with the consequent expected increase in electricity prices.

Energy dependence also has an important effect on electricity prices in Spain.

Spain is one of the most energy dependent countries of the European Union. This can have important effects on electricity prices as a Marginal Price auction System is used to assess the final wholesale electricity price. In this context, technologies mainly covering the demand are those based on gas and, in demand peaks, fossil production technologies. Therefore, the final Spanish electricity prices are linked to international primary energy prices because gas and petroleum used in electricity generation are wholly imported.

In order to reduce the vulnerability of Spain from high gas dependence in power generation, an increase in the efficiency of gas-fired power plants, energy source diversification and the development of new processes could be appropriate.

The liberalization of the electricity industry, in retail activities, has an estimated positive effect on electricity prices. This result does not fulfill the initial expectations as it is generally expected that an increased in the number of enterprises increases market competition thus reducing electricity prices. However, the obtaining of competitive prices depends on the characteristics of the electricity demand as for instance, the nature of consumers to switch from one retail supplier to another. With respect to those characteristics, some objectives of the reforms have not been fully achieved, producing deviation from competitive prices. For example, consumers are averse to change from their traditional retail electricity company as if they were to do so, they would have to face significant switching costs.

The proposed models can be extended in different directions: Firstly, in our research we have supposed uniform distribution as a priori distribution for our weights. If the possibility of having previous information regarding the probability distribution of the variables that explains the electricity prices is considered instead, it would be possible to undertake the analysis as a problem of minimization of some measure of divergence [34]. Therefore, further research would be necessary taking this in to account.

Secondly, although this analysis has concentrated on Shannon’s maximization entropy, the whole of entropy measures are numerous, thus the extension of this analysis to other measures opens up new research possibilities.

Thirdly, as detailed information about household consumers is available, the study could be extended by considering this information. This empirical analysis presented is concentrated on electricity prices of medium size household consumers (Consumption Band Dc with annual consumption between 2,500 and 5,000 kWh). However, there are in total five different types of households for which electricity prices are collected following different annual consumption bands (see http://epp.eurostat.ec.europa.eu/Eurostat database /environment and energy /energy prices/domestic electricity prices), and therefore the paper can be extended to test if there are different results among consumers.

Finally, some studies consider the ratio of industrial to residential electricity prices as a measure of improvement in the efficiency of relative prices so future research will be developed considering this ratio as a dependent variable.

REFERENCES

[1] EUROPEAN COMMISSION, *Directive 96/92/EC of the European Parliament and of the Council of 19 December 1996 concerning common rules for the internal market in electricity*: 1996, Brussels. Official Journal of the European Union OJ L27 of the 30/1/1997 p. 20 –29: 1997, Brussels.

[2] EUROPEAN COMMISSION, *Directive 2003/54/EC of the European Parliament and of the Council of 26 June 2003 concerning common rules for the internal market in electricity and repealing Directive 96/92/EC.* Official Journal of the European Union OJ L176 of the 15/7/2033 p. 37-56: 2003, Brussels.

[3] SPANISH GOVERNMENT, *Law 54/1997 of the 27 of November concerning rules for the Electricity Sector*. Official Journal of the Spanish Government BOE nº 285 of the 28/11/1997, p. 35097-35126: 1997, Madrid

[4] SPANISH GOVERNMENT, *Law 17/2007 of the 4 of July amending the Law 54/1997, of the 27 of November related to electricity sector to adapt it to Directive 2003/54/CE of the European Parliament and of the Council of 26 June*

2003 concerning common rules for the internal market in electricity. Official Journal of the Spanish Government BOE nº 160 of the 5/7/2007, p. 29047-29067: 2007, Madrid.

[5]PAVKOVIC, B.; ZANKI, V.; ČAČIC, G. *Energy efficiency in building sector in Croatia - Preliminary Energy Studies*, Strojarstvo, Vol. 52, pp. 681-694, 2010.

[6] KARASALIHOVIĆ SEDLAR, D.; HRNČEVIC, L.; DEKANIC, I. *Possibilities for implementation of energy strategy of the republic of Croatia*, Strojarstvo, Vol. 52, pp. 621-629, 2010.

[7] EUROPEAN COMMISSION, *Directive 2001/77/EC of the European Parliament and the Council of 27 September 2001 on the promotion of electricity produced from renewable energy sources in the internal electricity market*. L283/33-40. Official Journal of the European Union OJ L283 of the 17/10/2011 p. 33-40: 2001, Brussels.

[8] EUROPEAN COMMISSION, *Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC*. Official Journal of the European Union OJ L140 of the 5/6/2009 p. 16-62: 2009, Brussels.

[9]LEE C-C.; LEE J-D., *Energy prices, multiple structural breaks, and efficient market hypothesis*, Applied Energy, Vol. 86, pp 466–479, 2009.

[10]HROVATIN, N.; PITTMAN, R.; ZORIĆ, J., *Organisation and reforms of the electricity sector in Slovenia*, Utilities Policy, Vol. 17, pp 134-143, 2009.

[11]POLLITT, M., *Evaluating the evidence on electricity reform: Lessons for the South East Europe (SEE) market*, Utilities Policy, Vol. 17, pp 13-23, 2009.

[12]JENSEN, S.; SKYTTE, K., *Simultaneous attainment of energy goals by means of green certificates and emission permits*, Energy Policy, Vol. 31, pp. 63-71, 2003.

[13]WEIGT, H., *Germany's wind energy: The potential for fossil capacity replacement and cost saving*, Applied Energy, Vol. 86, pp 1857-1863, 2009.

[14]HAAS, R.; RESCH, G.; PANZER, C.; BUSCH, S.; RAGWITZ, M.; HELD, A., *Efficiency and effectiveness of promotion systems for electricity generation from renewable energy sources: Lessons from EU countries*, Energy, Vol. 36, pp 2186-2193, 2011.

[15]KLESSMANN, C.; NABE, C.; BURGES, K., *Pros and cons of exposing renewables to electricity market risks. A comparison of the market integration approaches in Germany, Spain, and the UK*, Energy Policy, Vol. 36, pp 3646-3661, 2008.

[16]SÁENZ DE MIERA, G.; DEL RÍO P.; VIZCAÍNO, I., *Analysing the impact of renewable electricity support schemes on power prices: The case of wind electricity in Spain*, Energy Policy , Vol. 36, pp 3345-3359, 2008.

[17]RATHMANN, M., *Do support systems for RES-E reduce EU-ETS-driven electricity prices?* Energy Policy, Vol. 35, pp 342–349, 2007.

[18]POLLITT, M., *Evaluating the evidence on electricity reform: Lessons for the South East Europe (SEE) market*, Utilities Policy, Vol. 17, pp 13-23, 2009.

[19]GOLAN, A., "*Information and entropy econometrics – Editor´s view*", Journal of Econometrics, vol. 107, 2002, pp. 1-15.

[20]SHANNON, C.E., *A Mathematical Theory of Communication*, Bell System Technology Journal, Vol. 27, pp 379-423, 1948.

[21]JAYNES, E.T., *Information Theory and Statistical Mechanics I*, Physics Review, Vol. 196, pp 620-630, 1957.

[22]JAYNES, E.T., *Information Theory and Statistical Mechanics II*, Physics Review, Vol. 108, pp171-190, 1957.

[23]GOLAN, A.; JUDGE, G.; MILLER, D., *Maximum Entropy Econometrics: robust estimation with limited data*, John Wiley & Sons Ltd: London, 1996.

[24]MAASOUMI,E., *A compendium to information theory in economics and econometrics*, Econometrics Reviews, Vol. 12, pp 137-181, 1993

[25]ULLAH, A., *Uses of entropy and divergence measures for evaluating econometric approximation and inference*, Journal of Econometrics, Vol. 107, pp 313-326, 2002.

[26]MORENO, B.; LÓPEZ, A.J., *Combining economic forecast by using a maximum entropy econometrics approach*, Journal of Forecasting , in press, 2011.

[27]BURNHAM, K.; ANDERTSON, D., *Model selection and multimodel inference*, Springer: New York, 2002.

[28]LEÓN GARCÍA-IZQUIERDO, A.; MORENO, B.; GARCÍA-IZQUIERDO, M., *Applying information theory to small groups assessment: emotions and well-being at work* , The Spanish Journal of Psychology , Vol. 13, pp 309-328, 2010.

[29]GOLAN, A., *A multi-variable stochastic theory size distribution of firms with empirical evidence*, Advances in Econometrics, Vol. 10, pp 1-46, 1994.

[30]SOOFI, E.S., *Capturing the intangible concept of information*, Journal of the American Statistical Association, Vol. 89, pp 1243-1254, 1994.

[31]PUKELSHEIM, F., *The three sigma rule*, The American Statician, Vol. 48, pp 88-91, 1994.

[32]GOLAN, A.; JUDGE, G.; PERLOFF, D., *Estimation and inference with censored and ordered multinomial response data*, Journal of Econometrics, Vol. 79, pp 23-51, 1997.

[33]TIBSHIRANI,R., *Regression shrinkage and selection via the Lasso*, Journal of the Royal Statistical Society, Series B, Vol. 58, pp 267-288, 1996.

[34]KULLBACK, S.; LEIBLER, R. A., On information and sufficiency, Annals of Mathematical Statistics, Vol. 22, pp 79-86, 1951.