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FURIÓ, DOLORES
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A Survey on the Spanish Electricity Intraday Market*

DOLORES FURIÓ
Departamento de Economía Financiera y Actuarial, UNIVERSIDAD DE VALENCIA, ESPAÑA. E-mail: m.dolores.furio@uv.es

ABSTRACT

The Spanish electricity intraday market presents a particular design that makes it unique in Europe. The study is carried out on an hourly basis in order to identify hourly patterns in prices and traded quantities by session. The study evidences an overall growing interest from market participants in intraday trading, particularly in the last-time-negotiated hours. Prices exhibit hourly and daily seasonality as well as mean reversion. Going in depth into the analysis of the current electricity intraday markets is of great relevance nowadays given that there is an open debate concerning the optimal design for intraday markets all over Europe as a consequence of the wholehearted integration of renewables into the power system.

Keywords: Intraday Market, Hourly Prices, Panel Data.

El mercado de electricidad español: El Mercado Intradiario

RESUMEN

El diseño del mercado intradiario de electricidad español no se repite en ningún otro mercado eléctrico europeo. El presente trabajo analiza precios y cantidades negociadas utilizando una frecuencia horaria con el fin de identificar pautas de comportamiento horarios en este mercado. Se evidencia en general un interés creciente por parte de los participantes en el mercado, especialmente en las horas de última posibilidad de negociación. Los precios presentan estacionalidad tanto horaria como diaria así como reversión a la media. La profundización en el análisis de los mercados intradiarios de electricidad existentes es un tema que reviste una gran importancia dado que actualmente existe un debate abierto en relación al diseño óptimo de los mercados intradiarios en Europa como consecuencia de la decidida incorporación de las energías renovables en el sistema eléctrico.

Palabras clave: Mercado Intradiario, precios horarios, datos de panel.

Clasificación JEL: D44, L97, Q48

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1. INTRODUCTION

In contrast to other commodities, electricity is characterized by some specific features that are difficult to deal with such as non-storability, the simultaneousness of electricity production, transmission and consumption, and potential network congestions, among others. All these issues lead to the inconvenience of having to program electricity generation in advance. For this reason, in the electricity liberalized markets, the day-ahead market is commonly referred to as the spot market.

Nevertheless, after the closure of the day-ahead market, participants are able to sell or buy the surplus or deficit electricity in "more real time" *Intraday* and *Balancing* markets[1]. Thus, during intraday trading, participants continue to fine-tune their positions in the light of new information about their own production, consumption and also the overall system position.

Although the design of the day-ahead market is almost identical in the countries or regions where a wholesale pool has been established, the design of the subsequent markets, once the day-ahead market has closed, presents notable disparities between them. The spot (day-ahead) market is normally based on an auction system where electricity market participants bid to sell or buy electricity to be delivered during specific hourly or half-hourly periods of the following day. However, there are a large variety of power market designs that allow for the adjustment of dispatch during the day between European countries.

Traditionally, in most of the European power exchanges, any deviations between demand and supply contracted at the day-ahead market were adjusted by the system operator[2] with energy from the balancing market. In addition, to allow participants to adjust their positions in the day-ahead market to new information, intraday markets have progressively been introduced all over European countries.

In the English and Welsh market, there is no centrally organized market until the gate closure which is an hour ahead of the delivery half hour. Participants submit their final intended production and consumption schedules to the system operator and the Balancing market opens, being a rolling schedule of balancing mechanism opening times. For intraday adjustments, market participants can

[1] Intraday markets allow for adjustments after the day-ahead market closes until gate-closure, a few hours before real time, while Balancing markets are used by the system operator to resolve remaining imbalances.

[2] The management of the liberalized markets is divided into two areas assigned to two different entities: the technical management of the transmission system is entrusted to the system operator, while the market operator is in charge of the economic management of the market. For the Spanish case, the market operator is OMEL (Operador del Mercado Ibérico de Energía-Polo Español, S.A.) and the system operator is REE (Red Eléctrica de España S.A.).

use bilateral trading and power exchanges like the APX Power UK[3] where the intraday market is a continuous market for half-an-hour contracts. The German European Energy Exchange (EEX) operates a continuous trading system where power in the intraday market can be traded until 1.25 hours before delivery. In the Netherlands, from September 2006, market participants have been able to continuously trade power products until two hours prior to delivery at the intraday market operated by APX Power NL. Since February 2011, the APX Power NL[4] intraday market is linked to the Belpex (Belgian Power Exchange) intraday market which is also based on a continuous trading system. The Elbas market is the intraday market of the Nordic power exchange and covers the Nordic countries, Germany and Estonia. It enables continuous trading with contracts that lead to physical delivery for the individual hours that were traded on the Nord Pool Spot market and that are more than one hour from delivery.

On June 2010, APX-ENDEX, Belpex and Nord Pool Spot agreed to create the European Market Coupling Company, a cross-border intraday electricity market based on Nord Pool Spot´s Elbas technology, as a first step towards a common European intraday market for electricity.

In contrast to all these European intraday markets where the trading takes place on a continuous basis, the Spanish electricity intraday market comprises successive auctions in which market participants can trade electricity for individual hours (which have previously contracted on the spot market) that are a decreasing number of hours from delivery. Moreover, in Spain the intraday market was included as a market segment from the very beginning of the market liberalization with the purpose of adjusting previously committed positions (mainly in the day-ahead market).

Previous literature has mainly focused on the Spanish day-ahead market[5] while few studies have recognized the need for considering also the intraday market as a significant issue. Furió and Lucia (2009) include the intraday market into their research to examine empirically how the trading strategies spanning several sections of the Spanish electricity market followed by market participants may have been influenced by regulation. A comparative analysis of the Spanish day-ahead market and the Spanish intraday market is carried out in Furió et al. (2009)).

Although the day-ahead market is much more important than the intraday

[3] APX Power UK (originally the UK´s first independent power exchange, UKPX) was acquired by APX-ENDEX in 2004.

[4] APX Power NL is the current name of the Amsterdam Power Exchange (APX), established in 1999 and the predecessor of APX-ENDEX.

[5] Amjadi et al. (2008), Muñoz and Dickey (2009) or Shafie-Khal et al. (2011) are some of the newly published ones.

market in terms of trade volume, the latter also deserves to be analyzed in-depth in order to gain a better knowledge of the Spanish electricity market as a whole. The reasons are at least twofold. Firstly, participants in the Spanish day-ahead market are shown to follow trading strategies that involves all the sections of the market (Furió and Lucia, 2009). The issue that market participants take into account the outcome of the sequence of markets and not each one in isolation was also addressed by Borenstein et al. (2004) for the Californian market. Secondly, the intraday market is set to become more and more relevant given the progressively increasing level of renewable energy sources into the Spanish generation mix which requires a greater need for regulating power in order to handle their intermittency and limited predictability.

Furthermore, the particular design of the Spanish intraday market cannot currently be found in any other European power market. This fact by itself justifies the thorough examination of its performance, and it may also be very relevant when deciding on the optimal design of the mentioned European common electricity intraday market.

Hence, this study aims to fill the gap in the literature by analyzing hourly price behavior in each of the trading sessions of the Spanish electricity intraday market, as well as assessing the evolution in the amount of energy traded over the last eleven years, namely from January 2000 to December 2010.

The remainder of the paper proceeds as follows. Section 2 briefly talks about the day-ahead market and goes into details of how the intraday market is structured. Section 3 describes the data used in this study. Section 4 analyses the evolution of the overall traded energy in the intraday market over the studied period. In section 5 the interest is centered on hourly prices by trading session and an empirical modeling exercise within a panel framework is carried out. Section 6 concludes with some final remarks.

2. THE SPANISH ELECTRICITY SPOT MARKET

The Spanish electricity spot market is organized as a daily market in which market participants can trade the electricity for delivery during each of the twenty four hours of the day ahead, and an intraday market in which participants can also trade the electricity for delivery in nearer real-time hourly periods. In addition, system technical operation procedures are applied by the System Operator to ensure that electricity is supplied and that production and consumption are continuously balanced. Over-the-counter physical bilateral contracting is also allowed, although bilateral agreements have to be communicated to the market operator so as to facilitate the system technical management.

Supply-side participants in the day-ahead market are essentially the Spanish electricity producers. Most of them are obliged to submit supply bids to the daily market for the amount of available capacity of their production units that has not been previously committed through bilateral trades. Demand-side participants in the daily market include last-resort suppliers[6], retailers, and consumers.

Participants in the day-ahead market can submit their bids until 10:00 a.m. of any day (trading day, *d*) for delivery the subsequent day (operating day, *d*+1). They trade electricity for delivery in each one of the twenty-four hours of the following day, through 24 distinctive uniform-price auctions. The market operator determines the corresponding dispatches and prices according to the market-clearing and marginal-price criteria.

After the closure of the day-ahead market, participants have the opportunity to trade again the electricity with the same hourly delivery periods, in the intraday market[7]. It consists of six (consecutive) trading sessions during which participants can submit sale and purchase bids for delivery of electricity in a given (decreasing) number of hours (as the delivery approaches).

Trading is organized as uniform-price auctions in which the market operator determines the clearing prices (which are referred to as the intraday marginal prices) by matching the hourly supply and demand curves. The hourly distribution of the trading sessions is displayed in Table 1.

Table 1
Hourly distribution of the Intraday Market Sessions

Sessions	1	2	3	4	5	6
Opening	16:00(d)	21:00(d)	01:00(d+1)	04:00(d+1)	08:00(d+1)	12:00(d+1)
Closing	17:45(d)	21:45(d)	01:45(d+1)	04:45(d+1)	08:45(d+1)	12:45(d+1)
Results	18:30(d)	22:30(d)	02:30(d+1)	05:30(d+1)	09:30(d+1)	13:30(d+1)
Schedule Horizon[8]	21-24(d) 1-24(d+1)	1-24 (d+1)	5-24(d+1)	8-24(d+1)	12-24(d+1)	16-24(d+1)

Source: own elaboration.

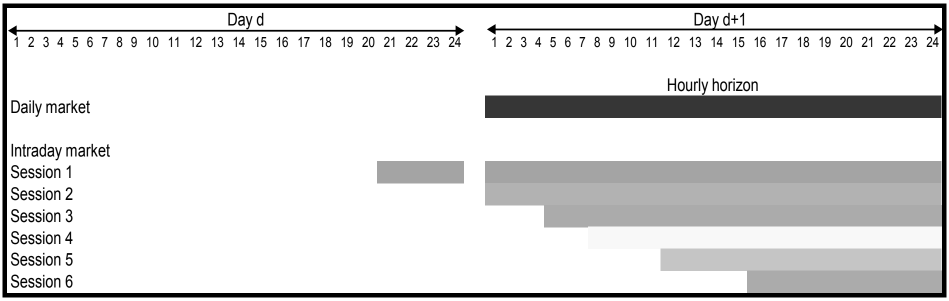
[6] Last-resort suppliers (originally known as distributors) are in charge of delivering the electricity to customers that do not wish to participate in the wholesale market. These customers pay a regulated price (last resort tariff) for electricity.

[7] During the first session (which opens at 4:00pm, day *d*) it is possible to trade electricity for delivery during each of the 24 hours of the following day and during each of the last four hours of day *d*.

[8] The Schedule Horizon is made up of hourly periods. The hour ‘h’ goes from the h-1 ‘hours’ to the h ‘hours’ of the corresponding day. For instance, the hourly period 1 starts one second after the 0 hours and ends at 1:00 a.m. of day d.

Participants can submit their bids for a forty-five minute period in each of the intraday market sessions, with the exception of the first one in which trading is allowed for longer (one hour more). Thus they can present their offers for selling or purchasing electricity with a minimum notice of three and a quarter hours before the delivery takes place. From one session to the next, the schedule horizon covers fewer hours since the horizon limit is given by the hour 24 of day d+1 (last hour traded in the daily market during day d). Note that during the first session of day d (session 1) it is possible to trade electricity for delivery in a total of twenty-eight hours: the last 4 hours of day d and the 24 hours of day d+1. Similarly, a schedule horizon of twenty-four, twenty, seventeen, thirteen and nine hours can be respectively traded in the sessions 2, 3, 4, 5 and 6. Figure 1 jointly shows the day-ahead and the intraday market schedule horizons.

Figure 1
Day-ahead and Intraday Market Schedule Horizons



Source: own elaboration.

In contrast to the day-ahead market, participants are not obliged to bid into the intraday market but can present their offers for buying or selling electricity provided that they had previously participated in the day-ahead market for the corresponding hourly delivery period. Moreover, both supply-side and demand-side units can submit, without differentiation, either supply or purchase bids to the intraday market.

3. DATA

The data set consists of the series of hourly intraday marginal prices and traded energy in each of the six intraday market sessions referred to in the previous section and covers the period from 1/1/2000 to 31/12/2010. In total, 891,996 data are dealt with. These databases are available at the Spanish Market Operator web page (www.omel.es).

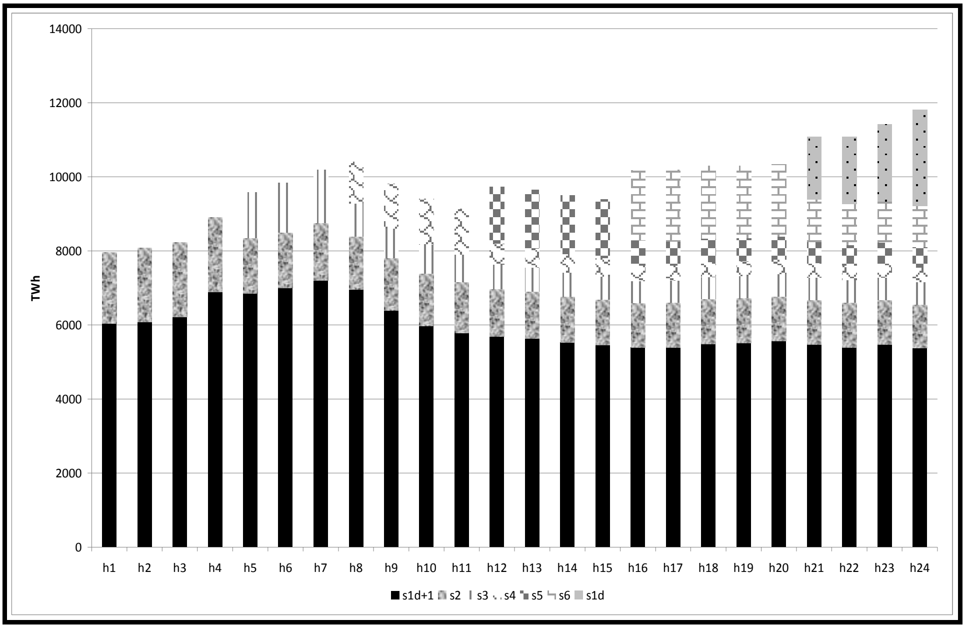
4. TRADED ENERGY IN THE INTRADAY MARKET

Although most Spanish electricity market transactions are carried out in the day-ahead market, there has been increasing interest in the intraday market over the studied sample. Specifically, the total traded energy in the intraday market added up to 11,482 GWh (around 7% of the day-ahead market) in 2000. It reached the amount of 20,503 GWh (12% of the day-ahead market) in 2005, growing to 35,338 GWh (18% of the day-ahead market) in 2010.

It is additionally interesting to examine the traded electricity through each session of the intraday market with the aim of finding out whether the amount of trading is uniformly distributed among them or if, on the contrary, there are sessions on which market participants focus their attention.

From this point on in the present paper and in order to make the reading lighter, the schedule horizon of the first session in the intraday market is divided into two hourly sets according to delivery date. Therefore the notation '1d' will be used when referring to the four hours from 21:00 to 24:00 of day d (the delivery takes place on the same trading day) while session '1d+1' will include the twenty-four hours of the day ahead.

Figure 2
Hourly traded electricity in the intraday market by session (01/01/2000 – 12/31/2010)



Source: own elaboration based on OMEL data.

Figure 2 shows the amount of traded electricity for each hourly period by session. As can be observed, the session 1d+1 stands out from the rest. It can be due to the fact that session 1 would be used by market participants to allocate the dispatch resulted from the day-ahead market (and assigned to their groups) between their different generation units, as stated in the white book of the electric generation regulatory reform in Spain (Pérez, 2005).

From Figure 2, it can also be remarked that, leaving session 1d+1 out of the analysis, the most negotiated hourly horizons within a determined trading session are those that are being traded for the last time. Focusing on the comparison of the average traded electricity for the last-time-negotiated hours with the average traded electricity corresponding to the same delivery hours in previous sessions of the intraday market, it is seen that the former is higher than the latter, indicating that the most representative trading session for each delivery hourly period in the intraday market is the one in which electricity can be negotiated for the last time.

Coming back to the schedule horizons of each session (Table 1 and Figure 1), we can easily identify the corresponding last-time-negotiated delivery hours. So, the first four hours (from hour 1 to hour 4) can be traded for the last time in session 2 of the intraday market, the following three (from hour 5 to hour 7) in session 3, and so on. Further on, we will refer to these delivery hours as the last-time-negotiated hours. In this sense, it is quite reasonable that these hourly sets particularly capture the interest of the market participants, since they will not have further opportunities to trade the electricity again.

Just to conclude this section, two aspects seem to be behind market participants' trading preferences: (i) the possibility of trading electricity for a determined delivery period in subsequent sessions reduces the incentives to participate in intermediate sessions, and (ii) the farther away the delivery moment is, the less interest by market participants in trading the electricity in a specified session.

5. ANALYSIS OF PRICES

In this section, as a first step, an analysis of the correlation of prices in each session is conducted. This preliminary study is followed by an empirical exercise that applies a panel data framework to explore the dynamics of hourly prices in the Spanish intraday market.

5.1. Hourly price correlation

As said, the intraday market comprises 6 trading sessions in which a different number of hourly horizons can be negotiated. A color code is used to help the reader to identify the different correlation degree among hours within a session. Table 2 shows the relationship between the correlation levels and colors.

Table 2
Colors and correlations

Correlation value (ρ)	Color
90% ≤ ρ ≤ 100%	
80% ≤ ρ < 90%	
60% ≤ ρ < 80%	
0% ≤ ρ < 60%	

Tables 3-9 report the correlation values between hourly prices by session. As well, different correlation areas have been marked. Firstly, correlation values between hours from 1 to 8 and 23 to 24 have been framed with dotted lines while hours from 9 to 22 have been framed with thick line. The resulting correlation areas can be considered as a proxy for the correlation between off-peak hours and peak hours[9]. It is just a proxy because there is no distinction between holidays or weekends and business days. In fact, hours 23, 24 and from 1 to 8 are always off-peak hours but hours from 9 to 22 will be peak or off-peak hours depending on whether it is a business or non-business day.

Coming back to Tables 3-9, it can be observed that peak (off-peak) hours within a session are in general more correlated with peak (off-peak) hours, though all the correlation values are higher than 40%. The greatest correlations are those between adjacent hours and between the central hours of the day. As seen, there is evidence for a correlation pattern between hours.

Table 3
Price correlation in session 1d (hours 21-24 of the day d)

	21	22	23	24
21	100%			
22	90%	100%		
23	84%	89%	100%	
24	83%	85%	91%	100%

Source: own elaboration based on OMEL data.

[9] Peak (off-peak) hours are hours with high (low) demand for electricity. In Spain, hours from 9 to 22 of business days are considered peak hours while the rest of the hours of business days as well as the 24 hours of weekends and holidays are considered off peak hours.

Table 4
Price correlation in session 1d+1 (hours 1-24 of the day d+1)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	100%																							
2	90%	100%																						
3	87%	94%	100%																					
4	86%	91%	96%	100%																				
5	82%	89%	93%	96%	100%																			
6	81%	88%	92%	95%	97%	100%																		
7	78%	82%	85%	87%	88%	92%	100%																	
8	67%	65%	66%	69%	69%	75%	88%	100%																
9	55%	51%	52%	55%	54%	61%	77%	91%	100%															
10	53%	47%	47%	50%	49%	56%	72%	86%	94%	100%														
11	56%	50%	50%	52%	51%	57%	71%	82%	88%	95%	100%													
12	63%	57%	56%	57%	55%	61%	72%	80%	84%	90%	95%	100%												
13	64%	59%	59%	60%	58%	63%	73%	78%	80%	86%	92%	97%	100%											
14	69%	66%	67%	67%	66%	70%	77%	78%	78%	83%	88%	94%	96%	100%										
15	75%	74%	76%	76%	75%	78%	81%	78%	74%	77%	81%	87%	90%	95%	100%									
16	73%	73%	74%	76%	75%	78%	82%	80%	76%	78%	81%	85%	90%	93%	98%	100%								
17	70%	71%	73%	74%	73%	76%	80%	79%	75%	77%	80%	84%	88%	92%	96%	98%	100%							
18	68%	67%	69%	70%	69%	72%	78%	79%	78%	80%	83%	86%	90%	92%	94%	96%	98%	100%						
19	66%	62%	63%	62%	61%	65%	73%	77%	79%	83%	85%	88%	88%	90%	88%	89%	89%	93%	100%					
20	64%	58%	58%	57%	55%	59%	68%	73%	77%	81%	83%	85%	84%	84%	81%	81%	81%	85%	94%	100%				
21	66%	60%	59%	59%	56%	60%	69%	75%	75%	78%	81%	83%	83%	82%	79%	79%	78%	82%	88%	93%	100%			
22	69%	63%	63%	62%	60%	63%	70%	71%	70%	73%	77%	81%	82%	83%	81%	79%	78%	81%	84%	86%	92%	100%		
23	80%	75%	76%	75%	73%	74%	75%	69%	63%	65%	70%	76%	78%	82%	86%	84%	82%	82%	80%	78%	82%	88%	100%	
24	87%	81%	81%	81%	78%	78%	75%	64%	56%	56%	60%	67%	70%	75%	80%	79%	77%	75%	74%	74%	75%	78%	91%	100%

Source: own elaboration based on OMEL data.

Table 5
Price correlation in session 2

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	100%																							
2	91%	100%																						
3	87%	95%	100%																					
4	86%	92%	96%	100%																				
5	82%	88%	92%	94%	100%																			
6	81%	87%	91%	92%	96%	100%																		
7	79%	83%	85%	86%	87%	92%	100%																	
8	66%	67%	69%	69%	71%	77%	88%	100%																
9	57%	55%	56%	56%	57%	63%	77%	89%	100%															
10	55%	52%	53%	52%	53%	59%	74%	85%	93%	100%														
11	59%	54%	55%	55%	55%	60%	73%	81%	87%	93%	100%													
12	63%	58%	58%	58%	58%	63%	73%	78%	82%	88%	95%	100%												
13	64%	60%	60%	61%	61%	65%	73%	77%	79%	85%	91%	95%	100%											
14	69%	67%	68%	68%	68%	71%	77%	77%	77%	82%	88%	92%	96%	100%										
15	75%	75%	76%	76%	76%	78%	80%	77%	73%	76%	81%	85%	89%	94%	100%									
16	73%	74%	75%	75%	75%	77%	80%	77%	75%	77%	80%	84%	88%	92%	97%	100%								
17	71%	73%	74%	74%	74%	76%	79%	78%	75%	77%	79%	83%	87%	91%	95%	97%	100%							
18	68%	69%	70%	70%	70%	73%	77%	77%	76%	79%	81%	85%	88%	91%	93%	95%	96%	100%						
19	66%	63%	64%	63%	63%	66%	73%	76%	78%	81%	84%	86%	87%	88%	87%	89%	90%	93%	100%					
20	65%	60%	60%	59%	58%	61%	69%	74%	78%	80%	83%	84%	84%	83%	81%	83%	82%	85%	93%	100%				
21	66%	61%	61%	60%	59%	62%	69%	74%	75%	77%	80%	82%	81%	81%	79%	79%	80%	82%	87%	92%	100%			
22	68%	64%	64%	63%	62%	65%	70%	72%	71%	73%	77%	80%	81%	82%	80%	80%	79%	80%	82%	85%	91%	100%		
23	79%	76%	76%	75%	73%	75%	75%	69%	64%	67%	71%	75%	77%	82%	85%	83%	82%	81%	79%	78%	81%	87%	100%	
24	86%	84%	82%	81%	78%	78%	75%	65%	59%	58%	62%	67%	70%	74%	80%	79%	78%	75%	74%	74%	75%	78%	90%	100%

Source: own elaboration based on OMEL data.

Table 6
Price correlation in session 3

	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
5	100%																			
6	96%	100%																		
7	91%	94%	100%																	
8	80%	82%	89%	100%																
9	44%	47%	59%	75%	100%															
10	39%	41%	54%	69%	91%	100%														
11	43%	43%	54%	67%	86%	91%	100%													
12	50%	49%	58%	69%	81%	86%	92%	100%												
13	54%	52%	61%	70%	77%	82%	89%	94%	100%											
14	60%	59%	66%	73%	75%	79%	86%	91%	94%	100%										
15	70%	70%	75%	78%	73%	74%	79%	84%	88%	93%	100%									
16	70%	70%	76%	79%	73%	74%	79%	83%	87%	91%	96%	100%								
17	69%	70%	75%	79%	73%	73%	78%	82%	86%	90%	94%	97%	100%							
18	65%	66%	72%	78%	75%	76%	80%	83%	87%	90%	92%	95%	96%	100%						
19	56%	57%	65%	73%	76%	78%	82%	84%	86%	87%	87%	88%	89%	92%	100%					
20	51%	51%	59%	68%	76%	79%	82%	83%	83%	82%	81%	81%	81%	84%	90%	100%				
21	52%	52%	60%	68%	74%	76%	79%	81%	81%	80%	79%	79%	79%	80%	85%	91%	100%			
22	55%	54%	61%	68%	69%	72%	75%	79%	80%	80%	79%	78%	78%	79%	82%	83%	89%	100%		
23	70%	69%	72%	74%	64%	65%	70%	75%	78%	80%	84%	83%	81%	81%	79%	78%	81%	86%	100%	
24	80%	77%	78%	77%	58%	56%	61%	67%	70%	73%	79%	78%	77%	75%	73%	72%	74%	76%	89%	100%

Source: own elaboration based on OMEL data.

Table 7
Price correlation in session 4

	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
8	100%																
9	90%	100%															
10	81%	91%	100%														
11	70%	81%	91%	100%													
12	59%	66%	75%	80%	100%												
13	61%	66%	73%	77%	90%	100%											
14	65%	70%	76%	78%	86%	89%	100%										
15	72%	74%	76%	74%	78%	83%	89%	100%									
16	72%	74%	75%	72%	74%	78%	84%	89%	100%								
17	71%	73%	74%	70%	72%	75%	81%	85%	92%	100%							
18	68%	72%	75%	73%	75%	78%	83%	84%	90%	91%	100%						
19	60%	67%	72%	72%	73%	75%	76%	77%	80%	81%	86%	100%					
20	54%	61%	66%	67%	70%	70%	70%	68%	72%	73%	75%	84%	100%				
21	54%	60%	65%	65%	68%	68%	67%	67%	69%	70%	72%	78%	85%	100%			
22	56%	59%	63%	63%	67%	67%	68%	68%	70%	71%	71%	75%	78%	84%	100%		
23	67%	65%	65%	62%	61%	64%	67%	70%	72%	73%	72%	69%	71%	74%	78%	100%	
24	74%	70%	65%	59%	57%	60%	62%	70%	71%	71%	68%	65%	65%	66%	70%	81%	100%

Source: own elaboration based on OMEL data.

Table 8
Price correlation in session 5

	12	13	14	15	16	17	18	19	20	21	22	23	24
12	100%												
13	93%	100%											
14	88%	92%	100%										
15	87%	89%	92%	100%									
16	83%	83%	83%	85%	100%								
17	81%	82%	82%	83%	97%	100%							
18	83%	84%	84%	84%	95%	96%	100%						
19	81%	81%	82%	81%	89%	89%	92%	100%					
20	79%	78%	78%	77%	83%	83%	86%	93%	100%				
21	74%	73%	73%	72%	78%	77%	80%	84%	90%	100%			
22	74%	73%	73%	73%	78%	77%	79%	81%	85%	90%	100%		
23	75%	73%	72%	74%	81%	79%	78%	77%	78%	80%	87%	100%	
24	73%	68%	65%	67%	76%	75%	72%	71%	72%	73%	76%	90%	100%

Source: own elaboration based on OMEL data.

Table 9
Price correlation in session 6

	16	17	18	19	20	21	22	23	24
16	100%								
17	96%	100%							
18	93%	95%	100%						
19	87%	87%	92%	100%					
20	79%	78%	83%	91%	100%				
21	74%	74%	77%	82%	89%	100%			
22	76%	75%	77%	79%	83%	91%	100%		
23	82%	79%	79%	77%	77%	82%	88%	100%	
24	80%	77%	73%	72%	72%	75%	78%	90%	100%

Source: own elaboration based on OMEL data.

5.2. Modeling prices using panel data

Most of the studies devoted to analyzing the dynamics of electricity prices focus on daily prices obtained as the mean of hourly prices. They are undoubtedly of great importance since these prices are commonly the reference price for derivatives contracts. Some examples are Cancelo and Espasa (1996), Lucia and Schwartz (2002), Nogales et al. (2002), Escribano, Peña and Villaplana (2002), Karakatsani and Bunn (2008), Amjady and Keynia (2008) and Cartea and Villaplana (2008), among many others.

In this paper, however, the focus is on hourly prices. In fact, in each intraday market session what we have got is a number of different (hourly) auctions. Hence, working with hourly prices (instead of lower frequency prices) allows us to gain greater insight into the performance of the market. There are not many studies in the literature that deal with hourly prices. Among these are Borenstein et al. (2001), Saravia (2003), Longstaff and Wang (2004), Karakatsani and

Bunn (2005), Huisman et al. (2007) and Norouzzadeh and Rahmani (2007).

Through the intraday market's auctions, as previously discussed, participants submit their bids and offers for delivery of electricity in a number of individual hourly horizons up to a certain market closing time. Therefore, the information set used for setting the price in all these hours is the same and, consequently, hourly prices can be seen as individuals of a panel framework. This is the approach of Huisman et al. (2007) who focus on the analysis of hourly electricity prices in the Dutch APX, German EEX and French PPX day-ahead markets. Following Huisman et al. (2007), this paper models hourly power prices in a panel framework. Accordingly, hours are seen as cross-sectional individuals whose prices vary from day to day. This approach is suited to auction-based markets where prices for different hours are quoted at the same moment on a day.

Electricity price can be approximated as the sum of a deterministic component and a stochastic component (Lucia and Schwartz, 2002), as follows:

$$p_{ht} = d_{ht} + s_{ht} \tag{1}$$

The deterministic component consists of predictable regularities like mean price levels and seasonality, while the stochastic component accounts for the variation around the deterministic component. In this paper, the deterministic component is the mean price level of each hour, μ_h, for h=1,…,24 as well as different price levels for the different days of the week (D_w is a dummy variable that equals 1 if the delivery day (d+1) is a weekday w (w=1 corresponds with Saturday, w=2 corresponds to Sunday and so on, until w=7 corresponds to Friday though α_7 is forced to be 0 to avoid multicollinearity problems). Also included is the amount of electricity traded in the intraday market for each particular hour, E_h, h=1,…,24.

The stochastic component is a mean reverting process. Equation (2) presents the model expressed in discrete form. κ_h is the rate of mean-reversion for hour h and reflects the speed with which the price moves back to its long-run equilibrium price. The error term, ε_{ht}, is assumed to be independent over the days but it allows for cross-sectional covariance between the hours.

$$\begin{aligned} p_{ht} &= \mu_h + \sum_w \alpha_w \cdot D_{wt} + \phi_h \cdot E_{ht} + s_{ht} \\ s_{ht} &= (1-\kappa_h) \cdot s_{t-1} + \varepsilon_{ht} \end{aligned} \tag{2}$$

The parameters in the model are simultaneously estimated using the least square method and setting a covariance structure that allows for both cross-sectionally heteroskedastic and contemporaneous correlated residuals. This fact is of great relevance here since when a market participant submits her offer for buying or selling electricity to the market, she is bidding for a number of hours at the same time and hence there is identical information supporting the submitted bids.

Estimation results are displayed in Table 10. The estimates for μ_1 through μ_{24} allow us to learn from the differences in prices among hours. It should be remembered that the dummy weekday variable associated with Friday has been left out of the model specification to avoid multicollinearity problems. Therefore, the estimated hourly mean values are prices for Friday. The estimates of the weekday dummy variables are helpful for obtaining the estimated hourly mean prices for the rest of days of the week in each case. In general, mean prices for Monday, α_3, and Tuesday, α_4, are usually similar to those for Friday, whereas mean prices for Wednesday, α_5, and Thursday, α_6, (Saturday, α_1, and Sunday, α_2) tend to be higher (lower). In overall terms, the hourly variations in price are apparent given the lower mean prices for most of the night hours (2am to 7am). It should also be noted that the price for the last-time-negotiated hours tends to be higher than the same hourly period traded in previously sessions. In fact, this is so for 17 out of 24 hours. This result is perfectly consistent with the market participants' willingness to pay higher prices for the electricity when it is their last chance to buy it.

The estimates for the traded energy parameters, φ_h for h=1 to 24, indicate that there is a positive relationship between traded energy and price in most of the hourly periods traded in the intraday market´s sessions. However, there are a few cases in which this relationship appears to be negative. This may seem a surprising result but perhaps it is not, considering the fact that the price results from an auction based on the marginal price criteria, and the different technologies used to generate electricity are generally stacked in order of increasing production variable costs. Thus, the greater the availability of the least expensive technologies to cover demand, the lower the need for higher production variable cost units to be dispatched and, in the absence of market power, the lower the price. Therefore, high levels of demand may hardly have any effect on price if they coexist with sufficient supply to cover demand. Moreover, the intraday market is essentially a market for adjustments and, consequently, the amount of electricity traded for a given hourly period in a particular session can be quite modest.

The estimates for the mean reversion parameters κ_h, though very small, turn out to be significant in all cases. They do not show clear differences between the peak and the off-peak hours. In contrast, except for the sessions 5 and 6, the last-time-negotiated hours exhibit less mean-reversion than the rest of the hours traded in the same session. This is a logical result since it makes sense that market participants would adopt more aggressive bidding strategies in order to rectify their previous positions when knowing that it is the last time they can do it. The conclusion is that the prices for these last-time-negotiated hours are less predictable.

Table 10

Estimation results of the Equation (2) for each of the sessions of the intraday market

*Estimated parameters have been separated into sections. Section A shows the estimates for the hourly mean price levels; Section B presents estimates for the weekly dummies (from μ_1, Saturday, to μ_6, Thursday); Section C displays estimates for the parameters associated with traded energy: Section D reports the estimates for the mean reversion parameters and, finally, Section E provides the adjusted R^2 and the Log-likelihood as good-fitness measures. *(**, ***) denote statistical significance at the 1% (5%, 10%) level.*

A: Estimates for the hourly mean price levels							
	Ses. 1d1	**Ses. 2**	**Ses. 3**	**Ses. 4**	**Ses. 5**	**Ses. 6**	**Ses. 1d**
μ_1	39.67*	42.42*					
μ_2	36.80*	36.42*					
μ_3	34.88*	33.46*					
μ_4	32.54*	30.84*					
μ_5	32.03*	29.40*	32.67*				
μ_6	31.11*	28.77*	33.11*				
μ_7	31.86*	30.02*	33.70*				
μ_8	32.36*	31.75*	35.32*	37.53*			
μ_9	35.20*	33.99*	33.90*	39.70*			
μ_{10}	38.22*	37.32*	36.74*	40.63*			
μ_{11}	40.33*	40.08*	39.70*	41.87*			
μ_{12}	41.40*	41.65*	41.88*	42.63*	43.72*		
μ_{13}	42.33*	43.07*	43.20*	43.58*	44.07*		
μ_{14}	42.64*	42.66*	43.05*	43.69*	42.32*		
μ_{15}	41.92*	41.77*	41.75*	42.31*	39.41*		
μ_{16}	41.38*	41.21*	42.12*	42.67*	42.02*	40.77*	
μ_{17}	40.98*	41.45*	42.58*	42.39*	42.13*	41.08*	
μ_{18}	41.19*	42.22*	42.93*	43.03*	42.62*	40.68*	
μ_{19}	42.36*	42.83*	43.02*	42.70*	43.20*	41.17*	
μ_{20}	43.16*	43.08*	43.32*	42.62*	43.93*	42.11*	
μ_{21}	44.37*	43.45*	43.18*	43.76*	44.25*	43.12*	46.67*
μ_{22}	46.40*	44.75*	45.18*	45.10*	45.47*	44.98*	47.21*
μ_{23}	45.22*	43.09*	43.17*	44.18*	43.94*	43.20*	43.21*
μ_{24}	42.04*	40.71*	41.44*	42.35*	42.36*	40.72*	39.00*
B: Estimates for the weekday dummies							
	Ses. 1d1	**Ses. 2**	**Ses. 3**	**Ses. 4**	**Ses. 5**	**Ses. 6**	**Ses. 1d**
α_1	-3.25*	-2.90*	-4.17*	-5.09*	-4.15*	-3.45*	0.21
α_2	-6.60*	-6.56*	-7.64*	-9.99*	-8.06*	-5.78*	0.65
α_3	0.16	-0.22	0.19	0.26	0.68	1.02***	0.95
α_4	0.27	0.10	0.62	0.09	0.81	1.14**	1.02***
α_5	0.57***	0.57***	0.89**	0.63	1.32*	1.69*	0.98***
α_6	0.59**	0.48***	0.87*	0.57	0.65***	0.80**	0.80***

Table 10 (continuation)

Estimation results of the Equation (2) for each of the sessions of the intraday market

C: Estimates for the traded energy parameters							
	Ses. 1d1	**Ses. 2**	**Ses. 3**	**Ses. 4**	**Ses. 5**	**Ses. 6**	**Ses. 1d**
φ_1	0.00070**	-0.001*					
φ_2	0.00043	0.003*					
φ_3	-0.00033	0.003*					
φ_4	-0.00038***	0.003*					
φ_5	-0.00068*	0.002*	0.003*				
φ_6	-0.00076*	0.002*	0.002*				
φ_7	-0.00056*	0.002*	0.002*				
φ_8	0.00037*	0.002*	0.003*	0.005*			
φ_9	0.00006	0.002*	0.005*	0.006*			
φ_{10}	0.00010	0.003*	0.005*	0.008*			
φ_{11}	0.00104*	0.003*	0.008*	0.008*			
φ_{12}	0.00176*	0.004*	0.009*	0.009*	0.007*		
φ_{13}	0.00207*	0.005*	0.009*	0.009*	0.007*		
φ_{14}	0.00165*	0.004*	0.008*	0.009*	0.006*		
φ_{15}	0.00122*	0.004*	0.007*	0.009*	0.005*		
φ_{16}	0.00148*	0.005*	0.005*	0.006*	0.008*	0.006*	
φ_{17}	0.00183*	0.005*	0.005*	0.006*	0.008*	0.005*	
φ_{18}	0.00218*	0.003*	0.005*	0.007*	0.007*	0.005*	
φ_{19}	0.00175*	0.003*	0.005*	0.007*	0.007*	0.005*	
φ_{20}	0.00168*	0.004*	0.008*	0.007*	0.007*	0.006*	
φ_{21}	0.00086*	0.003*	0.008*	0.004***	0.006*	0.006*	-0.00193*
φ_{22}	0.00021	0.003*	0.004*	0.005*	0.004*	0.004*	-0.00134***
φ_{23}	-0.00038	0.003*	0.005*	0.002	0.003*	0.003*	-0.00038
φ_{24}	0.00004	0.003*	0.005*	-0.001	0.004*	0.003*	-0.00101
D: Estimates for the mean reversion parameters							
	Ses. 1d1	**Ses. 2**	**Ses. 3**	**Ses. 4**	**Ses. 5**	**Ses. 6**	**Ses. 1d**
κ_1	0.18*	0.17*					
κ_2	0.17*	0.15*					
κ_3	0.14*	0.14*					
κ_4	0.12*	0.14*					
κ_5	0.12*	0.15*	0.13*				
κ_6	0.13*	0.16*	0.12*				
κ_7	0.13*	0.17*	0.15*				
κ_8	0.21*	0.24*	0.19*	0.18*			
κ_9	0.25*	0.27*	0.31*	0.23*			
κ_{10}	0.23*	0.25*	0.30*	0.25*			
κ_{11}	0.19*	0.24*	0.27*	0.25*			
κ_{12}	0.18*	0.23*	0.26*	0.32*	0.26*		
κ_{13}	0.18*	0.22*	0.26*	0.34*	0.26*		
κ_{14}	0.15*	0.19*	0.23*	0.31*	0.27*		
κ_{15}	0.12*	0.16*	0.19*	0.27*	0.26*		
κ_{16}	0.14*	0.18*	0.21*	0.26*	0.20*	0.20*	
κ_{17}	0.15*	0.18*	0.22*	0.29*	0.22*	0.21*	
κ_{18}	0.17*	0.20*	0.24*	0.30*	0.23*	0.25*	
κ_{19}	0.16*	0.21*	0.27*	0.33*	0.24*	0.24*	
κ_{20}	0.17*	0.22*	0.26*	0.35*	0.25*	0.23*	
κ_{21}	0.15*	0.19*	0.26*	0.34*	0.26*	0.21*	0.24*
κ_{22}	0.15*	0.21*	0.27*	0.37*	0.26*	0.22*	0.24*
κ_{23}	0.16*	0.18*	0.24*	0.34*	0.22*	0.20*	0.23*
κ_{24}	0.12*	0.15*	0.19*	0.28*	0.18*	0.18*	0.22*

Table 10 (continuation)
Estimation results of the Equation (2) for each of the sessions of the intraday market

E: Goodness-of-fit measures							
	Ses. 1d1	**Ses. 2**	**Ses. 3**	**Ses. 4**	**Ses. 5**	**Ses. 6**	**Ses. 1d**
Ad. R^2	74%	69%	63%	52%	59%	63%	61%
Log-lk	-349166	-352082	-288242	-236731	-188640	-138110	-61828

6. CONCLUDING REMARKS

The present study covers the analysis of the Spanish electricity intraday market, focusing both on prices and on the evolution of the registered electricity traded through their six trading sessions from January 2000 to December 2010.

The Spanish intraday market allows market participants, after the closure of the day-ahead market, to trade the electricity again a number of times, ranging from two to seven times, depending on the delivery hour. Given that the prices for all the hourly periods traded in a particular trading session are quoted at the same moment on a day, a panel framework has been used to model the dynamics of prices at an hourly level, following the approach by Huisman et al. (2007).

Estimation results allow us to learn from the differences in prices among hours. Thus, peak hours exhibit higher mean price values than off-peak hours. Daily seasonality is also apparent as a consequence of the lower demand during weekends. Moreover, the price for the last-time-negotiated hours tends to be higher than the same hourly period traded in previously sessions. As discussed, this is perfectly consistent with the market participants' willingness to pay higher prices for the electricity when it is their last chance to buy it. Additionally, a positive relationship between traded energy and price has been found in most of the hourly periods traded in the intraday market´s sessions. Another interesting insight is that the mean reversion parameters, though very small, turn out to be significant in all cases. It is also found that, except for the sessions 5 and 6, the last-time-negotiated hours exhibit less mean-reversion than the rest of hours traded in the same session.

Apart from anything else, as a consequence of the 20% renewable target articulated in the European Renewables Directive of 2008, the ratio of renewable energy sources is progressively increasing with the declared EU Member States governments' support. These new sources are intermittent, which involves a higher need for regulating and reserve power to handle their variability and limited predictability. Therefore, to successfully include these new sources into the system, greater deals of flexibility in the design of intraday (and balancing) markets are claimed.

As previously discussed, many European liberalized electricity markets have relatively recently included continuous-trading-based intraday markets into their respective designs. But the issue of the best design of the intraday market still remains as an open debate. As well, there is the issue of the European common electricity market that will imply that efforts to unify or at least make compatible different market designs should be made.

The intraday market was part of the design of the Spanish electricity spot market from the very beginning. Moreover, its features such as the way it is structured (six consecutive trading sessions) and the trading system it is based on (an auction) make it unique in Europe. This study has shown a growing trend in the amount of traded electricity through this market over the studied period, moving from 11,482 GWh (around 7% of the day-ahead market) in 2000 to 35,338 GWh (18%) in 2010. This spectacular increase can be explained at least partially by the no-less spectacular rise in renewables production which has reached 95,034 GWh in 2010 (339% higher than in 2007).

Whether the Spanish intraday market is flexible enough or whether its design may get improved to cope with the above-mentioned new challenges is left for further research.

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