Energy Economics 51 (2015) 157–165

Contents lists available at ScienceDirect

Energy Economics

journal homepage: www.elsevier.com/locate/eneco

Retail price effects of feed-in tariff regulation

Maria Teresa Costa-Campi [a], Elisa Trujillo-Baute [b,*]

[a] University of Barcelona & Barcelona Institute of Economics, Chair of Energy Sustainability
[b] University of Warwick & Barcelona Institute of Economics, Chair of Energy Sustainability

ARTICLE INFO

Article history:
Received 22 November 2014
Received in revised form 6 June 2015
Accepted 10 June 2015
Available online 19 June 2015

JEL classification:
L11
Q41
C24

Keywords:
Electricity prices
Feed-in-tariff
Retail market
Wholesale market

ABSTRACT

The feed-in tariff regulation is the widest spread instrument used to promote electricity generation from renewable energy sources in the EU, with the costs of resources devoted to this promotion usually being borne by final consumers. Two components of the electricity retail price are expected to be influenced by the feed-in tariff regulation: the incentive to those firms producing electricity from renewable energy sources and the wholesale price of electricity. In this study we analyze the effects that the feed-in tariff regulation has on the electricity retail price for industrial consumers. We estimate the relative intensity of the impact of the cost of support electricity generation under the feed-in tariff and the electricity wholesale price on the Spanish industrial retail price. Special attention is devoted to technology-specific considerations, as well as short and long run effects. The results show that there is not a strong link between the retail and wholesale market for Spanish industrial consumers. Moreover, the results indicate that an increase of solar generation leads to a higher increase in the industrial retail price than in the case of a proportional increase of wind generation. This suggests that, when evaluating the feed-in tariff regulation impact on the retail price, the cost of incentives effect prevails over the wholesale price effect, and this is stronger for solar than for wind generation.

1. Introduction

Within the European Union (EU) 2020 energy strategy, the Third Energy Package aimed to complete the liberalization process, and the Climate and Energy Package implemented the targets for 2020 (known as the "20-20-20" targets). One of the targets was to increase the share of EU energy consumption produced from renewable resources to 20% (Directive (2009/28/EC). The EU member states embraced this target promoting the production of electricity from renewable energy sources (RES-E), and the feed-in tariff (FIT) regulation is the wider spread promotion scheme used to encourage the take-up and development of generation from RES. Basically, under the FIT regulation, a specific remuneration level is guaranteed for electricity produced by generators of the targeted technologies to cover its long-term marginal costs and the access to grid is guaranteed through a dispatch priority for the generated RES-E.[1]

In most EU countries, the costs of resources devoted to promote the production of RES-E are borne by final consumers. The recent economic recession has raised the concerns of European governments, industry and consumers alike, worried by high energy prices. Some blame is attributed to climate policies in general and to FIT in particular. In Spain, around 8 Bn Euros a year, on average, have been devoted to promote RES-E production during the last four years. This amount of resources represents around 12% of the industry GDP. Electricity is a highly relevant economic factor and, thus, policy and regulatory decisions affecting its price should be deeply analyzed given the direct effect that energy prices have on the firms' production costs and, hence, on welfare. However, there is no empirical assessment of the actual impact that this scheme has on final consumer (retail) prices.

Two components of the electricity retail price are expected to be influenced by FIT regulation; the incentive to those firms producing RES-E and the wholesale price of electricity. On the one hand, from the characteristics of the electricity wholesale price (WP) formation (merit order) and the low marginal cost of renewable energy generation, the introduction of RES-E in the energy mix is expected to exert a downward pressure on the WP. This effect is represented on the *Wholesale Market* graph in Fig. 1. On the other hand, given the regulatory design of the incentive mechanisms, the FIT costs (FITC) are charged to the final electricity consumers. Hence, acting over the electricity retail price in opposite directions (see *Retail Market* graph in Fig. 1), both components are functions of the proportion of renewable sources in the energy mix but they have opposing influence on the retail price. However, the net effect cannot be predicted beforehand, and represents an empirical issue. Therefore, the aim of this paper is to analyze the relative intensity that these two components have on electricity retail prices.

With the exceptions of Finland and the Netherlands where the FITC are completely financed by general taxes, the costs of RES-E promotion

* Corresponding author at: Economic Modelling Forecasting Group, Warwick Business School, The University of Warwick, Coventry CV4 7AL, UK.
E-mail address: elisamtrujillob@gmail.com (E. Trujillo-Baute).

[1] For a detailed review of several feed-in tariff schemes see Couture and Gagnon (2010).

http://dx.doi.org/10.1016/j.eneco.2015.06.002

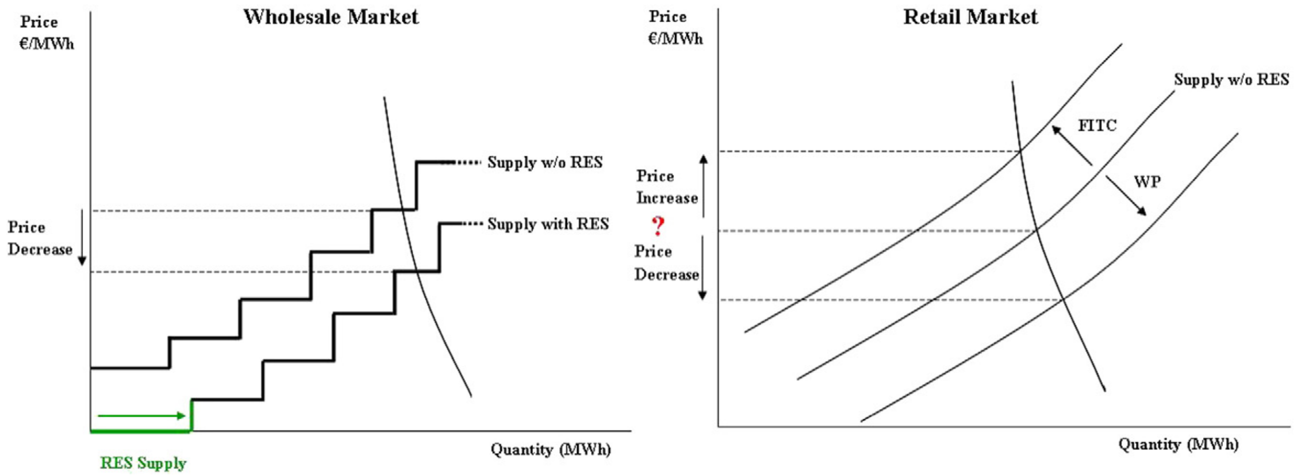

Fig. 1. FIT regulation effects.

in the EU member states are borne by final electricity consumers. Depending on the regulatory design, the FITC can be transferred into the electricity prices through two different channels; non-tax levies and pass down to end users of suppliers costs (CEER, 2013).[2] In both cases the FITC are transferred to the retail price after the wholesale price is set. Hence, the most common regulatory design is that in which the FITC are borne by end the consumer without having any impact on the wholesale price market formation mechanism.

In order to stimulate the development of certain technologies, the FIT guarantees generators of the targeted technologies a specific price per electricity produced. In Spain the FIT is granted to generation from RES and cogeneration plants with an installed capacity below 50 MW (the so-called Special Regime (SR)). The support is technology-specific granted and takes into account the fact that different technologies are at different levels of development and have different generation costs. Fig. 2 shows the yearly average FITC (in €/MWh) in Spain by technology over the last four years. While solar technology received an average of 375 €/MWh produced, the support level for wind and small hydro was, on average, 83 €/MWh, whereas for cogeneration (COG) and other renewable energy sources the average FITC was 110 €/MWh.

It should be stressed that wind and solar technologies make different contributions to the electricity system during the day, and that day times are characterized by different demand profiles. While the contribution of wind power is, in relative terms, higher during off-peak hours, the opposite is the case of solar power which is generated during daylight hours (peak hours). Moreover, the technologies within the FIT scheme provided different contributions to the energy consumed (see Fig. 3); while during the last years wind covered on average around 20% of the total load, solar covered 5% in the best case, small hydro only 3% or less, other renewable 2% or less, and COG (non-renewable) covered about 13% of the load. Hence, technology-specific considerations are important not only from the perspective of FITC but also from that of the WP, and this is carefully taken into account in the empirical study presented below.

To the best of our knowledge, none of the previous studies has assessed empirically from a disaggregated perspective the effect of both determinants (FITC and WP) on the retail price. Therefore, this paper seeks to contribute to the empirical analysis of the effect that the FIT regulation has on the electricity retail price for industrial consumers by quantifying the relative intensities of the FITC and the WP. This study is applied to Spain mainly because the more common regulatory design within the EU on RES-E promotion is applied, but also because of data availability and the fact that, within the EU, Spain has one of the highest renewable power capacities[3] (together with Germany and Italy), and one of the most significant wind power (together with Germany and Denmark) and solar power (together with Germany) generation penetrations. In what follows, special attention is devoted to technology-specific considerations, as well as to short- and long-run effects.

This article is organized as follows. Section 2 summarizes links to the existing literature. Section 3 describes the data and models used to estimate the retail price effects of the feed-in tariff regulation. Section 4 provides the estimation and results of our analysis. Finally, Section 5 discusses, interprets, and contextualizes our findings.

2. Links to the existing literature

Previous studies for different countries have analyzed (*ex-ante* and *ex-post*) the additional cost from supporting FIT, estimated the potential benefits from the merit of order effect, and compared aggregate figures for the potential cost savings from higher RES-E to direct FIT costs. Below we describe the main findings of these three closely related streams of the energy economics literature.

Numerous *ex-ante* studies calculate the additional cost from supporting schemes to electricity generated from renewable energy sources. Ragwitz et al. (2007) predicted that a steady rise of the average EU consumer price between 5.0 €/MWh and 7.7 €/MWh over the period 2005–2010 was required in order to finance RES-E deployment. In the German case, Frondel et al. (2010) calculated (dividing the overall amount of FIT by the overall electricity consumption) that in 2008 the price mark-up attributable to the FIT was about 7.5% of the average household electricity price. Using a quantitative electricity market model that accounts for factors such as oligopolistic behavior, emissions trading, and restricted cross-border transmission capacities, Traber and Kemfert (2009) also find an upward price effect of the German FIT. Relatively few *ex-post* studies have analyzed the price effects of FIT regulation. Del Rio and Gual (2007) assess the effect of the Spanish FIT between 1999 and 2003 in terms of the additional costs paid by consumers for renewables compared to conventional electricity (i.e. the share of RES-E promotion of the electricity bill). They found that the additional cost for the consumer increased annually by 23% during the period considered.

As discussed above, certain properties of RES-E generation can also potentially counter the upward-price effect associated with FIT

[2] To be more precise, while the non-tax levies are used in Austria, Belgium, France, Ireland, Italy, Lithuania, Luxembourg, Slovenia, and Spain, the pass through to end users of suppliers costs is used in Belgium, Czech Republic, Germany, Greece, Hungary, Norway, Poland, Portugal, Romania, Sweden, and UK.

[3] Excluding hydropower.

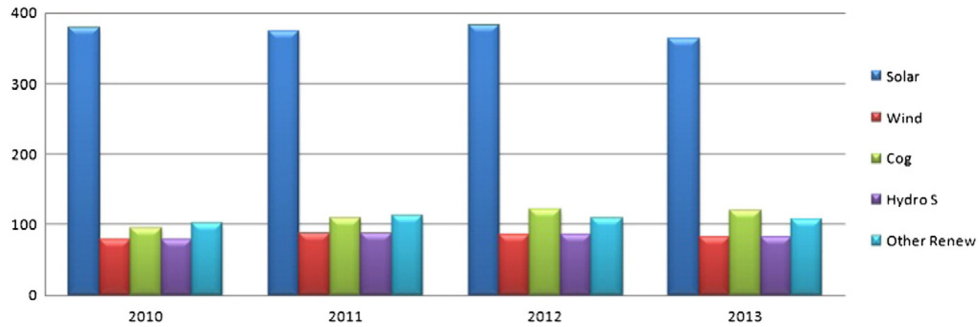

Fig. 2. Yearly average FITC (in €/MWh). *Source*: Own elaboration based on Spanish national regulatory agency information.

regulation. In the wholesale electricity market the supply curve is constructed by ordering the bids of all generators from lowest to highest. These bids should equate the marginal costs of the generators and, therefore, the supply curve should reflect the aggregate marginal cost curve for the market (if no market power exists). The market price is set at the intersection of the supply and demand curves, and all generators with lower marginal costs satisfy demand at this uniform price. The introduction of technologies under the FIT regulation tends to shift the supply curve to the right, given its low marginal cost of generation, which pushes more expensive marginal plants (e.g. coal, combined cycle, petroleum, etc.) out of the market, and exerts a downward pressure on the wholesale price of electricity (see *Wholesale Market graph* in Fig. 1). This is the so-called merit of order effect and is a well documented feature of wholesale prices in the context of the FIT.

Traber and Kemfert (2011), using a mixed complementary program computational model, found that higher wind supply reduces German market prices by more than 5%. Gelabert et al. (2011), using a multivariate regression model of daily average Spanish electricity prices for 2005 to 2009, also found that a marginal increase of 1 GWh of electricity from RES-E and COG is associated with a reduction of 1.9 €/MWh (3.7%) in wholesale electricity prices. Adopting a similar methodological approach Würzburg et al. (2013) found that in Germany and Austria electricity price fell by roughly 1 €/MWh (around 2% of the electricity price) for each additional GWh of average daily renewable electricity generation between July 2010 and June 2012.

Finally, there are studies that, in an attempt to account for both effects, compare the potential cost savings from higher RES-E (merit of order) and direct costs of the FIT, with one or both effects considered at an aggregate level. This is the case of the study by Sensfub et al. (2008), which offers a detailed analysis of the price effects of RES-E generation on German wholesale prices between 2001 and 2006. When comparing the computed cost savings due to RES-E feed-in to the total costs of the FIT in 2006 they showed that the cost savings outweighed total costs. Similarly, Saenz de Miera et al. (2008), through a simulation analysis for the Spanish wholesale price, found that when comparing the simulated reduction in the wholesale price of electricity as a result of more wind generation with the total yearly support for wind generation, there are net saving costs for consumers from the FIT scheme. Likewise, Ciarreta et al. (2014) compared the computed savings from the merit of order effect with the yearly total amount of subsidies in Spain. They found that while cost savings exceeded the subsidies between 2008 and 2009, the opposite was true between 2010 and 2012. Also for the Spanish case, Burgos-Payan et al. (2013) compared the aggregate costs and benefits from the FIT system over the period 2008–2009 and found that the magnitude of both effects were roughly counterbalanced.

Our research is related to the above literature, and particularly to the last group, given that we account for both effects, although from a disaggregated perspective. More precisely, through the estimation of three econometric models that take into consideration technology-specific factors, this paper contributes to the empirical assessment of the effect of the FIT regulation on the industrial retail price of electricity by quantifying its sensitivity to the incentives for electricity generation under the FIT and the electricity wholesale price.

3. Data and methods

The empirical assessment of the effect of the FIT regulation on the electricity retail price (RP) is conducted through the estimation of an RP equation that allows us to quantify the relative intensity of the effects attributable to both the FITC and the WP of electricity. This assessment is performed in a two-step strategy using weekly data. First, we estimate an inverse supply equation (Eq. (1)) where WP is a function of the energy supply mix and the load (equilibrium quantity), and a FITC equation (Eq. (2)) which captures the effect of the daily electricity production by RES-E and COG on the cost per unit of electricity consumption. Second, we introduce the estimates of WP and FITC (along with additional controls) into the RP equation (Eq. (3)) to evaluate the relative intensity of both components. Below we describe the models and data used to estimate the retail price effects of the feed-in tariff regulation.

$$\begin{aligned} \Delta WP_t = {} & \beta_0 + \beta_1 \Delta WP_{t-1} + \beta_2 \Delta Load_t + \beta_3 \Delta Mix_t \\ & + \Delta\beta_4 Y_t + \Delta\beta_5 Q_t + \Delta\beta_6 M_t + \Delta\beta_7 W_t + \epsilon_{1t} \end{aligned} \tag{1}$$

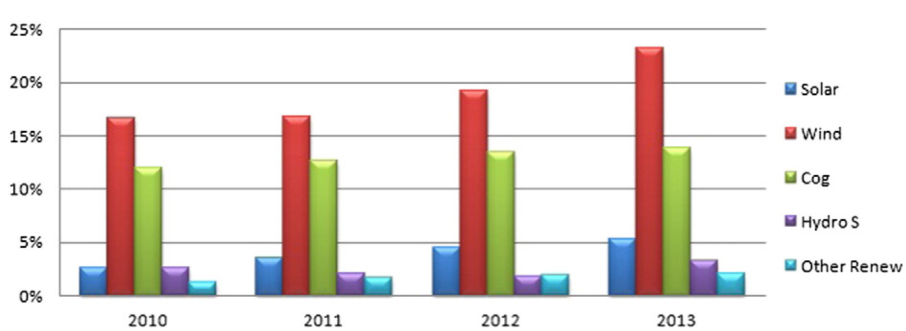

Fig. 3. Yearly average % of load. *Source*: Own elaboration based on Spanish national regulatory agency information.

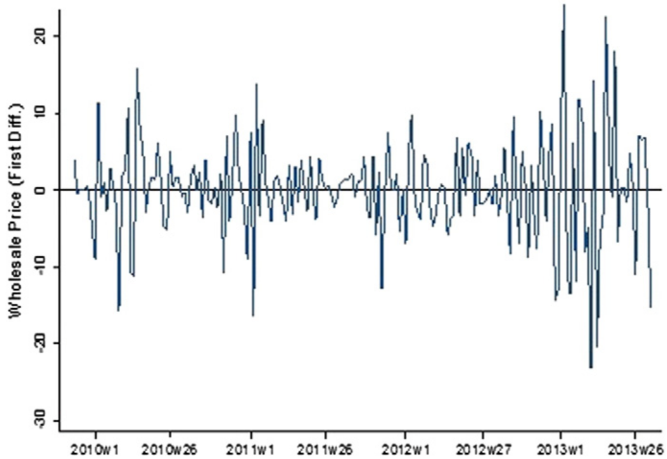

Fig. 4. Wholesale price (first differences).

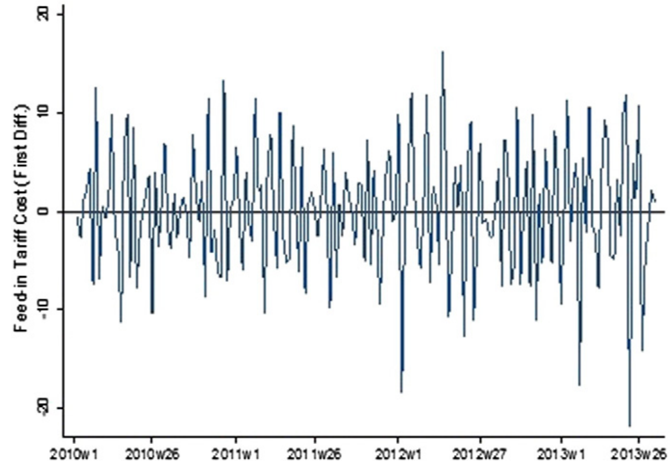

Fig. 5. Feed-in tariff cost (first differences).

$$\sigma_{1t}^2 = \delta_0 + \delta_1 \epsilon_{1t}^2 \tag{1.1}$$

$$\begin{aligned} \Delta FITC_t = {} & \lambda_0 + \lambda_1 \Delta FITC_{t-1} + \lambda_2 \Delta Mix_t \\ & + \lambda_3 \Delta Y_t + \lambda_4 \Delta Q_t + \lambda_5 \Delta M_t + \lambda_6 \Delta W_t + \lambda_7 \epsilon_{2t-1} + \epsilon_{2t} \end{aligned} \tag{2}$$

$$\begin{aligned} \Delta RP_t = {} & \alpha_0 + \alpha_1 \Delta RP_{t-1} + \alpha_2 \Delta \widehat{WP}_t + \alpha_3 \Delta \widehat{FITC}_t \\ & + \alpha_4 \Delta Y_t + \alpha_5 \Delta Q_t + \alpha_6 \Delta M_t + \alpha_7 \Delta W_t + \epsilon_{3t} \end{aligned} \tag{3}$$

We analyzed the FIT effect on the wholesale market price (WP_t) in Eq. (1) following the empirical strategy of estimation in differences as used by Gelabert et al. (2011) and Würzburg et al. (2013). In addition to the load ($\Delta Load_t$) and electricity generation by energy source (ΔMix_t which includes wind, solar, other renewables, cogeneration, combined cycle, nuclear, coal and hydro), we introduce an autoregressive component (ΔWP_{t-1}) in order to capture dynamic effects, and four sets of dummy variables: yearly (ΔY_t), quarterly (ΔQ_t), monthly (ΔM_t), and weekly (ΔW_t) dummies, for seasonality control.

The residuals in Eq. (1) are defined as an autoregressive process where all ϵ_{1t} are of the form $\epsilon_{1t} = Z_t \sigma_{1t}^2$ with Z_{tv} (0,1), and D_v (0,1) is the probability density function of the residuals with zero mean and unit variance.[4] Eq. (1.1) represents the variance equation of the first order ARCH process included to account for the increasing volatility effects that are observable in the first difference of the WP_t series (see Fig. 4). The wholesale price data were obtained from the Spanish market operator (OMEL) and electricity generation data by energy source were obtained from the Spanish transmission system operator (REE).

Following the same empirical strategy as in the ΔWP_t model, for the analysis of the feed-in tariff costs the estimation is performed in differences with a lagged dependent variable $\Delta FITC_{t-1}$. Eq. (2) represents the change in the cost of the FIT per unit of electricity consumption ($\Delta FITC_t$) capturing the effect from the change in the composition of electricity production by different sources (wind, solar, small hydro, other renewable, and cogeneration) covered through the FIT system (ΔMix_t). For seasonality control, we introduce the same sets of dummy variables as in Eq. (1). Unlike in the case of ΔWP_t, the $\Delta FITC_t$ variance (despite its volatility which is high though not increasing, see Fig. 5) does not follow an ARCH process. However, the $\Delta FITC_t$ series does follow a moving-average process of first order. For this reason we introduce a ϵ_{2t-1} component.[5]

To obtain the weekly $\Delta FITC_t$ the following procedure is used. First, along the same lines as Burgos-Payan et al. (2013), from the CNE statistics[6] on FIT payments we take the yearly amount of Euros by technology devoted to the incentives of firms producing electricity from RES-E and COG. Second, the yearly amount of Euros per technology is weighted by the daily proportion of their yearly production (Prod-day/Prod-year) and added to obtain the daily cost of FIT. Third, to account for volume differences, we compute the cost of the FITs per unit of electricity consumption (load). Finally, we compute the weekly average.

The period covered for the estimation of the wholesale price and the feed-in tariff cost equations is from November 2009 to July 2013 (195 weeks). The selection of this period was motivated by regulatory stability and data reliability: up to October 2009 the distribution companies were in charge of handling the FIT payments to the Special Regime (SR) producers. Since November 2009 the National Commission of Markets and Communications (by its acronym in Spanish CNMC, previously named National Commission of Energy, CNE) has been responsible for the FIT payments, providing public and reliable information on these payments.[7]

The analysis of the effect of the FIT regulation on the electricity retail price (RP_t) is performed by estimating Eq. (3), which quantifies the retail price change as a function of changes in both the cost of the incentive for electricity generation under the FIT and the wholesale price of electricity. To account for the dynamic effects, an autoregressive term (RP_{t-1}) was introduced in the model. $\widehat{WP}_t$ is the estimated weekly average of the (day-ahead) spot market price, which captures the effect of the composition of electricity production by energy source (Eq. (1)). $\widehat{FITC}_t$ is the estimated FIT cost per unit of electricity consumption, which captures the effect of electricity production by RES-E and COG (Eq. (2)). Seasonality is controlled with dummy variables as in the two previous equations.[8]

According to the Spanish price design, the industrial retail price (*RP*, excluding taxes) is the result of adding the Access Tariff (*AT*), the Net Retail Margins (*NRM*) and the Wholesale Cost (*WC*). The AT data comes from the Spanish national regulatory agency, the CNMC reports on monitoring the retail market.[9] The NRM, obtained from the same source, were computed quarterly by the CNMC based on two forward

[4] To characterize the error process of Eq. (1) we apply Engle's Lagrange multiplier test for the presence of autoregressive conditional heteroskedasticity which confirmed first order ARCH, and the Cumby–Huizinga test for moving average from which moving average was rejected.

[5] Following the same approach as in Eq. (1), we characterized the error process of Eq. (2), confirming a moving-average process of first order and rejecting ARCH.

[6] *"Informacion Estadistica sobre las Ventas de Energia del Regimen Especial"*, available at www.cne.es.

[7] In practice although it is possible to obtain the payments both as a direct tariff or as a premium over the market price, we use the total resources (the FITC) because it captures the overall cost of the policy.

[8] Also, along the same lines as in Eqs. (1) and (2), tests were performed on the error process for the retail price equation, leading to the rejection both ARCH and moving-average processes in Eq. (3).

[9] *"Informe de Supervision del Mercado Minorista de Electricidad Julio 2011–Junio 2012"*, (CNE, 2013). More precisely, we used the CNMC access tariff for the average industrial consumer according to the RD 110/2007 consumer classification.

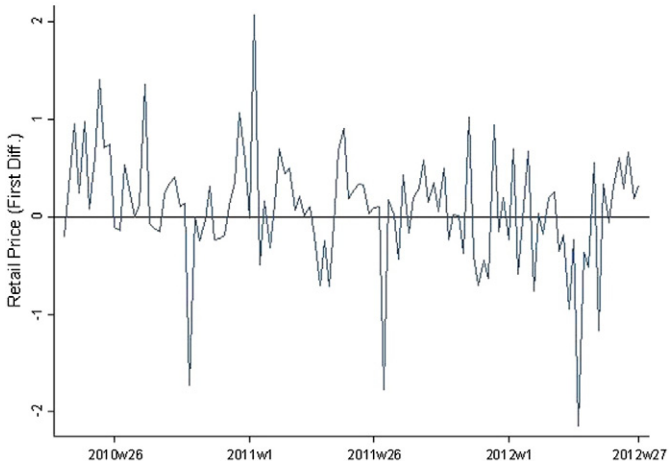

Fig. 6. Retail price (first differences).

purchasing strategies by retailers (see CNE, 2013). We follow the same methodology for one forward purchasing strategy to approach their WC on rolling basis; using weekly, monthly and quarterly contracts (see Appendix for additional details on the *RP* proxy).[10] In order to develop comprehensive empirical estimations, weekly data for the period between April 2010 and June 2012 were used (116 weeks). The selection of this period was motivated by data availability. Fig. 6 shows the industrial retail price in first differences. Table 1 shows the summary statistics of the data used. While all prices and costs (RP, WP and FITC) are measured in €/MWh, all electricity volumes are measured in GWh.

Having described the models and data used, we present the stationarity analysis of the series. We performed two tests, first, the augmented Dickey–Fuller (ADF) test (Dickey and Fuller, 1979) under the null hypothesis of a unit root and, second, the Kwiatkowski–Phillips–Schmidt–Shin (KPSS) tests (Kwiatkowski et al., 1992) under the null hypothesis of stationarity. While the results of the ADF test (see Table 2) in levels indicates that we cannot reject the null hypothesis of a unit root in WP, FITC or RP at any reasonable level of significance, the results in first differences indicate that we can reject the null hypothesis of a unit root for all three series. In addition, the KPSS results in levels indicate that we can reject the null hypothesis of stationarity in WP, FITC and RP in any case, and in first difference that we cannot reject the null hypothesis of stationarity at 1% level of significance. Both tests confirm that the WP, FITC and RP weekly series are stationary in first differences and, so, we estimate the models in first differences.

4. Results

Given that the effects of the FIT regulation are transferred via the proportion and type of renewable sources in the energy mix, three sets of estimations are performed for each equation with different technological aggregations of the electricity mix. While in Set 1 a single variable captures the electricity generated under the FIT system (SR), in Set 2 we distinguish between renewable (RES-E) and cogeneration (COG) under the FIT system, and in Set 3 the renewable sources are disaggregated in Wind, Solar, Small Hydro, and Other Renewable. In addition to the electricity generated under the FIT system, the other main technologies in the energy mix are introduced in the WP equation

Table 1
Summary statistics.

Variable	Obs	Mean	Std. dev.	Min	Max
RP industrial	116	79.8259	3.2661	69.7313	84.1047
WP	195	43.298	10.4807	3.25	63.6914
FITC	195	47.8293	10.1541	28.0443	82.564
Load	195	28.7619	2.0537	23.9702	34.1131
SR	195	11.2848	2.1422	7.0179	17.75
RES-E	195	7.5922	2.0167	3.994	13.6012
COG	195	3.693	0.2784	2.6667	4.2143
Wind	195	5.3534	1.969	1.9167	11.6012
Solar	195	1.073	0.5014	0.2396	2.4762
Hydro S	195	0.6869	0.2516	0.2083	1.1786
Hydro B	195	3.4741	1.677	1.3571	8.6905
Hydro T	195	4.161	1.8973	1.6667	9.7738
Other renew	195	0.4788	0.0931	0.3155	0.6667
Nuclear	195	6.7936	0.8035	4.0833	7.8869
Coal	195	4.3477	2.1268	0.3036	9.1607
Comb cycle	195	5.4349	2.2302	1.3452	11.5238

(Combined Cycle, Nuclear, Coal and Hydro[11]). Estimations are performed using Maximum Likelihood method to avoid bias and inconsistency problems that can arise with Least Squares method in presence of autocorrelated errors and lagged dependent variables. Tables 3 and 4 show the results of the three estimations with robust standard errors for the ΔWP_t (Eq. (1)) and $\Delta FITC_t$ (Eq. (2)), respectively. We first present our results from all the estimations in the short-run (contemporaneous effect) analysis. This is followed by a summary and comparison between short-run and long-run implications.

In general, the results from the WP equation are consistent with those reported in previous studies, i.e. the introduction of RES-E exerts a downward pressure on the wholesale price of electricity. At an aggregate level (Set 1), the results indicate that, in the short-run, one additional GWh of electricity generated under the FIT system (SR) reduces the WP (Table 3) by a magnitude of 1.13 €/MWh (−2.61%) and increases the FITC (Table 4) by 2.08 €/MWh (4.35%). When separating renewables from cogeneration (Set 2), our results for the former are very similar to those of the aggregate FIT system, showing that an additional GWh of RES-E production reduces the WP by 1.09 €/MWh (−2.53%) and increases the FITC by 2.07 €/MWh (4.33%).

The renewable energy sources are disaggregated in the last group of estimations (Set 3). Results show that one additional GWh of wind production reduces the WP by a magnitude of 1.11 €/MWh (−2.56%) and increases the FITC by 2.22 €/MWh (4.66%). In the case of solar production, an additional GWh reduces the WP by 2.51 €/MWh (−5.80%) and increases the FITC by 9.94 €/MWh (20.79%). Finally, our cogeneration results show that one additional GWh of production reduces the WP by 2.64 €/MWh (−6.12%) and increases the FITC by 4.62 €/MWh (9.67%).

The coefficients of the remaining explanatory variables are very similar across the specifications. Moreover, as measures of the reliability of the statistical estimates, Tables 3 and 4 show the relative standard deviation (RSD) and the standard deviation (SD) of residuals, respectively. The decreasing value of both indicators with the increasing disaggregation of the electricity mix (from Set 1 to Set 3) confirms both the adequacy and relevance of the technology-specific considerations in the context of this study. Furthermore, the models' goodness of fit are very high as can be seen in Figs. 7 and 8 which report the observed and predicted values from Eqs. (1) and (2), respectively.[12]

[10] As pointed out in CNE (2013) and Ofgem (2008), firms might employ a range of hedging strategies and these can change over time. For practical purposes we used one of the two purchasing strategies employed by the CNMC for industrial consumers. In the dynamic strategy we used, the supplier buys during remaining time before the rolling period ends to cover the delivery, while in the other strategy the portfolio length is uniformly distributed through the products within the rolling period. Given that our model is in first differences and captures long-term effects, results are expected to be consistent to the use of different strategies.

[11] Given that small hydro generation is part of the RES under the FIT system, to avoid double imputation of small hydro in the mix, only big hydro generation was introduced as additional control in the first two estimations of the WP. Furthermore, to avoid multicolineality problems coming from the high correlation between small and big hydro, total hydro was introduced in the third estimation of the WP.

[12] As a robustness check, when re-estimating the WP model we included the gas price as an additional control. The effect was positive but not significant, and the rest of the estimated coefficients remained unchanged. This non-significant result might be due to the fact that the gas price effect is captured, at least partially, by the contribution of the combined cycle to the electricity mix.

Table 2
Augmented Dickey–Fuller and Kwiatkowski–Phillips–Schmidt–Shin test.

	ADF test		KPSS test	
	Levels	First differences	Levels	First differences
Wholesale price (*WP*)	−3.061	−9.005***	1.060***	0.038
Feed-in tariff cost (*FITC*)	−3.247	−9.751***	3.090***	0.054
Retail price (*RP*)	−2.606	−4.695***	2.350***	0.541

Note: Test results are statistics. Lag length is determined by the Modified Akaike Information Criterion. The trend was not significant in any case, hence, it was excluded. ADF null hypothesis of unit root. KPSS null hypothesis of stationarity. ***Significant at 1%.

Once the effect of electricity produced under the FIT regulation on the WP and FITC has been considered, the overall impact of the FIT regulation on the retail price ultimately depends on the relative intensities of the effects exerted through the WP and FITC. This analysis is performed with the estimation of Eq. (3) for industrial consumers using the predicted values of WP and FITC obtained in the previous estimations.

Given that $\widehat{WP}_t$ and $\widehat{FITC}_t$ are both functions of the energy mix, there might be some concerns regarding the effect of a potentially high correlation between them on the retail price equation. However, the correlation between the two estimated variables is −0.1318 for the results in Set1, −0.1321 for those in Set2, and −0.1507 for those in Set3. The results from the estimations of Eq. (3) are presented in Table 5.

Table 3
Wholesale price.

ΔWP_t	(1)	(2)	(3)
ΔWP_{t-1}	−0.287***	−0.284***	−0.238***
	(0.044)	(0.044)	(0.047)
ΔLoad	0.814***	0.821***	0.844***
	(0.219)	(0.203)	(0.264)
ΔSR	−1.128***		
	(0.179)		
ΔRES - E		−1.095***	
		(0.167)	
ΔCOG		−2.330**	−2.648***
		(0.907)	(1.002)
ΔWind			−1.109***
			(0.210)
ΔSolar			−2.512***
			(0.758)
ΔOtherRenew			7.312
			(5.361)
ΔCombCycle	0.322	0.365*	0.280
	(0.210)	(0.200)	(0.258)
ΔNuclear	−0.248	−0.267	−0.426
	(0.270)	(0.279)	(0.370)
ΔCoal	0.951***	0.953***	0.939***
	(0.201)	(0.193)	(0.243)
ΔHydroB	−3.169***	−3.180***	
	(0.240)	(0.235)	
ΔHydroT			−2.836***
			(0.242)
Constant	0.145	0.134	0.0379
	(0.0945)	(0.0900)	(0.102)
δ_1	2.170***	2.203***	2.168***
	(0.826)	(0.820)	(0.634)
δ_0	1.200**	1.083**	0.949***
	(0.470)	(0.457)	(0.360)
Seasonality			
Year	Y	Y	Y
Quarter	Y	Y	Y
Month	Y	Y	Y
Week	N	N	N
Observations	194	194	194
RSD of residuals	46.620	43.033	25.049

Note: Robust standard errors are in parentheses. *Significant at 10%. **Significant at 5%. ***Significant at 1%. The 51 weekly dummies were excluded from the wholesale price seasonality to allow the optimization of the ARCH process.

Table 4
Feed-in tariff cost.

$\Delta FITC_t$	(1)	(2)	(3)
$\Delta FITC_{t-1}$	−0.231**	−0.256**	−0.344***
	(0.102)	(0.0995)	(0.104)
ΔSR	2.081***		
	(0.203)		
ΔRES − E		2.072***	
		(0.198)	
ΔCOG		6.034**	4.625*
		(2.974)	(2.535)
ΔWind			2.227***
			(0.189)
ΔSolar			9.944***
			(1.331)
ΔHydroS			1.671
			(1.908)
ΔOtherRenew			−9.837
			(8.006)
Constant	0.0816	0.0764	0.0612***
	(0.057)	(0.062)	(0.016)
ε_{2t-1}	−0.848***	−0.828***	−0.916***
	(0.098)	(0.075)	(0.036)
Seasonality			
Year	Y	Y	Y
Quarter	Y	Y	Y
Month	Y	Y	Y
Week	Y	Y	Y
Observations	194	194	194
SD of residuals	3.473	3.447	2.990

Note: Robust standard errors are in parentheses. *Significant at 10%. **Significant at 5%. ***Significant at 1%.

In general, all the estimations indicate that the short-run effects from changes in the WP and FITC on the RP change are similar, small and highly significant. At an aggregate level (Set 1), the results show that an increase of 1 €/MWh in the WP and in the FITC leads to an increase in the RP of 0.0337 €/MWh and 0.0344 €/MWh respectively. When we combine the estimated effects from Eqs. (1) and (2) on the WP and on the FITC with these retail price effects we find that, one additional GWh of production under the FIT system (9% more) increases the RP by 0.042%.[13] When separating renewables from cogeneration (Set 2), the results are very similar, so that an increase of 1/MWh in the WP and in the FITC leads to an increase in the RP of 0.0306 €/MWh and 0.0283 €/MWh respectively. Hence, in the short-run, one extra GWh of renewable production (13.2% more) increases the RP by 0.031%.

Finally, when renewable sources are disaggregated (Set 3), the results show that an increase of 1 €/MWh in the WP and in the FITC leads to an increase in the RP of 0.0366 €/MWh and 0.0373 €/MWh respectively. Therefore, in the short-run, one additional GWh of wind (18.7% more) and solar power (93.2% more) increases the RP by 0.053%, and 0.349%, respectively.

As in the previous models, using the SD of the residuals (see Table 4) as a measure of the reliability of the statistical estimates, we observe a decrease in value with increasing disaggregation of the electricity mix (from Set 1 to Set 3). Besides, the goodness of fit of the retail price model is very high, as can be seen in Fig. 9 which show the observed and predicted values from the retail price equation.

The estimated coefficients of the lagged dependent variables were used to calculate the long-run effects.[14] A summary of the short and long-run effects of the FIT regulation on the average WP, FITC and RP are presented in Table 6. In the case of the long-run effects it is interesting to highlight that they decrease in magnitude for the WP and the FITC

[13] The final short-run effect on the RP from one additional GWh of production is calculated as follows: $\alpha_2 * [\beta_3/\beta_3/\overline{WP}] + \alpha_3 * [\lambda_2/\overline{FITC}]$.

[14] In each case, the long-run effects are calculated as follows:
$WP: [\beta_3/1-\beta_1/\overline{WP}$
$FITC: [\lambda_2/1-\lambda_1]/\overline{FITC}$
$RP: \alpha_2 * [\beta_3/1-\beta_1]/\overline{WP}/[1-\alpha_1] + \alpha_3 * [\lambda_2/1-\lambda_1]/\overline{FITC}/1-\alpha_1]$.

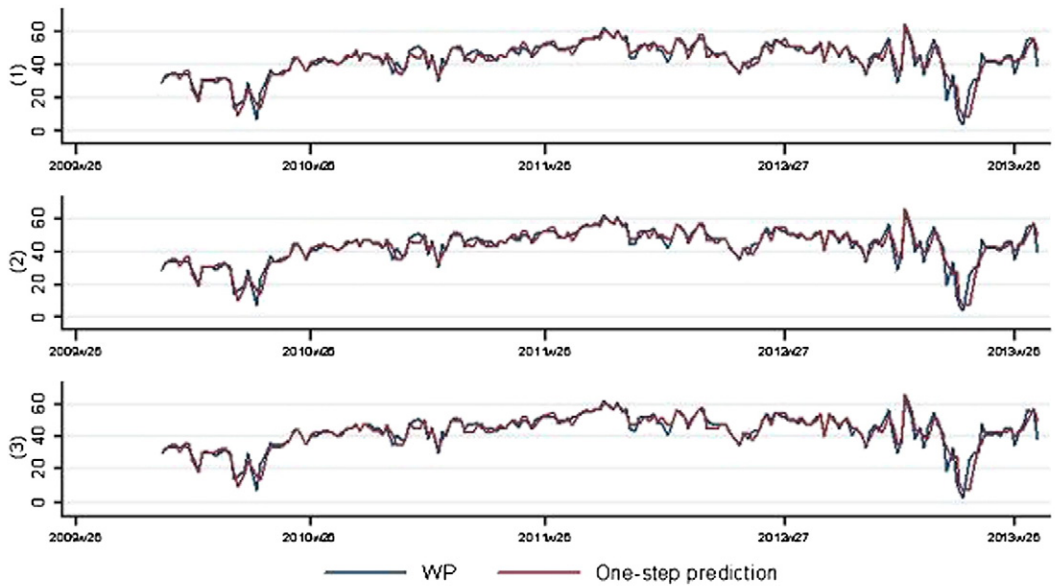

Fig. 7. Goodness of fit Eq. (1).

with respect to those in the short-run. The effect of one additional GWh of production under the FIT system on the WP and on the FITC is stronger in the short than in the long-run (β_1 and λ_1 are negative). However, the opposite is the case for the RP. In the long-run the effects of additional production under the FIT system increase with respect to those observed in the short-run (α_1 is positive).

5. Discussion and conclusions

In this study we have analyzed the effects of the feed-in tariff regulation on Spain's electricity retail prices. This analysis has been undertaken by quantifying the relative effects of the costs of incentives for electricity generation under the FIT and the electricity wholesale price on the industrial retail price. Overall, our results show that the downward pressure exerted by the wholesale price is offset by the cost of the incentives, and as a consequence, the electricity produced under the FIT system increases the retail prices. These general results are in line with those of Ciarreta et al. (2014), which from an aggregated approach of subsidies cost fund that they exceed the estimated merit of order effect. In addition to the general results, this study contribute to the literature with new insights on the effects form different RES-E technologies and on the link between the wholesale and retail markets in a liberalized electricity sector.

At an aggregate level, we find that an increase of about 9% in total production under the FIT system leads to a fall of 2.61% in the WP and an increase of 4.35% in the FIT cost. This means that final industrial consumers face a 0.042% increase in the average retail price. These results, although highly illustrative of the sector, must be interpreted carefully because they are for the aggregate mix of technologies within the FIT system.

At a technological-disaggregate level, we show that the effect of one additional GWh of solar production on the WP and on the FITC is stronger than that of one additional GWh of wind power. In the case of the WP, this seems to confirm the difference originating from the fact that the two technologies contribute different amounts of electricity to the system during the day, characterized by different demand profiles. Even though the contribution of solar power to the energy mix is relatively small (less than 5% on average), as it is available during peak hours, the downward pressure that it exerts on the WP is stronger than that exerted by wind power, which has a higher penetration (around 20%) but one that

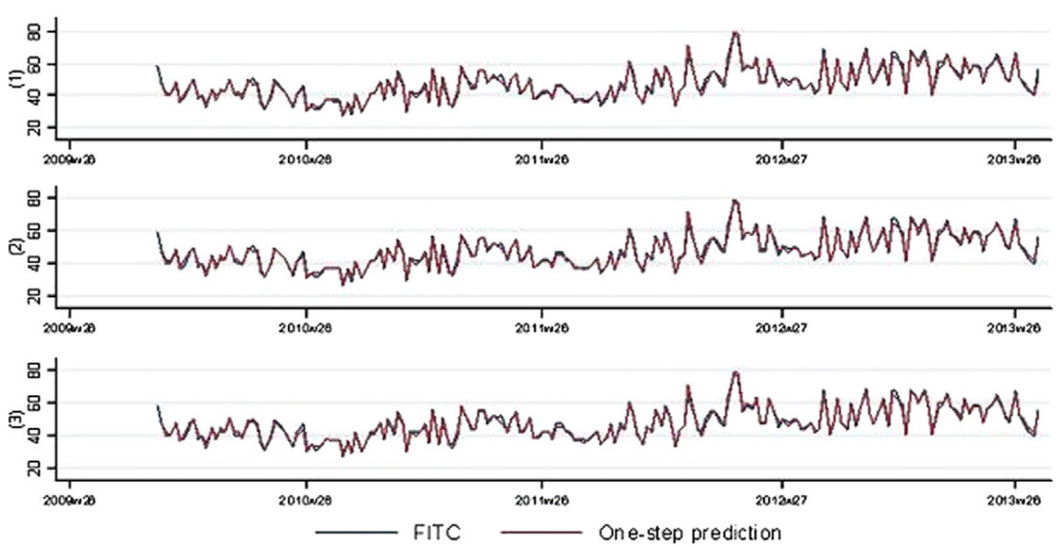

Fig. 8. Goodness of fit Eq. (2).

Table 5
Retail price industrial.

ΔRP_t	(1)	(2)	(3)
ΔRP_{t-1}	0.154**	0.155**	0.178**
	(0.073)	(0.072)	(0.076)
$\Delta\widehat{WP}_t$	0.034***	0.030***	0.037***
	(0.011)	(0.011)	(0.011)
$\Delta\widehat{FITC}_t$	0.034***	0.028***	0.037***
	(0.009)	(0.009)	(0.009)
Constant	0.059	0.060	0.057
	(0.037)	(0.037)	(0.037)
Seasonality			
Year	Y	Y	Y
Quarter	Y	Y	Y
Month	Y	Y	Y
Week	Y	Y	Y
Observations	116	116	116
SD of residuals	0.337	0.335	0.330

Note: Robust standard errors are in parentheses. *Significant at 10%. **Significant at 5%. ***Significant at 1%.

Table 6
Effects from one additional GWh of production.

	SR	RES	Wind	Solar
Short-run				
WP	−2.61%	−2.53%	−2.56%	−5.80%
FITC	4.35%	4.33%	4.66%	20.79%
RP	0.042%	0.031%	0.053%	0.349%
Long-run				
WP	−2.02%	−1.97%	−2.07%	−4.69%
FITC	3.54%	3.45%	3.47%	15.47%
RP	0.06%	0.04%	0.07%	0.49%

Note: 1 GWh represents 9%, 13.2%, 18.7% and 93.2% of the average generation for SR, RES, Wind, and Solar, respectively.

is relatively stronger during off-peak hours. However, any definite conclusion on this regard would require additional analysis using hourly data. In the case of FITC, the stronger effect of solar power is more straightforward, since here we capture the much higher FIT incentive in terms of €/MWh granted to this technology.

As for the final impact on the industrial retail price, these results indicate that the effect of one additional GWh of solar production is 6.6 times higher than the equivalent increase in wind power in the short-run and 7.6 times higher in the long-run. However, in considering these effects, it should be borne in mind that one additional GWh of solar power would mean increasing the average level of generation by 93.2% while in the case of wind the increase would be just 18.7%. To put these results into perspective, we computed the respective impact on the average retail price of a 10% increase in the average production of both technologies. Thus, a 10% increase in solar production would result in an increase in the retail price that is, in fact, only 1.5 times higher than that originating from a 10% increase in wind power.

With respect to the small magnitude of the retail price effects, it has been recently pointed out by the European Commission that, in an open and competitive retail market the pricing signals should provide a strong link between the retail and wholesale market, and the final consumers would then be able to adapt their economic decisions in line with supply and demand fundamentals. Yet, these conditions are rarely met in retail markets in the EU nowadays (EC, 2014). Indeed, the analysis reported here leads us to conclude that there is a highly significant but not a very strong link between the retail and wholesale markets for Spain's industrial consumers. This perhaps reflects the limited competition in the retail market, which prevents final consumers from facing the potential welfare effects that result from a competitive wholesale market, in which the FIT regulation has a price suppressing effect, and the costs of financing this renewable promotion mechanism.

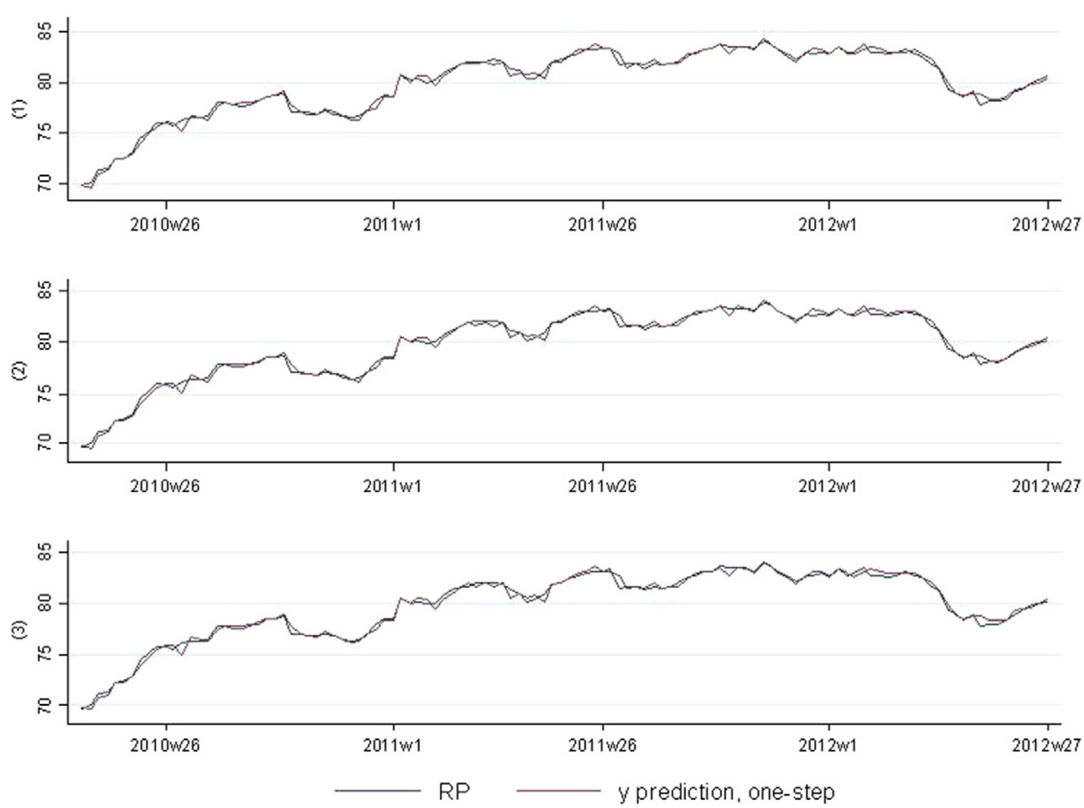

Fig. 9. Goodness of fit Eq. (3).

Finally, it is important to highlight that although this study is applied to Spain the results are of general interest mainly because the more common regulatory design within the EU on RES-E promotion is applied. Moreover, the results based one of the countries, within the EU, with the highest renewable power capacities, and one of the most significant wind and solar power generation penetration provides useful insight to other countries where the RES-E promotion it is at early stages and RES-E penetration is lower. For instance, it is a generalizable the stronger effect of solar on the wholesale price with respect to that of other technologies, because it responds to the contribution of solar to the system during the day. Furthermore, the results confirmed a weak link between the retail and wholesale market, highly relevant given the current concerns on the lack of competitive retail markets from supranational institutions as the European Commission.

Acknowledgments

We would like to thank to Joan Batalla, Pablo del Rio, Lola Gadea, Jose Garcia-Quevedo, Monica Giulietti, Daniel Montolio, Michael Pollitt, Pablo Villaplana, Francesco Vona and all the participants at the Mannheim Energy Conference on Sustainable Energy Markets of ZEW (2014), the 37th Conference of the International Association for Energy Economics (2014), and the International Academic Symposium on Energy Markets and Sustainability (2015) for helpful comments and discussion. Any remaining errors are our sole responsibility. We are also grateful for the support of the Generalitat de Catalunya SGR project 2014-SGR-531, and acknowledge financial support from the Chair on Energy and Environmental Sustainability (University of Barcelona and FUNSEAM grant number 306885).

Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.eneco.2015.06.002.

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