



## Full-length article

## Dynamic demand response to electricity prices: Evidence from the Spanish retail market

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## ABSTRACT

The energy transition is driving a significant transformation in the electricity sector, with a focus on demand-side engagement. Using the VAR-VEC model methodology, we explore hourly consumer responsiveness to electricity prices for two distinct consumer groups differentiated by their pricing schemes within the Spanish retail market. The research reveals that consumers under real-time pricing adapt their consumption patterns in response to expected retail price fluctuations, particularly during peak hours. These findings offer valuable insights for policymakers evaluating time-differentiated pricing policies. Additionally, retailers can benefit by incorporating these results into wholesale market bidding strategies and retail market planning.

## 1. Introduction

Electricity supply security has always been a priority for policymakers. Before liberalization, electricity systems were typically characterized by large-scale centralized generation and substantial oversupply (Lijesen, 2007). Following liberalization, generators were incentivized to optimize the cost efficiency of their processes, which may lead to a reduction in overcapacity and a corresponding reduction in the security of supply. In response, policymakers often focused on measures aimed at recovering the levels of installed capacity that were considered desirable, for example, by paying generators to keep plants running (which, otherwise, would be dismantled) to minimize the risk of blackouts in the event of excess demand.

Within the energy transition process, the transformation of the electricity sector is at least three-fold. On the supply side, we are witnessing the replacement of fossil fuels with renewable energies, which encourages the increased electrification of sectors still reliant on conventional generation sources to achieve a more sustainable economy through decarbonization. The demand side focuses mainly on electricity savings and a more active role for consumers when making electricity consumption decisions. Additionally, the role of self-consumption is expected to have a notable impact on the market in this new paradigm, as it reduces the demand for electricity from the wholesale market in

favor of distributed generation.

Spain has committed to some of Europe's most ambitious renewable energy targets. According to the Integrated National Energy and Climate Plan 2021–2030 (MITECO, 2020), Spain aims to double the share of renewables in its electricity mix from around 37% in 2015 to 74% in 2030 while also increasing the electrification of its energy system. Although there is a growing trend to generate electricity from renewable sources that can be stored, such as renewable gas or green hydrogen,<sup>1</sup> the technologies that mostly replace fossil fuels are solar and wind. These latter sources are intermittent since they are not economically storable on a large scale, which could diminish supply security. The challenge here is to ensure that electricity demand is always met. Policymakers have emphasized supply measures, such as capacity markets or payments, rather than demand. However, demand-side management can provide an alternative form of reserve, which is likely considerably cheaper than placing conventional plants on standby (as argued by Strbac, 2008).

Consequently, electrification will mean an increase in electricity demand, which will be (at least partially) offset by a reduction in wholesale market demand due to increasingly widespread energy-saving measures, energy efficiency gains, and self-consumption. In addition, if solutions for the storage of non-storable generation sources or more infrastructure for storable sources are unavailable, the gap between

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reliable supply and demand could narrow until levels where the security of supply is seriously jeopardized. Overbuilding capacity is both technically and economically inefficient. Therefore, as an additional adjustment tool to help balance the system and minimize risk, testing consumer price sensitivity and incentivizing consumers to modify their electricity usage by shifting from periods of high demand to periods of low demand is worthwhile.

Historically, electricity demand was inelastic (Al Faris, 2002; Filippini, 2011; Fabra et al., 2021). Gaining insight into the current level of demand response is a good place to start. The Spanish case offers an opportunity to examine the extent to which consumers react to price at an hourly level, given the design of the retail market and the fact that Spain is one of the leading EU countries in the deployment of smart meters following a government mandate,<sup>2</sup> which is a necessary condition for implementing real-time pricing schemes (Filippini, 2011; Kop-sakangas-Savolainen and Svento, 2012).

The remainder of this paper is organized as follows. In the next section, we present a summary of the Spanish electricity market. Section 3 reviews the relevant literature. Section 4 describes the data and the methodology employed for the research. Results are reported in Section 5. Section 6 discusses the results, and Section 7 summarizes the main findings and concludes.

## 2. The Spanish electricity market

The Spanish electricity sector was deregulated when the Electricity Sector Act was enacted in 1997. One of the main consequences of the reform was the implementation of the wholesale electricity market (the so-called spot market or pool), where producers and retailers bid for the sale and purchase of electricity. As of July 2007, Spain and Portugal share a wholesale market. The spot market is a day-ahead market since bids are made for each hour of the next delivery day. Prices resulting from the hourly auction mechanism are set as the intersection between the aggregated supply and demand curves. After the market closes, spot prices and trade volumes for each hour of the following day are published.

In the retail market, following the liberalization of the sector in 1998, the option to purchase electricity through competitive suppliers in the liberalized market or via payment of the corresponding regulated tariff coexisted. Various methodologies have been employed to calculate the regulated tariff. Until June 30, 2009, the state-administered “integral tariff” was determined entirely by the state. From July 1, 2009, as part of the EU-driven liberalization process, the integral tariff was replaced by the *Tarifa de Último Recurso* (TUR), comprising a regulated component established by the state to cover system costs, along with an energy component determined by the outcomes of CESUR auctions (quarterly auctions offering electricity for the subsequent three months). A significant price escalation resulting from an auction in December 2013 prompted the replacement of the TUR with a new tariff calculation method: the *precio voluntario para el pequeño consumidor* (PVPC). This system bases the energy component on wholesale market prices and took effect on April 1, 2014. A progressive schedule allowed consumers to transition from the regulated tariff to the free market based on their consumption level and installed power. By January 1, 2003, all consumers gained the right to access the liberalized market, and by January 1, 2007, the shift from the regulated tariff to the free market became irreversible for consumers connected to high-voltage networks. As of July 1, 2008, the tariff regime applies to consumers connected to low-voltage networks and final consumers. Consumers with contracted power equal to or less than 10 kW can remain on the regulated tariff or move to the free market, where they can choose from various pricing

schemes, such as flat pricing, block pricing, or time-of-use pricing. Consumers with a contracted power of more than 10 kW are required to purchase electricity from competitive retailers in the free market. Those consumers choosing the regulated tariff system are supplied by one of eight reference suppliers.<sup>3</sup>

By 2021, 65% of supply points (including residential, small and medium-sized enterprises (SMEs), and industrial consumers) were in the free market. A consistent trend since 2009 has been observed, with consumers transitioning from the regulated tariff to the free market, as illustrated in Table 1. By the end of 2010, 20.2% of supply points were in the free market, encompassing 27.5% of residential consumers, 86% of SME consumers, and 98.2% of industrial consumers. Since 2014, there has been a noticeable deceleration in the movement of consumers from the regulated tariff to the free market. Notably, by the end of 2013, nearly all SME and industrial consumers had already shifted to the free market, so the transition between both regimes is now confined to supply points with an installed power of less than 10 kW (primarily, residential consumers). By the end of 2018, the share of supply points in the free market had increased to 61% (59% among residential consumers, 96% among SMEs, and 99% among industrial consumers), according to the Spanish National Markets and Competition Commission (CNMC, 2019).<sup>4</sup> Among consumers in the free market, flat pricing appears to be the preferred option. Comparing both consumer groups would help assess the effects of demand response policies.

## 3. Literature review

A review of the literature based on different methodologies for electricity demand price elasticities and their determinants across various countries establishes that price elasticities of electricity demand are estimated to be generally low or even non-existent under certain conditions. A comparison of the results is challenging and typically inconclusive since the data types and model specifications used, as well as the price schedules that consumers face in each market, are dissimilar.

Studies are primarily based on empirical research relying on time series or panel data approaches to estimate demand equations for electricity. Some studies use aggregate consumption data with relatively low frequencies. Al Faris (2002) estimates a vector error correction model on annual data for each country in the Gulf Cooperation Council for 1970–1997 to conclude that electricity demand is inelastic to price in the short run, whereas price elasticities are relatively higher in the long run. Filippini (2011) uses annual data, distinguishing between peak and off-peak prices and residential demand from a sample of Swiss cities to estimate short- and long-run price elasticities for 2000–2006 using a log-linear panel data model. Price elasticities for both peak and off-peak periods are shown to be significantly negative, resulting in an inelastic demand in the short run that becomes elastic in the long run, although the values for long-run elasticities should be considered carefully due to the small data set used. Also based on annual data, Liddle et al. (2020) find that the price elasticity of energy is non-significant (or occasionally positive) using a log-linear panel data model with time-varying coefficients and a dataset for 26 primarily non-OCDE countries from 1996 to 2014. Gao et al. (2021) examine the price elasticity of energy demand in a sample of 65 countries from 1960 to 2016 by estimating a time-varying structural equation panel data model to conclude that the price elasticity of energy is significantly negative and varies over time.

Another group of papers empirically estimates the price elasticity of electricity demand using aggregated data on an hourly (or half-hourly) basis (Patrick and Wolak, 1997; Boisvert et al., 2007; Lijesen, 2007;

<sup>2</sup> Note that the EU target was to install smart meters across all homes, achieving 80% coverage by 2020. As of December 31, 2018, 98.14% of Spanish end-users with contracted power under 15 kW had smart meters (CNMC, 2019).

<sup>3</sup> In addition, reference suppliers are required to supply vulnerable consumers (with a 25% or 40% discount) and consumers with a contracted power greater than 10 kW who temporarily have no contract (with a 20% surcharge).

<sup>4</sup> Breakdowns by consumer type are not available in CNMC reports from this year onward.

**Table 1**Evolution of the percentage of supply points (domestic, SME, and industrial) in the free market (2009–2021)<sup>b</sup>.

| 2009 | 2010 | 2011 <sup>a</sup> | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 |
|------|------|-------------------|------|------|------|------|------|------|------|------|------|------|
| 14%  | 20%  | 24%               | 35%  | 43%  | 53%  | 54%  | 57%  | 59%  | 61%  | 63%  | 63%  | 65%  |

<sup>a</sup> Data for 2011 correspond to the end of the first semester of 2011.<sup>b</sup> Data has been obtained from the electricity retail market monitoring reports by the CNMC (CNMC, 2011; CNMC, 2012; CNMC, 2013; CNMC, 2014; CNMC, 2015; CNMC, 2017; CNMC, 2018; CNMC, 2019; CNMC, 2020; CNMC, 2021; CNMC, 2022).

Vesterberg and Krishnamurthy, 2016; Zethmayr and Kolata, 2018; Fabra et al., 2021). Patrick and Wolak (1997) develop an econometric model to quantify own-price elasticities of demand for electricity as well as the extent of intertemporal substitution in electricity consumption between pricing periods within the day and find substantial heterogeneity across the five industries considered in the English and Welsh power market from April 1991 to March 1995. Boisvert et al. (2007), using hourly electricity consumption and prices from the Niagara Mohawk Power Corporation's major customer accounts eligible for real-time pricing, assume a generalized Leontief functional form for the demand model and find that price responsiveness is modest and lower for industrial consumers compared to manufacturing, government/education, and commercial/retail customers. Lijesen (2007) applies a two-stage least squares regression model to estimate the relationship between total peak demand and spot market prices from the Netherlands for 2003 and finds the price elasticity of demand to be low. Vesterberg and Krishnamurthy (2016) use a direct metering data set of household electricity consumption in Sweden and employ a seemingly unrelated regression framework to estimate conditional load curves to better understand end-use-specific patterns. They estimate consumers' benefits from reallocating consumption from peak to off-peak hours and obtain small cost savings. Zethmayr and Kolata (2018) also use actual energy usage data, specifically from ComEd's residential customers in Chicago. Their study shows that nearly all these customers would have benefited from real-time pricing in 2016. They find a significant hedge premium embedded in the costs of flat-rate pricing for individual customers, resulting in customers paying 13% more than they would have under real-time pricing.

There have been few studies on the elasticity of demand for electricity prices in the Spanish market. Labandeira et al. (2012) use monthly aggregate consumption data from 28 Spanish provinces to estimate residential and industrial electricity demand through a log-linear panel data model from September 2005 to August 2007. Their results show that electricity demand is inelastic to price, although residential consumers (unlike industrial consumers) react to price in the short term. Blázquez et al. (2013) focus on residential consumption using aggregate data from 47 provinces from 2000 to 2008 with a log-linear dynamic demand function in a panel data model. Their results show that residential demand is inelastic but with demand elasticities appearing in the long run. Fabra et al. (2021) estimate a two-stage least squares regression model to investigate demand response to hourly price variation in the Spanish retail market from January 2016 to June 2017. Data are directly obtained from two utilities for hourly consumption of domestic customers with real-time pricing. Their findings suggest an average price elasticity of zero. At a European level, Pellini (2021) estimates a general unrestricted error correction model using a search algorithm to perform automatic specification for each country while controlling for outliers and structural breaks, with annual data from twelve countries for 1975–2018. This work also concludes that residential demand for electricity is inelastic in all the countries involved in the study, including Spain. Expanding the scope to a broader range of countries, Liddle and Huntington (2021) estimate a common correlated effects dynamic data panel model specification for high-income nations and use a mean-group estimator with country-specific trends for middle-income nations. They find a significant but small long-term price elasticity of demand for both groups of countries, although higher for high-income countries.

In an interesting recent paper, Ciarreta et al. (2023) propose a

theoretical model in which time-of-use pricing is applied, and consumers can switch between competing retailers based on the price schemes offered. For the Spanish market, assuming specific price elasticities of demand, they find that time-of-use pricing is more efficient than fixed tariffs (constituting a win-win scenario for consumers and retailers). Enrich et al. (2024), for their part, empirically evaluate the impact of a time-of-use pricing program (based on new regulations that came into effect in June 2021, establishing differentiating network and system costs within the day) on residential regulated tariff electricity consumption in Spain during the period 2018–2021 using machine learning techniques. They find, on average, evidence of a significant demand response during peak hours, mid-peak hours, and weekends.

According to previous literature, estimating the price elasticity of demand is not straightforward since there is a positive structural relationship between the price and quantity demanded. This positive association suggests endogeneity, as price changes may simultaneously affect quantity demanded and vice versa, thus counteracting the inverse relationship implicit in the price elasticity of demand. Various approaches have been proposed to overcome this drawback by using disaggregated demand data (as in Boisvert et al. (2007), including instrumental variables to substitute price in the demand equation (Lijesen, 2007; Fabra et al., 2021; Blázquez et al., 2013) or using instrumental variable estimators (Filippini, 2011).

Our approach differs from previous studies in the following ways. First, we use the vector autoregressive (VAR) and vector error correction (VEC) model methodology to examine the long- and short-run relationships between the series for wholesale market global price and quantity demanded by consumers. This model allows for the simultaneous estimation of both interdependent variables, thereby capturing the dynamic relationships among them while minimizing the risk of endogeneity biases. In each bivariate model, we include these series as endogenous variables, estimated separately for two types of consumer groups: those on a regulated tariff rate and therefore supplied by a reference retailer (hereinafter referred to as REF); and those in the free market and supplied by a competing retailer (hereinafter referred to as COM). It is important to note that the quantity demanded represents the aggregated quantity demanded by each type of retailer rather than the total system quantity demanded. The price series used as an endogenous variable in each bivariate model corresponds to the wholesale market global price associated with the quantity demanded by each type of retailer as determined by the Iberian Market NEMO.<sup>5</sup> These prices are calculated to cover all the wholesale market costs faced by each group of retailers. While these costs do not directly reflect prices applied to end-users, they serve as minimum threshold prices since they are prices paid by retailers for electricity. Second, to measure demand response to price signals, the spot price series, known one day before the consumption decision time, is included as a proxy of the expected retail price.<sup>6</sup> Third, to isolate such a response, we include three exogenous variables in the model to capture the impact of temperature and business/non-business days. These factors are recognized as primary determinants of Spanish electricity demand behavior, as identified by the Spanish TSO in their

<sup>5</sup> OMIE ([www.omie.es](http://www.omie.es)) is the Spanish nominated electricity market operator.<sup>6</sup> The spot price for each of the 24 h of the following day is known at t-1, since the spot market is a day-ahead market.

monthly electricity reports, which are accessible on the REE website.<sup>7</sup> Fourth, the total sample period is divided into two: from January 1, 2007, to December 31, 2018, and from January 1, 2019, to March 31, 2022. This division aims to identify changes in consumer behavior once the smart meter is widely deployed, enabling consumption to be registered hourly, a prerequisite for effective real-time pricing. Finally, for comparative purposes, the empirical exercise is separately made for each of the 24 hours.

This paper contributes to the literature on electricity demand analysis using hourly data on the wholesale market global price and quantity demanded by two types of retailers that supply electricity to consumers with different price schedules and differing incentives. Using a VAR-VEC methodology, our approach enables us to (i) examine the dynamic relationships between the wholesale market global price (that may be considered as a minimum retail price) and quantity demanded to infer information about the direction or directions of short-run causality, as well as to test for long-run equilibrium relationships between both variables; (ii) confirm temperature and business/non-business day as the main determinants that influence the behavior of electricity consumption in the Spanish market; and (iii) reveal price as a new determinant for demand from a particular group of consumers with incentives embedded into their pricing contracts to change their consumption habits and reduce their electricity bill. From our findings, it can be concluded that, from January 1, 2019, to March 31, 2022, consumers under the regulated tariff system reacted to changes in the expected retail prices and changed their consumption patterns (mainly during peak hours). Our results provide evidence for the rationality of the pricing decision-making process and can help policymakers assess the effectiveness of time-differentiated pricing policy, as well as help retailers plan supplies and pricing promotions or commercial tactics for customer engagement.

#### 4. Methodology and data

Vector autoregressive (VAR) models, introduced by Sims (1980), are widely used in time series research to characterize the joint dynamic behavior of two or more endogenous variables. It is a system of simultaneous equations where the endogenous variables are regressed on their lags and the lags of the other endogenous variables. Exogenous variables can also be included.

To correctly specify the model, a cointegration analysis is performed hourly to test for a long-run equilibrium relationship between the endogenous variables. A VEC model should be estimated instead of a VAR if the endogenous variables are cointegrated.

In this paper, the endogenous variables are the wholesale market global price and the quantity demanded associated with a type of retailer (REF or COM) whose consumers, respectively, are under a real-time pricing scheme or a variety of pricing options.

To isolate the impact of price on the quantity demanded, a dummy variable controlling for the business/non-business day effect and two temperature-derived series are included in the model as exogenous variables. To test for the sensitivity of demand to price, we additionally include the spot price as a proxy for the expected value of the retail price. Due to the technical complexity of the processes involved in generation, transmission, and consumption, the spot electricity market is a day-ahead market comprising 24 auctions for delivering electricity in each of the 24 hours of the following day. Spot prices for the electricity delivery at date  $t$  result from the hourly auctions at date  $t-1$ . Our point is that spot prices contain more valuable available information than any of the  $n$ -lagged wholesale market global prices associated with each type of retailer at any given consumption time. The former are traded one day in advance and refer to the price for delivering electricity during a particular hour of date  $t$ , while the latter refers to the price for

delivering electricity during a particular hour of date  $t-n$ . Furthermore, as electricity is not economically storable, the information matrix from one day to the next can change dramatically, and this justifies the inclusion of the spot price as a proxy for price in the retail market.<sup>8</sup>

The dataset comprises time series data on wholesale market global prices and quantity demanded by REF and COM, along with day-ahead market prices for each of the 24 hours of the day spanning from January 1, 2007, to March 31, 2022. These series have been downloaded from the CNMC website.<sup>9</sup> Primary temperature data are drawn from the Spanish Metrological Agency website ([www.aemet.es](http://www.aemet.es)). The dataset provides weather information gathered hourly from a network of weather stations nationwide. Given the nature of the demand series data, which refers to the entire Spanish market, it was necessary to build a national temperature series by compiling individualized station data. First, under the assumption that electricity demand concentrates in areas with high population density, based on demographic data drawn from the Spanish National Statistical Institute ([www.ine.es](http://www.ine.es)), the percentages of the population in each Spanish region were calculated to indicate relative importance to determine the corresponding number,  $n_i$ , of weather stations for each region  $i$ . Second, among all the weather stations within each region  $i$ , the  $n_i$  stations closest to the most populated areas within each region were chosen. Finally, the daily aggregated temperature series,  $T_t$ , was obtained as the average daily temperature registered at the weather stations selected according to the above criteria. Once the aggregated temperature series were obtained, we capture the non-linear response of the electricity demand to temperature with two temperature-derived series calculated as follows: heating degree days (hereinafter referred to as HDD) and cooling degree days (hereinafter referred to as CDD):  $HDD = \max(T_{tref} - T_t, 0)$  whereas  $CDD = \max(T_t - T_{tcref}, 0)$ , being  $T_t$  the temperature corresponding to day  $t$  and  $T_{tref}$  ( $T_{tcref}$ ) the reference temperature, which is considered to be the threshold below (above) which there is a need for heating (cooling) to maintain a comfortable indoor temperature. In this paper,  $T_{tref}$  and  $T_{tcref}$  have respectively been fixed at 18 °C and 22 °C<sup>10</sup>. Finally, a dummy variable for each day  $t$  of the studied period was constructed to capture the business/non-business day effect on electricity demand, taking the value of 1 if  $t$  corresponds to a working day (non-holiday, Monday to Friday) and 0 otherwise.

Each model is estimated separately for each of the 24 hours, as well as for each of the two considered types of retailers and for two sample periods for comparative purposes. Data series are log-transformed and differenced.

Thus, the VAR model to be estimated for each of the 24 h takes the following form:

<sup>8</sup> Please note that, regardless of the type of retailer, the spot price constitutes the benchmark for the wholesale market global cost.

<sup>9</sup> Data are available at [<https://www.cnmc.es/estadistica/precios-mercado-YYYY>], where 'YYYY' represents the specific year to which the data pertain. Last accessed on April 4, 2024.

<sup>10</sup> In establishing the reference temperatures for heating and cooling variables to define a comfort interval, we consider both empirical findings and technical recommendations. The conventional comfort temperature for Spain, as determined by Valor et al. (2001) and Pardo et al. (2002), stands at 18 °C. However, for this study, we opt to delineate distinct reference temperatures to encompass both heating and cooling needs. Drawing from guidance provided by the Spanish National Institute of Occupational Safety and Health, which suggests maintaining indoor temperatures between 17 °C and 24 °C in winter and between 23 °C and 27 °C in summer (Instituto Nacional de Seguridad e Higiene en el Trabajo), we adopt the conventional 18 °C for heating degree days calculation, while setting 22 °C as the reference temperature for cooling degree days computation. Moreover, Eskeland and Mideksa (2010) investigate the impact of climate variables on electricity consumption across 31 European countries, Spain included, utilizing a 10-year panel data model, and define the comfort temperature zone between 18 °C and 22 °C.

<sup>7</sup> [www.ree.es/es/datos/publicaciones/boletines-mensuales](http://www.ree.es/es/datos/publicaciones/boletines-mensuales).

$$\begin{aligned}\Delta \log(\text{RET}_{Q_t}) &= c_1 + \sum_{i=1}^p \varphi_{1i} \Delta \log(\text{RET}_{Q_{t-i}}) + \sum_{i=1}^p \theta_{1i} \Delta \log(\text{RET}_{P_{t-i}}) \\ &\quad + \beta_{11} \Delta \log[E_{t-1}(\text{RET}_{P_t})] + \beta_{12} \text{LAB}_t + \beta_{13} \Delta \log(\text{HDD}_t) \\ &\quad + \beta_{14} \Delta \log(\text{CDD}_t) + \varepsilon_{1t} \\ \Delta \log(\text{RET}_{P_t}) &= c_2 + \sum_{i=1}^p \varphi_{2i} \Delta \log(\text{RET}_{Q_{t-i}}) + \sum_{i=1}^p \theta_{2i} \Delta \log(\text{RET}_{P_{t-i}}) \\ &\quad + \beta_{21} \Delta \log[E_{t-1}(\text{RET}_{P_t})] + \beta_{22} \text{LAB}_t + \beta_{23} \Delta \log(\text{HDD}_t) \\ &\quad + \beta_{24} \Delta \log(\text{CDD}_t) + \varepsilon_{2t}\end{aligned}$$

where  $\text{RET}_{Q_t}$ : quantity demanded in the retail market by RET (REF or COM);  $\text{RET}_{P_t}$ : wholesale market global price associated with RET (REF or COM);  $\text{LAB}_t$ : a dummy variable taking value 1 if  $t$  corresponds to a working day (non-holiday, Monday to Friday) and 0, otherwise;  $\text{HDD}_t$ :  $\max(T_{\text{href}} - T_t, 0)$  being  $T_{\text{href}} = 18^\circ\text{C}$  and  $T_t$  the calculated average temperature at day  $t$ ;  $\text{CDD}_t$ :  $\max(T_t - T_{\text{cref}}, 0)$  being  $T_{\text{cref}} = 22^\circ\text{C}$  and  $T_t$  the calculated average temperature at day  $t$ ; and  $\varepsilon_{it}$ : error term  $i:1,2$ .

Each model is estimated using maximum likelihood. The VAR methodology requires data to be stationary or cointegrated to obtain consistent and unbiased estimates.<sup>11</sup> As previously indicated, when the endogenous variables are not stationary but cointegrated, the vector error correction (VEC) model should be used instead of the VAR model. In short, the VEC model is the appropriate econometric specification for variables with common underlying stochastic trends that move together on a non-stationary path.

As a preliminary step, we check the stationarity of the series of endogenous variables for each of the 24 h using the KPSS test (Kwiatkowski et al., 1992). If they are both individually non-stationary but integrated of order one, the Johansen cointegration test (Johansen, 1991, 1995), which involves the sequential implementation of two tests (trace and maximum eigenvalue tests), is used to test for the presence of cointegration. A VEC model is specified for cases in which the variables are then shown to be cointegrated.

In the VEC model, an error correction term measuring the previous period's deviation from long-run equilibrium is included:

$$\begin{aligned}\Delta \log(\text{RET}_{Q_t}) &= c_1 + \sum_{i=1}^p \varphi_{1i} \Delta \log(\text{RET}_{Q_{t-i}}) + \sum_{i=1}^p \theta_{1i} \Delta \log(\text{RET}_{P_{t-i}}) \\ &\quad + \beta_{11} \Delta \log[E_{t-1}(\text{RET}_{P_t})] + \beta_{12} \text{LAB}_t + \beta_{13} \Delta \log(\text{HDD}_t) \\ &\quad + \beta_{14} \Delta \log(\text{CDD}_t) + \lambda_Q (\text{RET}_{Q_{t-1}} - \alpha_0 - \alpha_1 \text{RET}_{P_{t-1}}) + v_{1t} \\ \Delta \log(\text{RET}_{P_t}) &= c_2 + \sum_{i=1}^p \varphi_{2i} \Delta \log(\text{RET}_{Q_{t-i}}) + \sum_{i=1}^p \theta_{2i} \Delta \log(\text{RET}_{P_{t-i}}) \\ &\quad + \beta_{21} \Delta \log[E_{t-1}(\text{RET}_{P_t})] + \beta_{22} \text{LAB}_t + \beta_{23} \Delta \log(\text{HDD}_t) \\ &\quad + \beta_{24} \Delta \log(\text{CDD}_t) + \lambda_P (\text{RET}_{Q_{t-1}} - \alpha_0 - \alpha_1 \text{RET}_{P_{t-1}}) + v_{2t}\end{aligned}$$

where  $\text{RET}_{Q_t}$ : quantity demanded in the retail market by RET (REF or COM);  $\text{RET}_{P_t}$ : wholesale market global price associated with RET (REF or COM);  $\text{LAB}_t$ : a dummy variable taking value 1 if  $t$  corresponds to a working day (non-holiday, Monday to Friday) and 0, otherwise;  $\text{HDD}_t$ :  $\max(T_{\text{href}} - T_t, 0)$  being  $T_{\text{href}} = 18^\circ\text{C}$ , and  $T_t$  the calculated average temperature at day  $t$ ;  $\text{CDD}_t$ :  $\max(T_t - T_{\text{cref}}, 0)$  being  $T_{\text{cref}} = 22^\circ\text{C}$ , and  $T_t$  the calculated average temperature at day  $t$ ;  $\text{RET}_{Q_{t-1}} - \alpha_0 - \alpha_1 \text{RET}_{P_{t-1}}$  is the long-run cointegration relationship between the quantity demanded and the wholesale market global price associated with RET (REF or COM);  $\lambda_Q$  and  $\lambda_P$  are the error-correction parameters that measure the speed of adjustment of the quantity demanded and wholesale market global price to long-run equilibrium, distinguishing RET (REF or COM); and  $v_{it}$ : error term  $i:1,2$ .

Before estimating the (VAR or VEC) model for each hour, type of

retailer, and sample period, the optimal number of lags was determined based on the Akaike information criterion (AIC).<sup>12</sup> Once the VAR-VEC model has been estimated, short-term causality between the endogenous variables is assessed through the Granger causality approach (Granger, 1969), which tests whether past values of one variable help predict another variable conditional on having already accounted for the effects on this latter of its past values. If they do, the former is said to “Granger cause” the latter. The cointegration analysis enables us to explore the presence of a long-run equilibrium relationship between them. We focus on the quantity demanded equation estimated results to analyze the impact of spot price, temperature, and business/non-business days on demand for each type of retailer. Given the expected positive structural relationship between quantity demanded and price, the spot price (which refers to electricity traded at  $t-1$  for delivery at  $t$ ) is included as a proxy of the expected value of the retail price. The spot price directly constitutes the benchmark for the regulated tariff rate and, to a greater or lesser extent, for the variety of pricing schemes effectively offered by the competing retailers to their current and potential customers. We test the significance of its parameter to measure the impact of variations in price on demand.

## 5. Results

The data are segmented into two sample periods. The first spans from January 1, 2007, to December 31, 2018, and the second covers January 1, 2019, to March 31, 2022. The analysis is conducted separately for each period for comparison.

This section is divided into four subsections, each focusing on a specific consumer group during the two time periods: before (January 1, 2007, to December 31, 2018) and after (January 1, 2019, to March 31, 2022) the deployment of smart meters. The consumer groups are those in the regulated tariff and those in the free market. The most relevant results are displayed in Tables 2–5.<sup>13</sup>

### 5.1. Consumers in the regulated tariff system from January 1, 2007, to December 31, 2018

Table 2 shows the estimated coefficients of the exogenous variables of the quantity demanded equation of the VAR or VEC model for each of the 24 hours, using as endogenous variables the wholesale market global price and quantity demanded series for consumers who are under the regulated tariff system (supplied by REF) during the period before the deployment of smart meters. Also reported are the Granger causality test results, and for the cases in which a VEC model is estimated, the estimated coefficients of the cointegration relationship equation and the error-correction parameters for both the quantity demanded and the wholesale market global price equations.

A bivariate VAR model is estimated for each of the hours in which there is no cointegration relationship between the endogenous variables. Although not shown due to space restrictions, as a result of the cointegration analysis, it is found that the wholesale market global price and the quantity demanded series by consumers under the regulated tariff system during this period are cointegrated for hours: 1, 4, 5, 13, 14, 20, 21, 22, 23 and 24. This result implies that there is a long-run equilibrium relationship between them. Consequently, a bivariate VEC model is specified for each of these hours. As can be observed in Table 2 (Panel B), the estimated coefficient of the cointegration equation,  $\alpha_1$ , is significantly negative in all cases, suggesting a long-run inverse relationship between wholesale market global prices and quantity

<sup>11</sup> Two non-stationary time series are cointegrated if a linear combination of these is stationary.

<sup>12</sup> To assess the validity of our estimations, we tested for both stability and autocorrelation of the residuals.

<sup>13</sup> The complete set of results are kept to save space but are available from the corresponding author, upon request.

**Table 2**

Quantity demanded and wholesale market global price associated with consumers on regulated tariffs (REF) from January 1, 2007, to December 31, 2018.

| VAR model specification                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |            |            |                                                      | VEC model specification                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                                |                                |                   |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------|------------|------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------|--------------------------------|-------------------|
| $\Delta \log(\text{COM\_Q}_t) = c_1 + \sum_{i=1}^p \varphi_{1i} \Delta \log(\text{COM\_Q}_{t-i}) + \sum_{i=1}^p \theta_{1i} \Delta \log(\text{COM\_P}_{t-i}) + \beta_{11} \Delta \log[\text{E}_{t-1}(\text{COM\_P}_t)] + \beta_{12} \text{LAB}_t + \beta_{13} \Delta \log(\text{HDD}_t) + \beta_{14} \Delta \log(\text{CDD}_t) + \varepsilon_{1t}$ $\Delta \log(\text{COM\_P}_t) = c_2 + \sum_{i=1}^p \varphi_{2i} \Delta \log(\text{COM\_Q}_{t-i}) + \sum_{i=1}^p \theta_{2i} \Delta \log(\text{COM\_P}_{t-i}) + \beta_{21} \Delta \log[\text{E}_{t-1}(\text{COM\_P}_t)] + \beta_{22} \text{LAB}_t + \beta_{23} \Delta \log(\text{HDD}_t) + \beta_{24} \Delta \log(\text{CDD}_t) + \varepsilon_{2t}$ |            |            |                                                      | $\Delta \log(\text{COM\_Q}_t) = c_1 + \sum_{i=1}^p \varphi_{1i} \Delta \log(\text{COM\_Q}_{t-i}) + \sum_{i=1}^p \theta_{1i} \Delta \log(\text{COM\_P}_{t-i}) + \beta_{11} \Delta \log[\text{E}_{t-1}(\text{COM\_P}_t)] + \beta_{12} \text{LAB}_t + \beta_{13} \Delta \log(\text{HDD}_t) + \beta_{14} \Delta \log(\text{CDD}_t) + \lambda_Q (\text{COM\_Q}_{t-1} - \alpha_0 - \alpha_1 \text{COM\_P}_{t-1}) + v_{1t}$ $\Delta \log(\text{COM\_P}_t) = c_2 + \sum_{i=1}^p \varphi_{2i} \Delta \log(\text{COM\_Q}_{t-i}) + \sum_{i=1}^p \theta_{2i} \Delta \log(\text{COM\_P}_{t-i}) + \beta_{21} \Delta \log[\text{E}_{t-1}(\text{COM\_P}_t)] + \beta_{22} \text{LAB}_t + \beta_{23} \Delta \log(\text{HDD}_t) + \beta_{24} \Delta \log(\text{CDD}_t) + \lambda_P (\text{COM\_Q}_{t-1} - \alpha_0 - \alpha_1 \text{COM\_P}_{t-1}) + v_{2t}$ |                                |                                |                   |
| Panel A: VAR-VEC model estimation results and Granger causality test results                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |            |            |                                                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                |                                |                   |
| Model                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | Hour       | $c_1$      | $[\text{E}_{t-1}(\text{RET}_{P_t})]$<br>$\beta_{11}$ | $[\text{LAB}_t]$<br>$\beta_{12}$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | $[\text{HDD}]$<br>$\beta_{13}$ | $[\text{CDD}]$<br>$\beta_{14}$ | Granger causality |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | H1         | 0.030224*  | 0.000462                                             | -0.044728*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 0.003382                       | 0.010915*                      | $Q \leq P$        |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | H2         | 0.040895*  | 0.001025*                                            | -0.060375*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 0.003962                       | 0.007434                       | $Q \leq P$        |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | H3         | 0.038454*  | 0.001237*                                            | -0.057136*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 0.003439                       | 0.007883                       | $Q \leq P$        |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | H4         | 0.032287*  | 0.000782*                                            | -0.048320*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 0.005245                       | 0.008214                       | $Q \leq P$        |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | H5         | 0.027028*  | 0.000748*                                            | -0.040587*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 0.008883                       | 0.006588                       | $Q \Rightarrow P$ |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | H6         | 0.020271*  | 0.000511*                                            | -0.030890*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 0.007279                       | 0.005358                       | $Q \Rightarrow P$ |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | H7         | 0.004698*  | 0.000764*                                            | -0.008279*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 0.006823                       | 0.010461*                      | $Q \leq P$        |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | H8         | -0.079742* | 0.000865*                                            | 0.113300*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | 0.011957*                      | 0.013981*                      | $Q \leq P$        |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | H9         | -0.107980* | 0.001844*                                            | 0.153501*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | 0.008535                       | 0.017356*                      | $Q \leq P$        |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | H10        | -0.045598* | 0.001635*                                            | 0.064279*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | 0.012393*                      | 0.021324*                      | $Q \leq P$        |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | H11        | -0.006358* | 0.000893*                                            | 0.007776*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | 0.017269*                      | 0.023590*                      | $Q \leq P$        |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | H12        | 0.005040*  | 0.000820*                                            | -0.008711*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 0.020908*                      | 0.026166*                      | $Q \leq P$        |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | H13        | 0.004818*  | 0.000815*                                            | -0.008346*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 0.026568*                      | 0.031855*                      | $Q \leq P$        |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | H14        | -0.001667  | 0.000456                                             | 0.001153                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | 0.028999*                      | 0.036295*                      | $Q \leq P$        |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | H15        | -0.002022  | 0.000322                                             | 0.001836                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | 0.030121*                      | 0.041174*                      | $Q \leq P$        |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | H16        | -0.008189* | 0.000443*                                            | 0.010660*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | 0.031248*                      | 0.047915*                      | $Q \leq P$        |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | H17        | -0.014235* | 0.000489*                                            | 0.019391*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | 0.032105*                      | 0.050834*                      | $Q \leq P$        |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | H18        | -0.022533* | 0.000329                                             | 0.031419*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | 0.033585*                      | 0.050994*                      | $Q \leq P$        |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | H19        | -0.020560* | 0.001363*                                            | 0.028813*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | 0.032700*                      | 0.049216*                      | $Q \leq P$        |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | H20        | -0.015825* | 0.001696*                                            | 0.022036*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | 0.030077*                      | 0.044761*                      | $Q \leq P$        |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | H21        | -0.002409  | 0.002350*                                            | 0.002727                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | 0.027736*                      | 0.036544*                      | $Q \leq P$        |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | H22        | 0.000220   | 0.003675*                                            | -0.001002                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | 0.026980*                      | 0.029483*                      | $Q \leq P$        |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | H23        | 0.001412   | 0.002275*                                            | -0.002628                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | 0.026966*                      | 0.030425*                      | $Q \leq P$        |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | H24        | -0.001148  | 0.000789*                                            | 0.001004                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | 0.025638*                      | 0.030948*                      | -                 |
| Panel B: Cointegration relationship estimation results                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |            |            |                                                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                |                                |                   |
| Hour                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | $\alpha_0$ | [Coint cf] |                                                      | [EC_Q]                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                                | [EC_P]                         |                   |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |            | $\alpha_1$ |                                                      | $\lambda_Q$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                                | $\lambda_P$                    |                   |
| H1                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | 10.77477*  | -0.50154*  |                                                      | -0.002754*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                | -0.005695                      |                   |
| H4                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | 9.99717*   | -0.43952*  |                                                      | -0.002697*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                | -0.005481                      |                   |
| H5                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | 9.95771*   | -0.44457*  |                                                      | -0.002967*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                | -0.005439                      |                   |
| H13                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | 9.68695*   | -0.21327*  |                                                      | -0.002120*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                | -0.003657                      |                   |
| H14                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | 9.86892*   | -0.24314*  |                                                      | -0.002014                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                                | -0.003969                      |                   |
| H20                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | 8.96662*   | -0.01494   |                                                      | -0.002563*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                | -0.004626                      |                   |
| H21                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | 9.70171*   | -0.17,334* |                                                      | -0.002108*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                | -0.004110                      |                   |
| H22                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | 10.1276*   | -0.2532*   |                                                      | -0.001952*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                | -0.003234                      |                   |
| H23                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | 11.10393*  | -0.49,716* |                                                      | -0.001950*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                | -0.004703                      |                   |
| H24                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | 10.92567*  | -0.49331*  |                                                      | -0.001823*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                | -0.005093                      |                   |

*Bivariate VAR-VEC model estimation results.* Granger causality outcomes: bidirectional Granger causality:  $Q \leq P$ ; unidirectional (quantity demanded Granger causes price):  $Q \Rightarrow P$ ; unidirectional (price Granger causes quantity demanded):  $Q \leq P$ ; no Granger causality: . \*denotes statistical significance at a 95% confidence level.

**Table 3**

Quantity demanded and wholesale market global price associated with consumers on regulated tariffs (REF) from January 1, 2019, to March 31, 2022.

| VAR model specification                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                |                              |                                                  | VEC model specification                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                          |                          |                   |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------|------------------------------|--------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------|--------------------------|-------------------|
| $\Delta \log(\text{COM}_t.Q_t) = c_1 + \sum_{i=1}^p \varphi_{1i} \Delta \log(\text{COM}_t.Q_{t-i}) + \sum_{i=1}^p \theta_{1i} \Delta \log(\text{COM}_t.P_{t-i}) + \beta_{11} \Delta \log[E_{t-1}(\text{COM}_t.P_t)] + \beta_{12} \text{LAB}_t + \beta_{13} \Delta \log(\text{HDD}_t) + \beta_{14} \Delta \log(\text{CDD}_t) + \varepsilon_{1t}$ $\Delta \log(\text{COM}_t.P_t) = c_2 + \sum_{i=1}^p \varphi_{2i} \Delta \log(\text{COM}_t.Q_{t-i}) + \sum_{i=1}^p \theta_{2i} \Delta \log(\text{COM}_t.P_{t-i}) + \beta_{21} \Delta \log[E_{t-1}(\text{COM}_t.P_t)] + \beta_{22} \text{LAB}_t + \beta_{23} \Delta \log(\text{HDD}_t) + \beta_{24} \Delta \log(\text{CDD}_t) + \varepsilon_{2t}$ |                |                              |                                                  | $\Delta \log(\text{COM}_t.Q_t) = c_1 + \sum_{i=1}^p \varphi_{1i} \Delta \log(\text{COM}_t.Q_{t-i}) + \sum_{i=1}^p \theta_{1i} \Delta \log(\text{COM}_t.P_{t-i}) + \beta_{11} \Delta \log[E_{t-1}(\text{COM}_t.P_t)] + \beta_{12} \text{LAB}_t + \beta_{13} \Delta \log(\text{HDD}_t) + \beta_{14} \Delta \log(\text{CDD}_t) + \lambda_Q (\text{COM}_t.Q_{t-1} - \alpha_0 - \alpha_1 \text{COM}_t.P_{t-1}) + v_{1t}$ $\Delta \log(\text{COM}_t.P_t) = c_2 + \sum_{i=1}^p \varphi_{2i} \Delta \log(\text{COM}_t.Q_{t-i}) + \sum_{i=1}^p \theta_{2i} \Delta \log(\text{COM}_t.P_{t-i}) + \beta_{21} \Delta \log[E_{t-1}(\text{COM}_t.P_t)] + \beta_{22} \text{LAB}_t + \beta_{23} \Delta \log(\text{HDD}_t) + \beta_{24} \Delta \log(\text{CDD}_t) + \lambda_P (\text{COM}_t.Q_{t-1} - \alpha_0 - \alpha_1 \text{COM}_t.P_{t-1}) + v_{2t}$ |                          |                          |                   |
| Panel A: VAR-VEC model estimation results and Granger causality test results                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                |                              |                                                  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                          |                          |                   |
| Model                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | Hour           | c <sub>1</sub>               | $[E_{t-1}(\text{RET}_{P_t})]$<br>β <sub>11</sub> | [LAB <sub>t</sub> ]<br>β <sub>12</sub>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | [HDD]<br>β <sub>13</sub> | [CDD]<br>β <sub>14</sub> | Granger causality |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H1             | 0.016391*                    | −0.006194*                                       | −0.023787*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 0.013110*                | 0.027932*                | Q => P            |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H2             | 0.034880*                    | −0.006446*                                       | −0.050370*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 0.012642*                | 0.025758*                | Q => P            |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H3             | 0.035667*                    | −0.002580                                        | −0.051551*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 0.012215*                | 0.025485*                | Q => P            |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H4             | 0.026106*                    | −0.000640                                        | −0.037755*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 0.013171*                | 0.024976*                | Q ≤ P             |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H5             | 0.016498*                    | −0.000462                                        | −0.023928*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 0.015055*                | 0.026573*                | Q ≤ P             |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H6             | 0.001197                     | −0.000343                                        | −0.002034                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 0.015372*                | 0.024697*                | Q ≤ P             |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H7             | −0.017683*                   | 0.003314*                                        | 0.025245*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 0.010042*                | 0.019445*                | Q ≤> P            |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H8             | −0.061177*                   | 0.016331*                                        | 0.086835*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | −0.003913                | 0.004262                 | Q => P            |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H9             | −0.066710*                   | 0.016461*                                        | 0.094908*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 0.003374                 | 0.007666                 | Q => P            |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H10            | −0.006622*                   | 0.004874                                         | 0.008829*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 0.022599*                | 0.010527                 | Q ≤> P            |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H11            | 0.025651*                    | −0.009262*                                       | −0.037155*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 0.035499*                | 0.011903*                | Q ≤> P            |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H12            | 0.047448*                    | −0.013798*                                       | −0.068367*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 0.044597*                | 0.020260*                | Q ≤> P            |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H13            | 0.051108*                    | −0.011199*                                       | −0.073689*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 0.048996*                | 0.030236*                | Q => P            |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H14            | 0.041924*                    | −0.012993*                                       | −0.060840*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 0.049866*                | 0.037072*                | Q ≤> P            |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H15            | 0.026022*                    | −0.007452*                                       | −0.037799*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 0.052741*                | 0.047441*                | Q ≤> P            |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H16            | 0.008841*                    | −0.002878                                        | −0.012954*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 0.060481*                | 0.063302*                | Q ≤> P            |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H17            | 0.003019                     | −0.002380                                        | −0.004555*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 0.066412*                | 0.071625*                | Q ≤> P            |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H18            | 0.002964                     | −0.006767*                                       | −0.004286                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 0.071926*                | 0.075661*                | Q ≤> P            |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H19            | 0.009675*                    | −0.014350*                                       | −0.014106*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 0.068593*                | 0.079165*                | −                 |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H20            | 0.012606*                    | −0.013072*                                       | −0.018620*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 0.057987*                | 0.073703*                | Q ≤> P            |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H21            | 0.017515*                    | −0.001700                                        | −0.025635*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 0.051250*                | 0.054841*                | Q ≤> P            |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H22            | 0.017516*                    | −0.002287                                        | −0.025224*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 0.046470*                | 0.042710*                | −                 |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H23            | 0.007092*                    | 0.002849                                         | −0.010235                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 0.044678*                | 0.040372*                | −                 |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H24            | −0.004584*                   | −0.002334                                        | 0.006524*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 0.043739*                | 0.046069*                | −                 |
| Panel B: Cointegration relationship estimation results                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                |                              |                                                  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                          |                          |                   |
| Hour                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | α <sub>0</sub> | [Coint cf]<br>α <sub>1</sub> | [EC_Q]<br>λ <sub>Q</sub>                         | [EC_P]<br>λ <sub>P</sub>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                          |                          |                   |
| H8                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 7.72508*       | 0.01208                      | −0.024174*                                       | −0.010283                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                          |                          |                   |
| H9                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 7.90702*       | −0.00793                     | −0.020648*                                       | −0.014698                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                          |                          |                   |
| H10                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 8.18001*       | −0.04932*                    | −0.014397*                                       | −0.011392                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                          |                          |                   |
| H11                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 8.37543*       | −0.07931*                    | −0.024515*                                       | −0.010946                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                          |                          |                   |
| H12                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 8.47591*       | −0.09789*                    | −0.036544*                                       | −0.012681                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                          |                          |                   |
| H13                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 8.50225*       | −0.09816*                    | −0.047035*                                       | −0.032426                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                          |                          |                   |
| H14                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 8.57175*       | −0.09607*                    | −0.039178*                                       | −0.029540                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                          |                          |                   |
| H15                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 8.50407*       | −0.07207*                    | −0.035499*                                       | −0.031750                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                          |                          |                   |
| H16                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 8.33827*       | −0.05056*                    | −0.030317*                                       | −0.030242                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                          |                          |                   |
| H17                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 8.22704*       | −0.03921*                    | −0.028908*                                       | −0.028196                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                          |                          |                   |
| H23                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 9.97223*       | 8.65538*                     | −0.08202*                                        | −0.016627*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                          |                          |                   |
| H24                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 9.91383*       | 8.52833*                     | −0.08894*                                        | −0.018973*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                          |                          |                   |

Bivariate VAR-VEC model estimation results. Granger causality outcomes: bidirectional Granger causality:  $Q \leq P$ ; unidirectional (quantity demanded Granger causes price):  $Q \Rightarrow P$ ; unidirectional (price Granger causes quantity demanded):  $Q \leq P$ ; no Granger causality: . \*denotes statistical significance at a 95% confidence level.

demand for all the mentioned hours. In addition, the estimated coefficient of the error correction term in the quantity demand equation,  $\lambda_Q$ , is statistically negative while being non-significant in the price equation ( $\lambda_P$ ), indicating that it is the quantity demanded that reacts to

short-term deviations and adjusts to long-run equilibrium.

Turning to Table 2 (Panel A), the Granger test for causality shows that there is short-run bidirectional causality in the Granger sense between price and quantity demanded for virtually all the hours of the day. Furthermore, the estimated coefficients of the business/non-business day dummy,  $\text{LAB}_t$ , are shown to be statistically significant for most of the hours, being negative (positive) overall for off-peak (peak) hours, thereby denoting lower (higher) variation in the quantity demanded for

**Table 4**

Quantity demanded and wholesale market global price associated with consumers in the free market (COM) from January 1, 2007, to December 31, 2018.

| VAR model specification                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |            |            |                                                      | VEC model specification                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                |                                |                   |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------|------------|------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------|--------------------------------|-------------------|
| $\Delta \log(\text{COM}_t) = c_1 + \sum_{i=1}^p \varphi_{1i} \Delta \log(\text{COM}_{t-i}) + \sum_{i=1}^p \theta_{1i} \Delta \log(\text{COM}_{t-i}) + \beta_{11} \Delta \log[\text{E}_{t-1}(\text{COM}_{P_t})] + \beta_{12} \text{LAB}_t + \beta_{13} \Delta \log(\text{HDD}_t) + \beta_{14} \Delta \log(\text{CDD}_t) + \varepsilon_{1t}$ $\Delta \log(\text{COM}_{P_t}) = c_2 + \sum_{i=1}^p \varphi_{2i} \Delta \log(\text{COM}_{t-i}) + \sum_{i=1}^p \theta_{2i} \Delta \log(\text{COM}_{P_{t-i}}) + \beta_{21} \Delta \log[\text{E}_{t-1}(\text{COM}_{P_t})] + \beta_{22} \text{LAB}_t + \beta_{23} \Delta \log(\text{HDD}_t) + \beta_{24} \Delta \log(\text{CDD}_t) + \varepsilon_{2t}$ |            |            |                                                      | $\Delta \log(\text{COM}_t) = c_1 + \sum_{i=1}^p \varphi_{1i} \Delta \log(\text{COM}_{t-i}) + \sum_{i=1}^p \theta_{1i} \Delta \log(\text{COM}_{P_{t-i}}) + \beta_{11} \Delta \log[\text{E}_{t-1}(\text{COM}_{P_t})] + \beta_{12} \text{LAB}_t + \beta_{13} \Delta \log(\text{HDD}_t) + \beta_{14} \Delta \log(\text{CDD}_t) + \lambda_Q (\text{COM}_{t-1} - \alpha_0 - \alpha_1 \text{COM}_{P_{t-1}}) + v_{1t}$ $\Delta \log(\text{COM}_{P_t}) = c_2 + \sum_{i=1}^p \varphi_{2i} \Delta \log(\text{COM}_{t-i}) + \sum_{i=1}^p \theta_{2i} \Delta \log(\text{COM}_{P_{t-i}}) + \beta_{21} \Delta \log[\text{E}_{t-1}(\text{COM}_{P_t})] + \beta_{22} \text{LAB}_t + \beta_{23} \Delta \log(\text{HDD}_t) + \beta_{24} \Delta \log(\text{CDD}_t) + \lambda_P (\text{COM}_{t-1} - \alpha_0 - \alpha_1 \text{COM}_{P_{t-1}}) + v_{2t}$ |                                |                                |                   |
| Panel A: VAR-VEC model estimation results and Granger causality test results                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |            |            |                                                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                                |                                |                   |
| Model                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | Hour       | $c_1$      | $[\text{E}_{t-1}(\text{RET}_{P_t})]$<br>$\beta_{11}$ | $[\text{LAB}_t]$<br>$\beta_{12}$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | $[\text{HDD}]$<br>$\beta_{13}$ | $[\text{CDD}]$<br>$\beta_{14}$ | Granger causality |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | H1         | -0.019066* | 0.000461*                                            | 0.028763*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | 0.001639                       | 0.004727                       | Q <=> P           |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | H2         | -0.018231* | 0.000430*                                            | 0.027484*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | 0.002174                       | 0.003300                       | Q <=> P           |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | H3         | -0.021386* | 0.000101                                             | 0.032135*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | 0.000853                       | 0.004174                       | Q <=> P           |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | H4         | -0.025317* | 0.000141                                             | 0.037759*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | 0.000896                       | 0.004707                       | Q <=> P           |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | H5         | -0.029153* | 0.000259*                                            | 0.043255*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | 0.002026                       | 0.005147                       | Q => P            |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | H6         | -0.037570* | 0.000209                                             | 0.055304*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | 0.001983                       | 0.006288*                      | Q => P            |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | H7         | -0.078123* | 0.000512*                                            | 0.114202*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | -0.000032                      | 0.008945*                      | Q <=> P           |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | H8         | -0.134093* | 0.000882*                                            | 0.195239*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | -0.000333                      | 0.011684*                      | Q <=> P           |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | H9         | -0.170467* | 0.001403*                                            | 0.247916*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | -0.001290                      | 0.016336*                      | Q => P            |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | H10        | -0.168253* | 0.001825*                                            | 0.244725*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | -0.000963                      | 0.018789*                      | Q <=> P           |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | H11        | -0.151338* | 0.001729*                                            | 0.220339*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | 0.000408                       | 0.021344*                      | Q <=> P           |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | H12        | -0.142576* | 0.001119*                                            | 0.207716*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | 0.002600                       | 0.024156*                      | Q <=> P           |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | H13        | -0.139135* | 0.001223*                                            | 0.202729*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | 0.003000                       | 0.026875*                      | Q <=> P           |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | H14        | -0.129991* | 0.000993*                                            | 0.189574*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | 0.002591                       | 0.029743*                      | Q <=> P           |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | H15        | -0.117395* | 0.000796*                                            | 0.171326*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | 0.001936                       | 0.031781*                      | Q <=> P           |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | H16        | -0.121043* | 0.000924*                                            | 0.176541*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | 0.001117                       | 0.033270*                      | Q <=> P           |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | H17        | -0.126890* | 0.000986*                                            | 0.184914*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | 0.001005                       | 0.034089*                      | Q <=> P           |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | H18        | -0.129676* | 0.001023*                                            | 0.188926*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | 0.001091                       | 0.033798*                      | Q <=> P           |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | H19        | -0.113600* | 0.001867*                                            | 0.165679*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | 0.002944                       | 0.032513*                      | Q <=> P           |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | H20        | -0.100283* | 0.001468*                                            | 0.146322*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | 0.003438                       | 0.030212*                      | Q <=> P           |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | H21        | -0.079936* | 0.003260*                                            | 0.116942*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | 0.004286                       | 0.025800*                      | Q <=> P           |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | H22        | -0.055503* | 0.004218*                                            | 0.081629*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | 0.004091                       | 0.021853*                      | Q <=> P           |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | H23        | -0.030174* | 0.002157*                                            | 0.044964*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | 0.004356                       | 0.019793*                      | Q <=> P           |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | H24        | -0.020746* | 0.001075*                                            | 0.031109*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | 0.004357                       | 0.018716*                      | Q <=> P           |
| Panel B: Cointegration relationship estimation results                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |            |            |                                                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                                |                                |                   |
| Hour                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | $\alpha_0$ |            | [Coint cf]                                           | [EC, Q]                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                | [EC, P]                        |                   |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |            |            | $\alpha_1$                                           | $\lambda_Q$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                                | $\lambda_P$                    |                   |
| H1                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | 9.15350*   |            | 0.15636*                                             | -0.004866*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                | 0.006843                       |                   |
| H2                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | 9.19581*   |            | 0.13625*                                             | -0.005046*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                | 0.007765                       |                   |
| H3                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | 9.22775*   |            | 0.12025*                                             | -0.005149*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                | 0.010106                       |                   |
| H4                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | 9.19958*   |            | 0.12469*                                             | -0.005182*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                | 0.011442                       |                   |
| H5                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | 9.21256*   |            | 0.12111*                                             | -0.005263*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                | 0.012254                       |                   |
| H6                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | 9.13525*   |            | 0.14598*                                             | -0.005388*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                | 0.011252                       |                   |
| H23                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | 8.96527*   |            | 0.22201*                                             | -0.005428*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                | 0.003448                       |                   |
| H24                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | 9.09813*   |            | 0.17792*                                             | -0.004843*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                | 0.004716                       |                   |

Bivariate VAR-VEC model estimation results. Granger causality outcomes: bidirectional Granger causality: Q <=> P; unidirectional (quantity demanded Granger causes price): Q => P; unidirectional (price Granger causes quantity demanded): Q <= P; no Granger causality: . \*denotes statistical significance at a 95% confidence level.

off-peak (peak) hours during business days.<sup>14</sup> Both temperature-derived variables (HDD<sub>t</sub> and CDD<sub>t</sub>) show significantly positive estimated coefficients for most peak hours, reflecting that the variation in the quantity demanded increases with high (low) temperatures due to the use of air conditioning (heating), except for the night hours where the estimated coefficients are not statistically significant.

Finally, we examine the reaction of the quantity demanded to price

<sup>14</sup> Off-peak hours encompass weekends, national holidays, and from 0 a.m. to 8 a.m. (hours from 1 to 7) on working days, with the remaining hours traditionally considered as peak hours. Peak load futures contracts for the Iberian market area define peak hours as those spanning from 8 a.m. to 8 p.m. (<https://www.omip.pt/es/downloads>). Following a regulatory change affecting all electricity consumers (MITECO, 2021), since June 2021, three periods have been distinguished for the purpose of applying system and network regulatory charges, resulting in the peak hours being divided into peak (ranging from 10 a.m. to 2 p.m. and from 6 p.m. to 10 p.m. on working days) and mid-peak periods (the remaining hours). Throughout this study, we refer to peak hours as those outside off-peak hours (without distinguishing between peak and mid-peak periods).

variations through the estimated coefficient of the expected value of the retail price,  $\beta_{11}$ , which is approximated by the spot (day-ahead) market for the same hour that is published (hence, known by consumers) one day in advance. The estimated value for this coefficient is significantly positive for 20 out of 24 hours, showing the structural positive relationship between the wholesale market global price and the quantity demanded. Therefore, from the results obtained, we find no evidence for price elasticity of demand when using data from consumers under the regulated tariff system for the period before the deployment of smart meters.

## 5.2. Consumers in the regulated tariff system from January 1, 2019, to March 31, 2022

The selected test and VAR-VEC model estimation results for consumers under the regulated tariff system (supplied by REF) during the period after the deployment of smart meters (from January 1, 2019, to March 31, 2022) are displayed in Table 3.

In this case, we obtain evidence of cointegration between price and quantity demanded for most peak hours (from hours 8 to 17 and hours

**Table 5**

Quantity demanded and wholesale market global price associated with consumers in the free market (COM) from January 1, 2019, to March 31, 2022.

| VAR model specification                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |            |            |                                                      | VEC model specification                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                                |                                |                   |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------|------------|------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------|--------------------------------|-------------------|
| $\Delta \log(\text{COM}_t) = c_1 + \sum_{i=1}^p \varphi_{1i} \Delta \log(\text{COM}_{t-i}) + \sum_{i=1}^p \theta_{1i} \Delta \log(\text{COM}_{t-i}) + \beta_{11} \Delta \log[\text{E}_{t-1}(\text{COM}_t)] + \beta_{12} \text{LAB}_t + \beta_{13} \Delta \log(\text{HDD}_t) + \beta_{14} \Delta \log(\text{CDD}_t) + \varepsilon_{1t}$ $\Delta \log(\text{COM}_{t-1}) = c_2 + \sum_{i=1}^p \varphi_{2i} \Delta \log(\text{COM}_{t-i}) + \sum_{i=1}^p \theta_{2i} \Delta \log(\text{COM}_{t-i}) + \beta_{21} \Delta \log[\text{E}_{t-1}(\text{COM}_t)] + \beta_{22} \text{LAB}_t + \beta_{23} \Delta \log(\text{HDD}_t) + \beta_{24} \Delta \log(\text{CDD}_t) + \varepsilon_{2t}$ |            |            |                                                      | $\Delta \log(\text{COM}_t) = c_1 + \sum_{i=1}^p \varphi_{1i} \Delta \log(\text{COM}_{t-i}) + \sum_{i=1}^p \theta_{1i} \Delta \log(\text{COM}_{t-i}) + \beta_{11} \Delta \log[\text{E}_{t-1}(\text{COM}_t)] + \beta_{12} \text{LAB}_t + \beta_{13} \Delta \log(\text{HDD}_t) + \beta_{14} \Delta \log(\text{CDD}_t) + \lambda_Q (\text{COM}_{t-1} - \alpha_0 - \alpha_1 \text{COM}_{t-1}) + v_{1t}$ $\Delta \log(\text{COM}_{t-1}) = c_2 + \sum_{i=1}^p \varphi_{2i} \Delta \log(\text{COM}_{t-i}) + \sum_{i=1}^p \theta_{2i} \Delta \log(\text{COM}_{t-i}) + \beta_{21} \Delta \log[\text{E}_{t-1}(\text{COM}_t)] + \beta_{22} \text{LAB}_t + \beta_{23} \Delta \log(\text{HDD}_t) + \beta_{24} \Delta \log(\text{CDD}_t) + \lambda_P (\text{COM}_{t-1} - \alpha_0 - \alpha_1 \text{COM}_{t-1}) + v_{2t}$ |                                |                                |                   |
| Panel A: VAR-VEC model estimation results and Granger causality test results                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |            |            |                                                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                |                                |                   |
| Model                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | Hour       | $c_1$      | $[\text{E}_{t-1}(\text{RET}_{P_t})]$<br>$\beta_{11}$ | $[\text{LAB}_t]$<br>$\beta_{12}$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | $[\text{HDD}]$<br>$\beta_{13}$ | $[\text{CDD}]$<br>$\beta_{14}$ | Granger causality |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | H1         | -0.033465* | 0.003228                                             | 0.047691*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | 0.005600                       | 0.007559                       | $Q \leq P$        |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | H2         | -0.034121* | 0.003182                                             | 0.048693*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | 0.007049                       | 0.007673                       | $Q \leq P$        |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | H3         | -0.036803* | 0.003654*                                            | 0.052543*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | 0.005781                       | 0.005296                       | $Q \leq P$        |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | H4         | -0.041771* | 0.003404*                                            | 0.059654*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | 0.003563                       | 0.003776                       | $Q \leq P$        |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | H5         | -0.048338* | 0.003057*                                            | 0.069065*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | 0.002949                       | 0.003310                       | $Q \leq P$        |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | H6         | -0.060361* | 0.004127*                                            | 0.086211*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | -0.000143                      | 0.005314*                      | $Q \leq P$        |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | H7         | -0.113084* | 0.009006*                                            | 0.161734*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | -0.005444                      | 0.003424                       | $Q \Rightarrow P$ |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | H8         | -0.164636* | 0.018545*                                            | 0.235512*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | -0.008468                      | 0.001678                       | $Q \Rightarrow P$ |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | H9         | -0.193058* | 0.027286*                                            | 0.275850*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | -0.009247                      | 0.004242                       | $Q \Rightarrow P$ |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | H10        | -0.190231* | 0.030897*                                            | 0.271781*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | -0.003369                      | 0.009117                       | $Q \Rightarrow P$ |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | H11        | -0.172842* | 0.023088*                                            | 0.247205*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | 0.003208                       | 0.012140                       | $Q \Rightarrow P$ |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | H12        | -0.159135* | 0.015551*                                            | 0.227638*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | 0.006308                       | 0.017100*                      | -                 |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | H13        | -0.153640* | 0.008411*                                            | 0.219879*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | 0.008919                       | 0.022226*                      | -                 |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | H14        | -0.141040* | 0.007764*                                            | 0.201813*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | 0.009550                       | 0.026728*                      | $Q \Rightarrow P$ |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | H15        | -0.127182* | 0.005624*                                            | 0.182047*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | 0.011073                       | 0.030474*                      | $Q \Rightarrow P$ |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | H16        | -0.136496* | 0.005235*                                            | 0.195373*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | 0.009937                       | 0.034035*                      | $Q \Rightarrow P$ |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | H17        | -0.144909* | 0.004741*                                            | 0.207263*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | 0.008811                       | 0.037433*                      | $Q \Rightarrow P$ |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | H18        | -0.144226* | 0.006423*                                            | 0.206180*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | 0.009904                       | 0.038539*                      | $Q \Rightarrow P$ |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | H19        | -0.122274* | 0.008997*                                            | 0.174638*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | 0.011836                       | 0.037507*                      | $Q \Rightarrow P$ |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | H20        | -0.100828* | 0.013658*                                            | 0.143759*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | 0.008862                       | 0.035651*                      | $Q \leq P$        |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | H21        | -0.078640* | 0.016728*                                            | 0.112171*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | 0.010042                       | 0.028938*                      | $Q \leq P$        |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | H22        | -0.056758* | 0.012885*                                            | 0.080923*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | 0.009413                       | 0.026287*                      | $Q \leq P$        |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | H23        | -0.034064* | 0.009020*                                            | 0.048496*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | 0.008902*                      | 0.025408*                      | $Q \leq P$        |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | H24        | -0.028846* | 0.004123                                             | 0.041003*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | 0.007192                       | 0.025521*                      | $Q \Rightarrow P$ |
| Panel B. Cointegration relationship estimation results                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |            |            |                                                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                |                                |                   |
| Hour                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | $\alpha_0$ |            | [Coint cf]                                           | [EC_Q]                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                                | [EC_P]                         |                   |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |            |            | $\alpha_1$                                           | $\lambda_Q$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                                | $\lambda_P$                    |                   |
| H1                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 9.86794*   |            | 0.02699*                                             | -0.052446*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                | 0.008547                       |                   |
| H2                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 9.81963*   |            | 0.02687*                                             | -0.054380*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                | 0.012101                       |                   |
| H3                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 9.79069*   |            | 0.02514*                                             | -0.056832*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                | 0.019049                       |                   |
| H4                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 9.77161*   |            | 0.02540*                                             | -0.060083*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                | 0.034108                       |                   |
| H5                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 9.76309*   |            | 0.02627*                                             | -0.064042*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                | 0.024376                       |                   |
| H6                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 9.76023*   |            | 0.03071*                                             | -0.074809*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                | 0.005521                       |                   |
| H7                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 9.77546*   |            | 0.04396*                                             | -0.109042*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                | 0.003789                       |                   |
| H8                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 9.74021*   |            | 0.07145*                                             | -0.108566*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                | -0.006134                      |                   |
| H11                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 9.89674*   |            | 0.06609*                                             | -0.102165*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                | -0.020697                      |                   |
| H12                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 9.93916*   |            | 0.05960*                                             | -0.106970*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                | -0.029878                      |                   |
| H13                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 9.96597*   |            | 0.05515*                                             | -0.113614*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                | -0.051210                      |                   |
| H14                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 9.99276*   |            | 0.04866*                                             | -0.107400*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                | -0.040829                      |                   |
| H15                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 9.96602*   |            | 0.04936*                                             | -0.100803*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                | -0.039298                      |                   |
| H16                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 9.89802*   |            | 0.05929*                                             | -0.093207*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                | -0.037803                      |                   |
| H17                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 9.86960*   |            | 0.06276*                                             | -0.087726*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                | -0.035485                      |                   |
| H18                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 9.86278*   |            | 0.06273*                                             | -0.081279*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                | -0.018900                      |                   |
| H19                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 9.85928*   |            | 0.06429*                                             | -0.063965*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                | -0.007180                      |                   |
| H21                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 9.9083*    |            | 0.0597*                                              | -0.055071*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                | -0.005969                      |                   |
| H22                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 9.98762*   |            | 0.03973*                                             | -0.063421*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                | -0.008034                      |                   |
| H23                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 9.97223*   |            | 0.02981*                                             | -0.064646*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                | -0.008015                      |                   |
| H24                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 9.91383*   |            | 0.02681*                                             | -0.058474*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                | -0.010372                      |                   |

Bivariate VAR-VEC model estimation results. Granger causality outcomes: bidirectional Granger causality:  $Q \leq P$ ; unidirectional (quantity demanded Granger causes price):  $Q \Rightarrow P$ ; unidirectional (price Granger causes quantity demanded):  $Q \leq P$ ; no Granger causality: . \*denotes statistical significance at a 95% confidence level.

23 and 24). The wholesale market global price and the quantity demanded by consumers in the regulated tariff system for each of the mentioned hours were given a dynamic specification using the bivariate VEC model. The corresponding estimated cointegration coefficients,  $\alpha_1$ , are significantly negative, evidencing a long-run inverse relationship between price and quantity demanded. The estimated coefficient of the error correction term in the quantity demanded equation,  $\lambda_Q$  is statistically negative, while it is non-significant in the price equation ( $\lambda_P$ ), which leads us to conclude that the quantity demanded reacts to short-

term deviations and adjusts to long-run equilibrium. The corresponding bivariate VAR model is estimated for the remainder of the hours.

The results of the Granger causality test reveal that there is a bidirectional causality in the Granger sense between price and quantity demanded for hours 7, from 10 to 12, from 14 to 18, 20, and 21, whereas it is unidirectional flowing from quantity demanded to price for hours from 1 to 3, 8, 9 and 13, and unidirectional flowing from price to quantity demanded from hours 4 to 6. The estimated coefficients of the business/non-business day dummy,  $\text{LAB}_t$ , are significantly negative overall, except for hours 7, 8, 9, 10, and 24, which are shown to be

positive. The estimated coefficients of both temperature-derived variables ( $HDD_t$  and  $CDD_t$ ) are significantly positive, with the only exceptions being hours 8 and 9, which are not statistically different from zero.

Interestingly, when examining the reaction of demand to price variations through the estimated coefficient of the expected value of the retail price,  $\beta_{11}$ , which is approximated by the spot (day-ahead) market price, the results considerably differ from those obtained for the period before the deployment of smart meters. For January 2019 to March 2022, the estimated values of  $\beta_{11}$  become significantly negative for several hours (1, 2, 11 to 15, and 18 to 20) or statistically non-significant (3–6, 10, 16 to 17, and 21 to 24). It is worth highlighting that this indicates a change in customer behavior, constituting statistical evidence of a consumer reaction to prices. Furthermore, it is noteworthy that most of the hours for the parameter  $\beta_{11}$  value is significantly negative during peak hours.<sup>15</sup>

In light of the shift in demand profile resulting from the implementation of restrictive measures during the lockdown period in Spain (Santiago et al., 2021), the models were re-estimated as a robustness test of the obtained results. This re-estimation covers the period from January 1, 2019, to March 31, 2022, excluding the COVID-19 lockdown period (from March 14 to June 21, 2020).<sup>16</sup> The outcomes are detailed in Table A.1.1 of Appendix 1. The wholesale market global price series and the corresponding quantity demanded by consumers under the regulated tariff are found to be cointegrated for nearly the same set of hours. Some disparities emerge in the results of the Granger short-term causality tests. It is worth noting that the Granger causality test is notably influenced by the time horizon (Hurn et al., 2016). The estimated parameter values of the business/non-business day and the two temperature variables display consistent signs and significance levels with those obtained from January 2019 to March 2022. Furthermore, evidence continues to emerge regarding the demand responsiveness to variations in the expected retail price, albeit for fewer hours, specifically for hours 12 to 15, 19, and 20.<sup>17</sup>

### 5.3. Consumers in the free market from January 1, 2007, to December 31, 2018

Comparing the results from the previous two subsections (5.1 and 5.2) with those of consumers who directly contract with a competing retailer in the free market is worthwhile. It should be remembered that the regulated tariff is calculated as a function of the spot (day-ahead) price. Under the free market system, consumers are offered a wide range of options, including flat tariffs (for all hours or specific blocks of hours) and tariffs indexed to the spot price. Therefore, it should be emphasized that consumers in the so-called free market may constitute a much more heterogeneous group than those of the regulated tariff system, although prices contracted in the free market tend to be time-invariant (Fabra

et al., 2021).

Table 4 presents the selected tests and VAR-VEC estimation results for each of the 24 hours and consumers who were in the free market before the deployment of smart meters (from January 1, 2007 to December 31, 2018). As can be seen, a VEC model is estimated for hours from 1 to 6, 23, and 24, as the wholesale market global price and the quantity demanded series are shown to be cointegrated, meaning that they share a long-run equilibrium relationship. A VAR model is estimated for the remaining hours. In contrast to the case of consumers on the regulated tariff system, the estimated coefficient for the cointegration equation,  $\alpha_1$ , is significantly positive in all cases, suggesting a long-run direct relationship between price and quantity demanded for consumers in the free market. The estimated coefficient of the error correction term in the quantity demand equation,  $\lambda_Q$ , is statistically negative, while it is non-significant in the price equation ( $\lambda_P$ ). This finding enables us to state that the quantity demanded reacts to short-term deviations and adjusts to long-run equilibrium.

Regarding short-run causality, we find statistical evidence of bidirectional causality in the Granger sense between the wholesale market global price and the quantity demanded for all hours of the day, except for hours from 5 to 6 and 9, where a unidirectional relationship is found flowing from the quantity demanded to price. To capture the impact of factors other than price on the quantity demanded, we then analyze the estimated values of the coefficients associated with these additional variables included in the model. The estimated coefficients of the business/non-business day dummy,  $LAB_t$ , are significantly positive for all cases. Similar results are obtained for the temperature-derived variable,  $CDD_t$ , for most hours (from 6 to 24), reflecting more use of air-conditioning on hot days. There appears to be no impact of low temperature on the variations in the quantity demanded by consumers in the free market during this period, as can be deduced from the non-significance of the coefficient of the temperature-derived variable  $HDD_t$ . This result would be somewhat consistent with that of Labandeira et al. (2012), who found greater sensitivity to heat than cold.

Lastly, we study the reaction of the quantity demanded to price variations using the significance test of the estimated coefficient of the expected value of the retail price,  $\beta_{11}$ , which is approximated by the spot (day-ahead) market. The estimated value for this coefficient is significantly positive for 21 out of 24 hours, showing a structurally positive relationship between price and quantity demand. Thus, no evidence of demand sensitivity to price changes is found for consumers in the free market (supplied by COM) before the deployment of smart meters (from January 1, 2007, to December 31, 2018).

### 5.4. Consumers in the free market from January 1, 2019, to March 31, 2022

Like the previous subsections, the selected test and VAR-VEC model estimation results for consumers in the free market for the period after the deployment of smart meters are shown in Table 5.

In this case, it is remarkable that the wholesale market global price and quantity demanded series for virtually all the hours are cointegrated, with only the exceptions of hours 9, 10, and 20 (for which a VAR model is estimated). Consequently, a VEC model is specified for the remaining hours. The estimated cointegration coefficients,  $\alpha_1$ , are all significantly positive, evidencing a long-run direct relationship between the wholesale market global price and the quantity demanded. The estimated coefficient of the error correction term in the quantity demanded equation,  $\lambda_Q$  is statistically negative, while it is non-significant in the price equation ( $\lambda_P$ ), indicating that the quantity demanded reacts to short-term deviations and adjusts to long-run equilibrium.

The Granger causality test provides evidence of a bidirectional causality in the Granger sense between the wholesale market global price and the quantity demanded by consumers supplied by COM for hours from 3 to 6 and from 20 to 23, whereas it is unidirectional flowing from

<sup>15</sup> During winter, the daily maximum demand occurs at hours 11 and 19. In summer, peak demand levels are additionally registered at hours 13, 16, and 17 (REE, 2013).

<sup>16</sup> The Spanish Government declared a state of alarm due to the health emergency posed by COVID-19 on March 14, 2020, instituting a nationwide lockdown. This state of alarm, along with the confinement measures, was extended until June 21, 2020.

<sup>17</sup> To ensure that the results obtained during the period from January 1, 2019 to March 31, 2022 were not solely influenced by the extraordinary circumstances of COVID-19 and the episodes of high market prices beginning in June 2021, but rather remain under normal market conditions following the deployment of smart meters, the models were re-estimated for the period from January 1, 2019, to March 13, 2020 (the day before the onset of COVID-19 confinement). The results are presented in Appendix 2 (Table A.2.1). The findings are fully consistent with those obtained for the sample period spanning from January 1, 2019, to March 31, 2022. However, evidence of consumer responsiveness to variations in the expected price is limited to hours 12, 13, and 14 during this period.

quantity demanded to price for hours 7 to 11, from 14 to 19 and hour 24, and also unidirectional but flowing from price to quantity demanded for hour 2. The estimated coefficients of the business/non-business day dummy,  $LAB_t$ , are always significantly positive. Like the period before the deployment of smart meters, the estimated coefficient for the temperature-derived variable,  $CDD_t$ , is significantly positive for hours 6 and 12 to 24. However, the estimated coefficient for the other temperature-derived variable,  $HDD_t$ , is not statistically significant for most hours.

Finally, when examining the reaction of demand to price variations through the significance test of the estimated coefficient of the expected value of the retail price,  $\beta_{11}$ , which is approximated by the spot (day-ahead) market price, the results coincide with those obtained for the consumers supplied by COM in the previous subsection. Specifically, the estimated value for this coefficient is significantly positive for 21 out of 24 hours, showing a structurally positive relationship between price and quantity demanded. Therefore, no evidence of demand sensitivity to price is found for consumers in the free market, neither during the period before the deployment of smart meters (from January 1, 2007 to December 31, 2018) nor during the period afterward (from January 1, 2019 to March 31, 2022). It is worth noting that consumers who are in the liberalized market do not have, in many cases, the incentive to adjust their consumption to price variations, given that, in most instances, they contract a fixed price for all hours; in other words, for these consumers, there is no incentive to manage demand actively.

Like the preceding Section 5.2, given the alteration in demand profile during the COVID-19 confinement, the models underwent re-estimation to validate the findings obtained. This re-estimation covers the period from January 1, 2019, to March 31, 2022, excluding the COVID-19 lockdown period (from March 14 to June 21, 2020). The results are displayed in Table A.1.2 of Appendix 1. Upon excluding the lockdown period, the number of hours for which the wholesale market global price and the quantity demanded by consumers in the free market are found to be cointegrated reduces considerably, showing a picture much more similar to that obtained for this consumer group in the period for 2007–2018. The Granger causality tests, along with the estimated parameter values of the business/non-business day and the two temperature variables, consistently yield results comparable to those from January 2019 to March 2022. The same can be said regarding the findings related to the primary objective of this paper. The lack of statistical significance of  $\beta_{11}$  for hours 1, 2, and 24, along with its significantly positive value for the remaining hours, contradicts any evidence of active demand management by consumers in the free market.<sup>18</sup>

## 6. Discussion

Based on the estimation results, we find a long-run equilibrium relationship between the wholesale market global price and the quantity demanded in a non-negligible number of hours, with a noticeable trend towards peak hours from January 2019 to March 2022. Two series are said to be cointegrated when they maintain a long-term equilibrium relationship, that is, when they evolve together. Thus, any permanent departure from their equilibrium level by one variable requires a corresponding permanent departure of the other series, ensuring their linear combination remains close to their equilibrium level. From the

results obtained, there seems to be a pattern so that cointegration relationships could be more plausibly observed in hours with stable or more easily predictable demand, such as those with low variability (off-peak) or rigid demand periods.

This intuition could help explain the change observed when comparing the results for consumers in the free market during this period, depending on whether the days of COVID-19 confinement are excluded. Excluding the lockdown period reduces the number of hours for which the price and demand series of consumers in the free market are cointegrated, specifically from 21 to just 12 hours (2–8, 10 to 12, 17, and 18). It should be noted that during confinement, demand from industrial and service sector consumers decreased significantly (Santiago et al., 2021), likely contributing to more demand stability.

Contrarily, the confinement period does not affect the cointegration results between the price and demand series for consumers in the tariff-regulated system. Notably, a significant change was observed when comparing the period before the deployment of smart meters (2007–2018) with the period afterward (2019–March 2022). During the latter, the emergence of long-term equilibrium relationships between price and quantity demanded for hours from 8 to 12 and from 15 to 17 may suggest these consumers' implementation of active demand strategies. However, it should be noted that a more detailed analysis will be necessary to identify the factors behind cointegration, which are beyond the scope of this study.

Statistical evidence is found for bidirectional short-run causality in the Granger sense for virtually every hour during the period 2007–2018, changing to unidirectional Granger causality during the period January 2019 to March 2022 for some hours in the case of reference suppliers and most hours in the case of competing retailers.

The signs of the estimated coefficients accompanying the variables included to control for demand variations other than price contain some insightful results. First, a change can be observed for consumers on the regulated tariff system between the two periods under consideration. In particular, the number of hours in which the estimated coefficient for the business/non-business day dummy variable is negative, indicating that variations in the quantity demanded are lower for business days, increases from 12 to 19 hours from the first to the second period. Such a result contrasts with that for consumers in the free market, in which the estimated coefficients for this variable are always positive (for all hours and both periods). This finding may indicate that reference supplier consumers are more dynamic in managing their demand during non-business days because they have more flexibility in shifting their consumption according to price expectations.

Regarding the estimated coefficients of the temperature-derived variables, they are significantly positive overall for the case of consumers who obtain their electricity from reference suppliers, indicating that greater variations follow greater needs for heating and air-conditioning in the quantity demanded. The cooling degree day parameter estimates also display significantly positive signs for competing retailer consumers. However, low average temperatures, approximated in the model by the heating degree day variable, do not affect the variation in quantity demanded significantly. This finding may be attributed to the characteristic climate of Spain, which features mild winters and hot summers. Additionally, unlike cooling systems that heavily rely on electricity, the availability of alternative energy sources for heating purposes (such as natural gas, diesel, oil, and steam) could also contribute to this result. Differences in heating systems could explain the disparity in results between the two types of consumers. It is worth considering that consumers on regulated tariffs are primarily residential, while consumers in the free market represent a much more heterogeneous group, including residential, commercial, and industrial. For example, steam heating systems in Spain are predominantly used by industrial enterprises rather than by domestic consumers.

Finally, the estimated coefficients of the variable included to capture the price sensitivity from the quantity demanded clearly evidence a change in consumption decisions by consumers under the regulated

<sup>18</sup> Similarly to what was done for the group of consumers in the regulated tariff system, the models were re-estimated for the period from January 1, 2019, to March 13, 2020 (the day before the onset of COVID-19 confinement). The results are presented in Appendix 2 (Table A.2.2). The findings are fully consistent with those obtained for the period spanning from January 1, 2019, to March 31, 2022, except for certain discrepancies observed in the outcomes of Granger short-term causality tests. No evidence of consumer responsiveness to variations in the expected price is found for consumers in the free market during this period.

tariff system. In this paper, the spot price is considered a proxy for the expected retail price since this is the main cost component of the wholesale market global price, which applies to all retailers and, in turn, to their consumers. Unlike consumers in the free market who contract their electricity with a competing retailer under various pricing schemes (with flat pricing being the most common), the tariff paid by consumers in the regulated market is a function of the spot price. Therefore, those consumers are incentivized to reduce their consumption when the spot price increases, as, *ceteris paribus*, the higher the spot price, the higher the tariff. Our findings show that for the period after the deployment of smart meters, consumers under the regulated tariff system demonstrate price sensitivity during certain hours, particularly during peak hours when the incentive is stronger.<sup>19</sup>

Although results are not directly comparable with those from previous research (due to remarkable differences in the dataset used, the methodology employed, or the regulation of each analyzed market), the magnitude of the responsiveness, measured as the estimated coefficient accompanying the expected retail price, is relatively low and this is consistent with the literature. Nevertheless, more important than magnitude is the detected change in consumption behavior of a particular group of end-users who opt for real-time pricing (under the so-called regulated tariff system) between the period before and after the deployment of smart meters. This result makes us optimistic about the willingness of residential demand-side participants to actively manage their consumption now that they have the technology to monitor their hourly electricity usage, enabling them to adapt to expected price variations during the day. Furthermore, skyrocketing energy prices beginning in the summer of 2021 presumably boosted interest in demand-side management strategies. Be that as it may, our results show a drastic change in how consumers react to expected price variations when they have incentives embedded in their tariff structure (linked to wholesale market price) and have technology installed that enables the hourly recording of consumption.

Moreover, it should be emphasized that smaller consumers are increasingly opting for real-time pricing tariffs. Specifically, the percentage of consumers with contracted power under 15 kW choosing these tariffs rose from 22% in 2018 to 34% in 2019. Nevertheless, there remains significant room for improvement.

Real-time pricing can contribute to efficient use of existing generation capacity, reducing the need for increasing spare capacity to deal with bottlenecks and market imbalances and guaranteeing supply security, especially given the penetration of intermittent renewable sources. Under ideal market conditions, the most efficient retail pricing regime would vary in real time to reflect the level of scarcity (Fabra et al., 2021). Kopsakangas-Savolainen and Svento (2012) find that real-time pricing diminishes the need for total capacity even with inelastic demand. Thus, emphasis should be placed on (i) market reform to allow wholesale prices to be competitive, (ii) promoting real-time pricing to transmit price signals to the highest number of consumers, and (iii) information campaigns about the economic benefits of strategies for adjusting consumption to price changes, which in turn may reduce price volatility in the wholesale market (Patrick and Wolak, 1997); (iv) continuous energy information feedback and social marketing (Batalla-Bejerano et al., 2020); (v) promotion of training in price risk hedging strategies, especially for retailers and large consumers (Flaim, 2000); and (vi) subsidizing the acquisition or installing energy-efficient devices and appliances, as well as energy rehabilitation of buildings.

## 7. Conclusions

This analysis contributes to the empirical literature on consumer

sensitivity to price variations. Identifying the factors that most influence sensitiveness is critical since demand-side management can reduce electricity consumption, help manage supply security, and reach climate goals.

Focused on the Spanish market, we analyze the response of the aggregated quantity demanded by each of the two types of retailers in the Spanish electricity market to price, on an hourly basis. Spanish consumers can be under a regulated tariff regime and obtain electricity from reference suppliers (the default option for small consumers) or from competing retailers in the free market. Consumers under the regulated tariff system are exposed to real-time pricing, while consumers in the free market can contract their supply with any competing retailer under differentiated price schemes, although time-invariant pricing appears to be the preferred option. Our research enables us to compare the behavior of consumers under two different pricing schemes for each of the 24 hours of the day. For comparison purposes, the analysis is separately conducted for the period before and after the widespread deployment of smart meters in Spain, achieved at the beginning of 2019, given that these meters provide consumers with real-time data about their electricity consumption and enable the implementation of real-time pricing tariffs.

Unlike from 2007 to 2018, from January 2019 to March 2022, we obtain empirical evidence that consumers under the regulated tariff regime react to increases (decreases) in expected prices by decreasing (increasing) consumption. This responsiveness is not observed among consumers in the free market, most of whom have fixed-price contracts throughout the day. These results remain consistent even when we exclude the COVID-19 lockdown period from the second sample sub-period. We acknowledge that our approach does not allow us to account for consumers transitioning from the regulated tariff to the free market or vice versa, nor to differentiate between shifts in consumption across hours and potential energy savings. Another framework will be necessary to analyze these issues, leaving them open for future research.

## CRedit authorship contribution statement

**Dolores Furió:** Writing – review & editing, Writing – original draft, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis. **Javier Moreno-del-Castillo:** Writing – original draft, Software, Resources, Methodology, Investigation, Data curation.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data availability

Data will be made available on request.

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<sup>19</sup> Excluding the lockdown period from the period after the deployment of smart meters, all the hours for which there is evidence of price responsiveness are peak hours.

## Appendix 1

Estimation results for the period January 01, 2019 to March 31, 2022 excluding the lockdown period (March 13, 2020 to June 21, 2020).

Table A.1.1

Quantity demanded and wholesale market global price associated with consumers on regulated tariffs (REF). January 01, 2019 to March 13, 2020 and June 22, 2020 to March 31, 2022.

| VAR model specification                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |            |            |                                               | VEC model specification                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                                |                                |                   |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------|------------|-----------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------|--------------------------------|-------------------|
| $\Delta \log(\text{COM}_{t-i}) = c_1 + \sum_{i=1}^p \varphi_{1i} \Delta \log(\text{COM}_{t-i}) + \sum_{i=1}^p \theta_{1i} \Delta \log(\text{COM}_{t-i}) + \beta_{11} \Delta \log[E_{t-1}(\text{COM}_{t-i})] + \beta_{12} \text{LAB}_t + \beta_{13} \Delta \log(\text{HDD}_t) + \beta_{14} \Delta \log(\text{CDD}_t) + \varepsilon_{1t}$ $\Delta \log(\text{COM}_{t-i}) = c_2 + \sum_{i=1}^p \varphi_{2i} \Delta \log(\text{COM}_{t-i}) + \sum_{i=1}^p \theta_{2i} \Delta \log(\text{COM}_{t-i}) + \beta_{21} \Delta \log[E_{t-1}(\text{COM}_{t-i})] + \beta_{22} \text{LAB}_t + \beta_{23} \Delta \log(\text{HDD}_t) + \beta_{24} \Delta \log(\text{CDD}_t) + \varepsilon_{2t}$ |            |            |                                               | $\Delta \log(\text{COM}_{t-i}) = c_1 + \sum_{i=1}^p \varphi_{1i} \Delta \log(\text{COM}_{t-i}) + \sum_{i=1}^p \theta_{1i} \Delta \log(\text{COM}_{t-i}) + \beta_{11} \Delta \log[E_{t-1}(\text{COM}_{t-i})] + \beta_{12} \text{LAB}_t + \beta_{13} \Delta \log(\text{HDD}_t) + \beta_{14} \Delta \log(\text{CDD}_t) + \lambda_Q (\text{COM}_{t-i} - \alpha_0 - \alpha_1 \text{COM}_{t-i}) + v_{1t}$ $\Delta \log(\text{COM}_{t-i}) = c_2 + \sum_{i=1}^p \varphi_{2i} \Delta \log(\text{COM}_{t-i}) + \sum_{i=1}^p \theta_{2i} \Delta \log(\text{COM}_{t-i}) + \beta_{21} \Delta \log[E_{t-1}(\text{COM}_{t-i})] + \beta_{22} \text{LAB}_t + \beta_{23} \Delta \log(\text{HDD}_t) + \beta_{24} \Delta \log(\text{CDD}_t) + \lambda_P (\text{COM}_{t-i} - \alpha_0 - \alpha_1 \text{COM}_{t-i}) + v_{2t}$ |                                |                                |                   |
| Panel A: VAR-VEC model estimation results and Granger causality test results                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |            |            |                                               |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                                |                                |                   |
| Model                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | Hour       | $c_1$      | $[E_{t-1}(\text{RET}_{P_t})]$<br>$\beta_{11}$ | $[\text{LAB}_t]$<br>$\beta_{12}$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | $[\text{HDD}]$<br>$\beta_{13}$ | $[\text{CDD}]$<br>$\beta_{14}$ | Granger causality |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H1         | 0.01481*   | −0.004036                                     | −0.02159*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 0.014361*                      | 0.027998*                      | −                 |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H2         | 0.03502*   | −0.004945                                     | −0.05039*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 0.014628*                      | 0.027192*                      | $Q \leq P$        |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H3         | 0.03603*   | −0.001310                                     | −0.05192*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 0.013294*                      | 0.027378*                      | $Q \leq P$        |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H4         | 0.02611*   | −0.000095                                     | −0.03760*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 0.016042*                      | 0.027524*                      | $Q \Rightarrow P$ |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H5         | 0.01680*   | −0.000055                                     | −0.02423*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 0.017731*                      | 0.029149*                      | $Q \leq P$        |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H6         | 0.00103    | 0.000105                                      | −0.001694                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 0.018010*                      | 0.027105*                      | $Q \leq P$        |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H7         | −0.02064*  | 0.003922*                                     | 0.029625*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 0.011600*                      | 0.019611*                      | $Q \leq P$        |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H8         | −0.07292*  | 0.019180*                                     | 0.10415*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 0.000076                       | 0.003073                       | $Q \leq P$        |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H9         | −0.07284*  | 0.020589*                                     | 0.10388*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 0.007946                       | 0.006677                       | $Q \Rightarrow P$ |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H10        | −0.00552*  | 0.006801*                                     | 0.00759*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 0.024032*                      | 0.010544                       | $Q \leq P$        |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H11        | 0.03190*   | −0.006344                                     | −0.04606*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 0.032779*                      | 0.012559*                      | $Q \leq P$        |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H12        | 0.054883*  | −0.011475*                                    | −0.07911*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 0.040081*                      | 0.020855*                      | $Q \leq P$        |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H13        | 0.055253*  | −0.009205*                                    | −0.07981*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 0.043575*                      | 0.032212*                      | $Q \leq P$        |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H14        | 0.043654*  | −0.010311*                                    | −0.06362*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 0.044211*                      | 0.041028*                      | $Q \leq P$        |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H15        | 0.025705*  | −0.005742*                                    | −0.03762*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 0.048151*                      | 0.053033*                      | $Q \leq P$        |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H16        | 0.007840*  | −0.001670                                     | −0.01177*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 0.056759*                      | 0.070721*                      | $Q \leq P$        |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H17        | 0.002341   | −0.001265                                     | −0.003862                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 0.062699*                      | 0.080007*                      | $Q \leq P$        |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H18        | 0.002185   | −0.004916                                     | −0.003694                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 0.064651*                      | 0.084428*                      | $Q \leq P$        |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H19        | 0.010278*  | −0.012498*                                    | −0.01509*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 0.063193*                      | 0.087099*                      | $Q \Rightarrow P$ |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H20        | 0.012202*  | −0.014747*                                    | −0.01779*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 0.053638*                      | 0.081401*                      | $Q \leq P$        |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H21        | 0.019288*  | −0.005709                                     | −0.02768*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 0.046264*                      | 0.061358*                      | $Q \leq P$        |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H22        | 0.020722*  | 0.000622                                      | −0.02947*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 0.044659*                      | 0.047475*                      | $Q \leq P$        |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H23        | 0.008600*  | 0.004975                                      | −0.01222*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 0.044782*                      | 0.044785*                      | −                 |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H24        | −0.005215* | −0.000991                                     | 0.00742*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 0.044730*                      | 0.051491*                      | −                 |
| Panel B: Cointegration relationship estimation results                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |            |            |                                               |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                                |                                |                   |
| Hour                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | $\alpha_0$ | [CoInt cf] | [EC_Q]                                        | [EC_P]                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                                |                                |                   |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |            | $\alpha_1$ | $\lambda_Q$                                   | $\lambda_P$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                |                                |                   |
| H8                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 7.89833*   | −0.02410*  | −0.024052*                                    | −0.013401                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                                |                                |                   |
| H9                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 8.06256*   | −0.04049*  | −0.019512*                                    | −0.016407                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                                |                                |                   |
| H10                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 8.29839*   | −0.07426*  | −0.017821*                                    | −0.007823                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                                |                                |                   |
| H11                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 8.45986*   | −0.09726*  | −0.027158*                                    | −0.005265                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                                |                                |                   |
| H12                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 8.52416*   | −0.10819*  | −0.038120*                                    | −0.008548                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                                |                                |                   |
| H13                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 8.51574*   | −0.10104*  | −0.047053*                                    | −0.026433                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                                |                                |                   |
| H14                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 8.56451*   | −0.09456*  | −0.038211*                                    | −0.023293                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                                |                                |                   |
| H15                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 8.49880*   | −0.07098*  | −0.034316*                                    | −0.026020                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                                |                                |                   |
| H16                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 8.38560*   | −0.06083*  | −0.029845*                                    | −0.025641                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                                |                                |                   |
| H17                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 8.30087*   | −0.05512*  | −0.028746*                                    | −0.024159                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                                |                                |                   |
| H18                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 8.27356*   | −0.05125*  | −0.027341*                                    | −0.013769                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                                |                                |                   |
| H24                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 8.60979*   | −0.10615*  | −0.020356*                                    | −0.004151                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                                |                                |                   |

Bivariate VAR/VEC model estimation results. Granger causality outcomes: bidirectional Granger causality:  $Q \leq P$ ; unidirectional (quantity demanded Granger causes price):  $Q \Rightarrow P$ ; unidirectional (price Granger causes quantity demanded):  $Q \leq P$ ; no Granger causality: .\*denotes statistical significance at a 95% confidence level.

**Table A.1.2**

Quantity demanded and wholesale market global price associated with consumers in the free market (COM). January 01, 2019 to March 13, 2020 & June 22, 2020 to March 31, 2022.

| VAR model specification                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |            |                          |                                        | VEC model specification                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                         |                         |                   |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------|--------------------------|----------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------|-------------------------|-------------------|
| $\Delta \log(\text{COM}_{-Q_t}) = c_1 + \sum_{i=1}^p \varphi_{1i} \Delta \log(\text{COM}_{-Q_{t-i}}) + \sum_{i=1}^p \theta_{1i} \Delta \log(\text{COM}_{-P_{t-i}}) + \beta_{11} \Delta \log[E_{t-1}(\text{COM}_{-P_t})] + \beta_{12} \text{LAB}_t + \beta_{13} \Delta \log(\text{HDD}_t) + \beta_{14} \Delta \log(\text{CDD}_t) + \varepsilon_{1t}$ $\Delta \log(\text{COM}_{-P_t}) = c_2 + \sum_{i=1}^p \varphi_{2i} \Delta \log(\text{COM}_{-Q_{t-i}}) + \sum_{i=1}^p \theta_{2i} \Delta \log(\text{COM}_{-P_{t-i}}) + \beta_{21} \Delta \log[E_{t-1}(\text{COM}_{-P_t})] + \beta_{22} \text{LAB}_t + \beta_{23} \Delta \log(\text{HDD}_t) + \beta_{24} \Delta \log(\text{CDD}_t) + \varepsilon_{2t}$ |            |                          |                                        | $\Delta \log(\text{COM}_{-Q_t}) = c_1 + \sum_{i=1}^p \varphi_{1i} \Delta \log(\text{COM}_{-Q_{t-i}}) + \sum_{i=1}^p \theta_{1i} \Delta \log(\text{COM}_{-P_{t-i}}) + \beta_{11} \Delta \log[E_{t-1}(\text{COM}_{-P_t})] + \beta_{12} \text{LAB}_t + \beta_{13} \Delta \log(\text{HDD}_t) + \beta_{14} \Delta \log(\text{CDD}_t) + \lambda_Q (\text{COM}_{-Q_{t-1}} - \alpha_0 - \alpha_1 \text{COM}_{-P_{t-1}}) + v_{1t}$ $\Delta \log(\text{COM}_{-P_t}) = c_2 + \sum_{i=1}^p \varphi_{2i} \Delta \log(\text{COM}_{-Q_{t-i}}) + \sum_{i=1}^p \theta_{2i} \Delta \log(\text{COM}_{-P_{t-i}}) + \beta_{21} \Delta \log[E_{t-1}(\text{COM}_{-P_t})] + \beta_{22} \text{LAB}_t + \beta_{23} \Delta \log(\text{HDD}_t) + \beta_{24} \Delta \log(\text{CDD}_t) + \lambda_P (\text{COM}_{-Q_{t-1}} - \alpha_0 - \alpha_1 \text{COM}_{-P_{t-1}}) + v_{2t}$ |                         |                         |                   |
| Panel A: VAR-VEC model estimation results and Granger causality test results                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |            |                          |                                        |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                         |                         |                   |
| Model                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | Hour       | $c_1$                    | $[E_{t-1}(RET_{P_t})]$<br>$\beta_{11}$ | $[LAB_t]$<br>$\beta_{12}$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | $[HDD]$<br>$\beta_{13}$ | $[CDD]$<br>$\beta_{14}$ | Granger causality |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | H1         | -0.035249*               | 0.004279                               | 0.050284*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | 0.004974                | 0.010741*               | $Q \leq P$        |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | H2         | -0.038083*               | 0.003493                               | 0.054392*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | 0.006299                | 0.008972*               | $Q \leq P$        |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | H3         | -0.041454*               | 0.003799*                              | 0.059227*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | 0.004749                | 0.007093                | $Q \leq P$        |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | H4         | -0.045914*               | 0.003283*                              | 0.065642*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | 0.002803                | 0.004570                | $Q \leq P$        |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | H5         | -0.051991*               | 0.002839*                              | 0.074227*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | 0.003135                | 0.004451                | $Q \leq P$        |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | H6         | -0.065428*               | 0.003607*                              | 0.093456*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | 0.000537                | 0.005953                | $Q \leq P$        |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | H7         | -0.119982*               | 0.007532*                              | 0.171649*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | -0.005337               | 0.004702                | $Q \Rightarrow P$ |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | H8         | -0.175045*               | 0.016955*                              | 0.251017*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | -0.007517               | 0.002131                | $Q \Rightarrow P$ |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | H9         | -0.202394*               | 0.027191*                              | 0.290831*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | -0.006764               | 0.005702                | $Q \Rightarrow P$ |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | H10        | -0.196685*               | 0.031099*                              | 0.281666*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | -0.002390               | 0.005488                | $Q \Rightarrow P$ |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | H11        | -0.177974*               | 0.026557*                              | 0.254604*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | 0.003572                | 0.011850                | $Q \Rightarrow P$ |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | H12        | -0.166877*               | 0.017185*                              | 0.238747*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | 0.007076                | 0.017100*               | -                 |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | H13        | -0.161683*               | 0.011012*                              | 0.231834*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | 0.010833                | 0.025083*               | $Q \Rightarrow P$ |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | H14        | -0.152858*               | 0.008253*                              | 0.219195*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | 0.009579                | 0.032677*               | $Q \Rightarrow P$ |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | H15        | -0.138115*               | 0.006088*                              | 0.197851*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | 0.011224                | 0.035829*               | $Q \leq P$        |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | H16        | -0.146318*               | 0.005731*                              | 0.209561*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | 0.011337                | 0.039314*               | $Q \leq P$        |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | H17        | -0.156818*               | 0.004800*                              | 0.224262*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | 0.010447                | 0.040726*               | $Q \leq P$        |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | H18        | -0.156531*               | 0.006383*                              | 0.223639*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | 0.012077                | 0.042015*               | $Q \Rightarrow P$ |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | H19        | -0.133213*               | 0.010397*                              | 0.190261*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | 0.015411*               | 0.040973*               | $Q \leq P$        |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | H20        | -0.111103*               | 0.013914*                              | 0.159075*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | 0.009338                | 0.040316*               | $Q \leq P$        |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | H21        | -0.085565*               | 0.018030*                              | 0.122952*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | 0.009935                | 0.035125*               | $Q \leq P$        |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | H22        | -0.060572*               | 0.015917*                              | 0.087173*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | 0.010736*               | 0.032504*               | $Q \leq P$        |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | H23        | -0.034695*               | 0.009337*                              | 0.049419*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | 0.011201*               | 0.026825*               | $Q \leq P$        |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | H24        | -0.028399*               | 0.004071                               | 0.040552*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | 0.008094                | 0.028215*               | $Q \Rightarrow P$ |
| Panel B: Cointegration relationship estimation results                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |            |                          |                                        |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                         |                         |                   |
| Hour                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | $\alpha_0$ | [Coint cf]<br>$\alpha_1$ | [EC, Q]<br>$\lambda_Q$                 | [EC, P]<br>$\lambda_P$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                         |                         |                   |
| H2                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | 9.90290*   | 0.00911*                 | -0.091663*                             | 0.001198                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                         |                         |                   |
| H3                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | 9.86672*   | 0.00892*                 | -0.095734*                             | -0.008497                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                         |                         |                   |
| H4                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | 9.84472*   | 0.00983*                 | -0.106428*                             | 0.013729                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                         |                         |                   |
| H5                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | 9.83610*   | 0.01071*                 | -0.125742*                             | 0.047933                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                         |                         |                   |
| H6                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | 9.83969*   | 0.01376*                 | -0.150545*                             | 0.031419                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                         |                         |                   |
| H7                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | 9.86463*   | 0.02507*                 | -0.219520*                             | -0.012787                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                         |                         |                   |
| H8                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | 9.85420*   | 0.04736*                 | -0.187294*                             | -0.033332                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                         |                         |                   |
| H10                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | 9.97569*   | 0.04327*                 | -0.174727*                             | -0.048433                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                         |                         |                   |
| H11                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | 10.0390*   | 0.0356*                  | -0.171551*                             | -0.033388                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                         |                         |                   |
| H12                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | 10.0739*   | 0.03062*                 | -0.186105*                             | -0.054424                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                         |                         |                   |
| H17                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | 10.0022*   | 0.03393*                 | -0.155016*                             | -0.087895                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                         |                         |                   |
| H18                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | 10.0113*   | 0.03068*                 | -0.144591*                             | -0.052150                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                         |                         |                   |

Bivariate VAR/VEC model estimation results. Granger causality outcomes: bidirectional Granger causality:  $Q < = > P$ ; unidirectional (quantity demanded Granger causes price):  $Q = > P$ ; unidirectional (price Granger causes quantity demanded):  $Q \leq P$ ; no Granger causality: . \* denotes statistical significance at a 95% confidence level.

## Appendix 2

Estimation results for the period January 01, 2019 to March 13, 2020.

Table A.2.1

Quantity demanded and wholesale market global price associated with consumers on regulated tariffs (REF). January 01, 2019 to March 13, 2020.

| VAR model specification                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |            |            |                                               | VEC model specification                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                                |                                |                   |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------|------------|-----------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------|--------------------------------|-------------------|
| $\Delta \log(\text{COM}_{t-i}) = c_1 + \sum_{i=1}^p \varphi_{1i} \Delta \log(\text{COM}_{t-i}) + \sum_{i=1}^p \theta_{1i} \Delta \log(\text{COM}_{t-i}) + \beta_{11} \Delta \log[E_{t-1}(\text{COM}_{t-i})] + \beta_{12} \text{LAB}_t + \beta_{13} \Delta \log(\text{HDD}_t) + \beta_{14} \Delta \log(\text{CDD}_t) + \varepsilon_{1t}$ $\Delta \log(\text{COM}_{t-i}) = c_2 + \sum_{i=1}^p \varphi_{2i} \Delta \log(\text{COM}_{t-i}) + \sum_{i=1}^p \theta_{2i} \Delta \log(\text{COM}_{t-i}) + \beta_{21} \Delta \log[E_{t-1}(\text{COM}_{t-i})] + \beta_{22} \text{LAB}_t + \beta_{23} \Delta \log(\text{HDD}_t) + \beta_{24} \Delta \log(\text{CDD}_t) + \varepsilon_{2t}$ |            |            |                                               | $\Delta \log(\text{COM}_{t-i}) = c_1 + \sum_{i=1}^p \varphi_{1i} \Delta \log(\text{COM}_{t-i}) + \sum_{i=1}^p \theta_{1i} \Delta \log(\text{COM}_{t-i}) + \beta_{11} \Delta \log[E_{t-1}(\text{COM}_{t-i})] + \beta_{12} \text{LAB}_t + \beta_{13} \Delta \log(\text{HDD}_t) + \beta_{14} \Delta \log(\text{CDD}_t) + \lambda_Q (\text{COM}_{t-1} - \alpha_0 - \alpha_1 \text{COM}_{t-1}) + v_{1t}$ $\Delta \log(\text{COM}_{t-i}) = c_2 + \sum_{i=1}^p \varphi_{2i} \Delta \log(\text{COM}_{t-i}) + \sum_{i=1}^p \theta_{2i} \Delta \log(\text{COM}_{t-i}) + \beta_{21} \Delta \log[E_{t-1}(\text{COM}_{t-i})] + \beta_{22} \text{LAB}_t + \beta_{23} \Delta \log(\text{HDD}_t) + \beta_{24} \Delta \log(\text{CDD}_t) + \lambda_P (\text{COM}_{t-1} - \alpha_0 - \alpha_1 \text{COM}_{t-1}) + v_{2t}$ |                                |                                |                   |
| Panel A: VAR-VEC model estimation results and Granger causality test results                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |            |            |                                               |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                                |                                |                   |
| Model                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | Hour       | $c_1$      | $[E_{t-1}(\text{RET}_{P_t})]$<br>$\beta_{11}$ | $[\text{LAB}_t]$<br>$\beta_{12}$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | $[\text{HDD}]$<br>$\beta_{13}$ | $[\text{CDD}]$<br>$\beta_{14}$ | Granger causality |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H1         | 0.019302*  | 0.007530                                      | -0.02821*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 0.015838*                      | 0.026014*                      | -                 |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H2         | 0.043023*  | 0.001191                                      | -0.06291*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 0.016624*                      | 0.022920*                      | $Q \leq P$        |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H3         | 0.039125*  | 0.004140                                      | -0.05701*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 0.014558*                      | 0.023204*                      | -                 |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H4         | 0.037799*  | 0.001845                                      | -0.05531*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 0.01316*                       | 0.019372*                      | $Q \leq P$        |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H5         | 0.017969*  | 0.001999                                      | -0.02596*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 0.016039*                      | 0.022188*                      | $Q \Rightarrow P$ |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H6         | 0.004093*  | 0.002721                                      | -0.00588*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 0.021358*                      | 0.025070*                      | $Q \leq P$        |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H7         | -0.019560* | 0.002449                                      | 0.027975*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 0.015924*                      | 0.019551*                      | $Q \leq P$        |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H8         | -0.073276* | 0.016271*                                     | 0.103716*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 0.001147                       | 0.012138                       | $Q \leq P$        |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H9         | -0.069620  | 0.027335*                                     | 0.098702*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 0.003750                       | 0.008116                       | $Q \leq P$        |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H10        | -0.004620  | 0.009830                                      | 0.006543                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 0.028331*                      | 0.008007                       | $Q \leq P$        |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H11        | 0.033049*  | -0.009821                                     | -0.04803*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 0.037200*                      | 0.012859                       | $Q \leq P$        |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H12        | 0.047322*  | -0.025318*                                    | -0.06859*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 0.050100*                      | 0.024963*                      | $Q \leq P$        |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H13        | 0.046844*  | -0.028378*                                    | -0.06747*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 0.054339*                      | 0.036245*                      | $Q \leq P$        |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H14        | 0.033150*  | -0.023943*                                    | -0.04746*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 0.053223*                      | 0.040816*                      | $Q \leq P$        |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H15        | 0.026077*  | -0.012449                                     | -0.03666*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 0.053941*                      | 0.049848*                      | $Q \leq P$        |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H16        | 0.002076   | -0.000363                                     | -0.002007                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 0.061159*                      | 0.065608*                      | $Q \leq P$        |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H17        | -0.003215  | 0.000540                                      | 0.005978                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 0.069655*                      | 0.077483*                      | $Q \leq P$        |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H18        | 0.002340   | -0.008369                                     | -0.002204                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 0.074329*                      | 0.085642*                      | $Q \leq P$        |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H19        | 0.012238*  | -0.007512                                     | -0.01702*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 0.068728*                      | 0.087213*                      | $Q \leq P$        |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H20        | 0.014515*  | -0.005642                                     | -0.02005*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 0.058553*                      | 0.071096*                      | $Q \leq P$        |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H21        | 0.019153*  | -0.008776                                     | -0.02747*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 0.038704*                      | 0.047718*                      | $Q \leq P$        |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H22        | 0.028472*  | -0.000298                                     | -0.04045*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 0.042553*                      | 0.032667*                      | $Q \leq P$        |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H23        | 0.014520*  | 0.007596                                      | -0.02035*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 0.046216*                      | 0.030898*                      | $Q \leq P$        |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H24        | -0.008567* | 0.004497                                      | 0.01270*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 0.049722*                      | 0.040603*                      | -                 |
| Panel B Cointegration relationship estimation results                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |            |            |                                               |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                                |                                |                   |
| Hour                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | $\alpha_0$ | [Coint cf] |                                               | [EC, Q]                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                                | [EC, P]                        |                   |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |            | $\alpha_1$ |                                               | $\lambda_Q$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                | $\lambda_P$                    |                   |
| H4                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 7.77818*   | -0.03660*  |                                               | -0.030561*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                                | -0.015042                      |                   |
| H5                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 7.76958*   | -0.04296*  |                                               | -0.022326*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                                | -0.023713                      |                   |
| H18                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 7.49937*   | 0.14396*   |                                               | -0.029591*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                                | -0.023714                      |                   |
| H19                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 7.18575*   | 0.23388*   |                                               | -0.026878*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                                | -0.000239                      |                   |
| H20                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 7.06792*   | 0.28263*   |                                               | -0.020312*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                                | 0.000624                       |                   |
| H21                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 7.53681*   | 0.19172*   |                                               | -0.01422**                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                                | -0.000305                      |                   |

Bivariate VAR/VEC model estimation results. Granger causality outcomes: bidirectional Granger causality:  $Q \leq P$ ; unidirectional (quantity demanded Granger causes price):  $Q \Rightarrow P$ ; unidirectional (price Granger causes quantity demanded):  $Q \leq P$ ; no Granger causality: . \* and \*\* denotes statistical significance at a 95% confidence level and a 90% confidence level.

**Table A.2.2**

Quantity demanded and wholesale market global price associated with consumers in the free market (COM). January 01, 2019 to March 13, 2020.

| VAR model specification                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |            |            |                                        | VEC model specification                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                                |                                |                   |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------|------------|----------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------|--------------------------------|-------------------|
| $\Delta \log(\text{COM}_{t_i}) = c_1 + \sum_{i=1}^p \varphi_{1i} \Delta \log(\text{COM}_{t-i}) + \sum_{i=1}^p \theta_{1i} \Delta \log(\text{COM}_{t-i}) + \beta_{11} \Delta \log[E_{t-1}(\text{COM}_{t_i})] + \beta_{12} \text{LAB}_t + \beta_{13} \Delta \log(\text{HDD}_t) + \beta_{14} \Delta \log(\text{CDD}_t) + \varepsilon_{1t}$ $\Delta \log(\text{COM}_{t_i}) = c_2 + \sum_{i=1}^p \varphi_{2i} \Delta \log(\text{COM}_{t-i}) + \sum_{i=1}^p \theta_{2i} \Delta \log(\text{COM}_{t-i}) + \beta_{21} \Delta \log[E_{t-1}(\text{COM}_{t_i})] + \beta_{22} \text{LAB}_t + \beta_{23} \Delta \log(\text{HDD}_t) + \beta_{24} \Delta \log(\text{CDD}_t) + \varepsilon_{2t}$ |            |            |                                        | $\Delta \log(\text{COM}_{t_i}) = c_1 + \sum_{i=1}^p \varphi_{1i} \Delta \log(\text{COM}_{t-i}) + \sum_{i=1}^p \theta_{1i} \Delta \log(\text{COM}_{t-i}) + \beta_{11} \Delta \log[E_{t-1}(\text{COM}_{t_i})] + \beta_{12} \text{LAB}_t + \beta_{13} \Delta \log(\text{HDD}_t) + \beta_{14} \Delta \log(\text{CDD}_t) + \lambda_Q (\text{COM}_{t-1} - \alpha_0 - \alpha_1 \text{COM}_{t-1}) + v_{1t}$ $\Delta \log(\text{COM}_{t_i}) = c_2 + \sum_{i=1}^p \varphi_{2i} \Delta \log(\text{COM}_{t-i}) + \sum_{i=1}^p \theta_{2i} \Delta \log(\text{COM}_{t-i}) + \beta_{21} \Delta \log[E_{t-1}(\text{COM}_{t_i})] + \beta_{22} \text{LAB}_t + \beta_{23} \Delta \log(\text{HDD}_t) + \beta_{24} \Delta \log(\text{CDD}_t) + \lambda_P (\text{COM}_{t-1} - \alpha_0 - \alpha_1 \text{COM}_{t-1}) + v_{2t}$ |                                |                                |                   |
| Panel A: VAR-VEC model estimation results and Granger causality test results                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |            |            |                                        |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                                |                                |                   |
| Model                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | Hour       | $c_1$      | $[E_{t-1}(RET_{P_t})]$<br>$\beta_{11}$ | $[\text{LAB}_t]$<br>$\beta_{12}$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | $[\text{HDD}]$<br>$\beta_{13}$ | $[\text{CDD}]$<br>$\beta_{14}$ | Granger causality |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H1         | -0.036022* | 0.014583*                              | 0.052104*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | -0.001970                      | 0.013946*                      | $Q \leq P$        |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H2         | -0.035858* | 0.014227*                              | 0.052012*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | -0.000083                      | 0.015648*                      | $Q \leq P$        |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H3         | -0.041514* | 0.007270*                              | 0.059937*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | -0.001585                      | 0.014376*                      | $Q \leq P$        |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H4         | -0.04605*  | 0.003722                               | 0.066380*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | -0.002722                      | 0.012547*                      | $Q \leq P$        |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H5         | -0.04859*  | 0.002374                               | 0.070166*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 0.000323                       | 0.01062**                      | $Q \leq P$        |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H6         | -0.062282* | 0.002953                               | 0.089788*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 0.000230                       | 0.01063**                      | $Q \leq P$        |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H7         | -0.115794* | 0.012815*                              | 0.167133*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | -0.007321                      | 0.009459                       | $Q \leq P$        |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H8         | -0.165997* | 0.029488*                              | 0.239303*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | -0.009434                      | 0.007739                       | $Q \leq P$        |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H9         | -0.189977* | 0.040928*                              | 0.273683*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | -0.017139                      | 0.004762                       | $Q \leq P$        |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H10        | -0.186586* | 0.049524*                              | 0.269209*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | -0.011513                      | 0.007540                       | $Q \leq P$        |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H11        | -0.173370* | 0.047216*                              | 0.248955*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 0.002214                       | 0.016504                       | $Q \leq P$        |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H12        | -0.161720* | 0.044890*                              | 0.233609*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 0.008445                       | 0.020737*                      | $Q \leq P$        |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H13        | -0.161492* | 0.032579*                              | 0.233531*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 0.012648                       | 0.028063*                      | $Q \leq P$        |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H14        | -0.152391* | 0.030262*                              | 0.220454*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 0.010454                       | 0.032811*                      | $Q \leq P$        |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H15        | -0.142102* | 0.019784*                              | 0.204864*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 0.012161                       | 0.036859*                      | $Q \leq P$        |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H16        | -0.147280* | 0.018113*                              | 0.213082*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 0.010990                       | 0.041437*                      | $Q \leq P$        |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H17        | -0.159847* | 0.017248*                              | 0.231231*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 0.010225                       | 0.046401*                      | $Q \leq P$        |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H18        | -0.156979* | 0.026013*                              | 0.226620*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 0.011243                       | 0.042395*                      | $Q \leq P$        |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H19        | -0.142331* | 0.024956*                              | 0.205073*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 0.014789                       | 0.047424*                      | $Q \leq P$        |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H20        | -0.117368* | 0.023547*                              | 0.169049*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 0.012415                       | 0.044764*                      | $Q \leq P$        |
| VEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H21        | -0.095218* | 0.033218*                              | 0.137467*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 0.01479**                      | 0.036422*                      | $Q \leq P$        |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H22        | -0.072983* | 0.015598*                              | 0.105357*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 0.010862                       | 0.037427*                      | $Q \leq P$        |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H23        | -0.042128* | 0.009989                               | 0.061082*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 0.014570*                      | 0.030731*                      | $Q \leq P$        |
| VAR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | H24        | -0.035467* | -0.002156                              | 0.051515*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 0.010990*                      | 0.031250*                      | $Q \leq P$        |
| Panel B: Cointegration relationship estimation results                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |            |            |                                        |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                                |                                |                   |
| Hour                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | $\alpha_0$ | [Coint cf] | $\alpha_1$                             | [EC, Q]                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | $\lambda_Q$                    | [EC, P]                        | $\lambda_P$       |
| H11                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 9.20787*   | 0.25422*   |                                        | -0.100107*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                                | -0.016319                      |                   |
| H15                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 9.46443*   | 0.18732*   |                                        | -0.159224*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                                | -0.017301                      |                   |
| H18                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 9.09577*   | 0.27232*   |                                        | -0.150839*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                                | -0.006884                      |                   |
| H19                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 9.09354*   | 0.27116*   |                                        | -0.075424*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                                | -0.005631                      |                   |
| H20                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 9.14117*   | 0.26184*   |                                        | -0.092904*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                                | -0.002370                      |                   |
| H21                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 9.33567*   | 0.2154*    |                                        | -0.090488*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                                | 0.007340                       |                   |

Bivariate VAR/VEC model estimation results. Granger causality outcomes: bidirectional Granger causality:  $Q < = > P$ ; unidirectional (quantity demanded Granger causes price):  $Q > P$ ; unidirectional (price Granger causes quantity demanded):  $Q \leq P$ ; no Granger causality: . \* and \*\* denotes statistical significance at a 95% confidence level and a 90% confidence level.

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