EQUILIBRIUM FORWARD PREMIUMAND OPTIMAL HEDGING IN ELECTRICITY MARKETS WITH GREEN AND BROWN PRODUCERS

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Equilibrium Forward Premium and Optimal Hedging in Electricity Markets with Green and Brown Producers

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We develop an equilibrium model to price forward contracts for electricity introducing green (renewable energy) producers besides the conventional (brown) producers and retailers. Assuming inelastic spot demand and market power of the conventional producers, we get the optimal production of each producer as a function of both forward and spot prices. The model provides the optimal forward positions of risk-averse market participants and predicts that the forward premium is negatively (positively) related to the variance of spot prices, and positively (negatively) related to the skewness of spot prices when the expected demand is low (high) and is negatively related to the kurtosis of spot prices at all levels of expected demand. The forward premium increases when the uncertainty risk of green production growths. We test the model's theoretical predictions through an empirical application based on hourly data of the Spanish electricity day-ahead and spot (real-time) markets during 2017. The empirical results largely support the theoretical predictions.

Keywords: Electricity markets; Forward markets; Equilibrium risk premium; Optimal hedging; Green producers

JEL Codes: C51; G13; L94; Q40

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1. Introduction

Wholesale electricity markets are one of the world's largest commodity markets. The European Commission (2017) reports in 2017 the total volume of electricity traded on the EU amounted to 12,647 million MWh with an average price of 50 €/MWh, totalling about €632,350 million[1]. The churn rate, the ratio of the total volume of power trade and electricity consumption, measuring market liquidity, was estimated to be four[2], and so traded volume was four times as much as the electricity consumption during this period, suggesting the growing importance of these markets. Since, at this time, electricity cannot be economically stored, spot prices are volatile (Escribano et al., 2011). So, forward markets play a key role as facilitators of hedging decisions by market participants. The extent to which electricity forward trading offers benefits to electricity producers and consumers depends on the sign, size, and determinants of the forward premium, defined as the difference between the forward price and the expected spot price during the delivery period.

Economic theory (e.g. Hirshleifer, 1990) suggests the forward premium should compensate risk-averse market participants for bearing systematic risk. Therefore, the forward premium should be related to economic risks and the willingness of different market agents to bear these risks. Bessembinder and Lemmon (2002, B&L from now on) posit an equilibrium model in which risk-averse producers compete in power supply and trade with retailers who are also risk-averse. In their model prices are determined by industry participants rather than by financial traders, and the forward premium decreases with the variance of spot prices but increases with the skewness of spot prices. The negative impact of the variance of spot prices on the forward premium reflects the net hedge pressure from the retailers' side, as the retail price charged to the final customer by the retailers is fixed. The positive effect of the skewness of spot prices on the forward premium arises from the net hedge pressure of the producers' side, since producers may face upward spikes in marginal production cost when demand is positively skewed. Longstaff and Wang (2004) find

[1] As a comparison, the world's largest metal market by value is gold, worth around €170,000 million per year at the average price during 2017.
[2] In the most liquid of European power markets, Germany and the Nordic, churn ratios are close to 8.

supportive evidence to B&L model in the PJM market. Geman and Roncoroni (2006) and Douglas and Popova (2008) also report empirical evidence consistent with B&L. Other papers present mixed evidence. Bunn and Chen (2013) focus on the British market where the variance of spot prices has a significant positive (instead of negative) impact on the forward premium in peak hours, while the skewness has a negative (instead of positive) impact. These findings remark the influence of fundamental factors such as the expected demand or fuel costs on power prices' distribution and on the forward premium. So, the net hedging pressure in the forward market may switch among players because of facts other than revenue risk or cost risk. Redl et al. (2009) study the ex-post forward premium in the EEX and Nord Pool markets and report evidence of a positive effect of the variance of spot prices on the forward premium with EEX, but no impact of the variance or the skewness with Nord Pool. Thus, market-specific elements may play a role in market participants' hedge decisions.

Recently, a new challenge in the modelling of the forward premium appears because renewable power production has been growing in many countries thanks to technological development and government support. For instance, in December 2017 wind power generation in the EU reached the highest level ever, amounting to 41 TWh and representing a share of 16% in the monthly electricity generation mix (European Commission, 2017). The 20-20-20 Climate and Energy Package (CEP2020 from now on) is binding legislation adopted in late 2008 setting an EU-wide share of 20% of gross final energy consumption from Renewable Energy Sources (RES), although mandatory national targets vary from 10% in Malta to 49% in Sweden. Many papers in this line of research already confirm the impact of renewable production on power prices. Jonsson et al. (2013) posit that wind power generation should be considered in the forecasting model for electricity spot prices. Acemoglu et al. (2017) suggest that power producers may diversify their energy portfolio into renewable generation as a response to the price decline. Ito and Reguant (2016) show the strategic behaviour of green producers in sequential power markets and show how spot prices are affected by factors related to renewable production. However, although several empirical papers (e.g. Green and Vasilakos, 2010, Gelabert, et al., 2011, Würzburg, et al. , 2013., Ciarreta et al., 2014 among others) have documented stylized facts of the impact of RES on electricity spot prices, namely a decrease in prices but an increase in their volatility, there is scarce theory-based literature studying the impact of RES on the forward premium and the change of hedging behaviour of market participants when producers with different generation assets (e.g. “brown” or “green”) are competing in the market.

To fill this gap in the literature, we propose a new equilibrium model by introducing both conventional (brown) and RES (green) producers and study the consequences of this new market structure on the forward premium and on the hedging strategies of market participants. We can reconcile the mixed evidence found in the literature about the impact of the volatility and skewness of spot prices on the forward premium. In doing so, we shed light on the relationship between the forward premium and the percentage of RES production over total production. We account for the uncertainty risk in renewable production and analyse the influence of this production risk on the forward premium.

The rest of this paper is organized as follows. Section 2 reviews the literature. After describing the methodology in Section 3, we present data in Section 4. Section 5 discusses empirical results. Section 6 concludes.

2. Literature Review

Informationally efficient forward markets generate unbiased predictors of future spot prices. Through this paper we use the notion of the forward premium or forward risk premium defined as the difference between the forward price and the expect spot price during the delivery period. Note that the expectation of the spot price at time *t* is taken with respect to the real-world probability measure, but the futures price is the expectation made also at time *t* of the spot price but with respect to the risk-neutral measure. But because of non-storability, we cannot use the traditional no-arbitrage arguments based on the cost-of-carry in a commodity market for pricing electricity forwards. The existence of forward premium in electricity futures markets justified from a combination of the non-storability of the commodity, specific economic and technical fundamentals, the existence of asymmetries of information and asynchronous risk exposures, the exercise of market power by some generators, and physical and legal constraints posed by the infrastructure, regulations and market design.

The forward premium has been studied by comparing forward prices against expected spot prices. Expected spot prices cannot be observed but must be estimated. If realized (ex-post) spot prices are used, forward prices contain forecast errors that may induce bias in estimated risk premia. If estimated (ex-ante) spot prices are used, estimated risk premia become dependent on the spot price model used. There are many models of the spot price and none enjoys general acceptance (see the comparisons in Benth et al., 2012 and in Weron and Zator, 2014).

An alternative way of dealing with this problem is by formulating a theoretical model including some specific characteristics of electricity markets. Bessembinder and Lemmon (2002) present an equilibrium hedging model, with risk-averse identical generators, retailers and no speculators, predicting a forward premium increasing with expected demand a with a convex relation with the volatility of demand, first decreasing and then increasing. The model suggests a negative impact of spot price variance and positive impact of price skewness on the forward premium. The intuition is that high demand associated with high prices boosts the risk aversion of retailers and their hedging pressure increases forward prices. In low-demand and low-price periods, generators' concerns about hedging price risk dominates, decreasing forward prices. They present evidence suggesting that the forward prices in the Pennsylvania, New Jersey and Maryland (PJM) market and the California market are upward biased estimators of the spot market prices when the demand is high, or the market risk is high, consistent with the testable implications of their model. Powell (1993) and Anderson and Hu (2008) introduce a game-theoretic approach element when modeling the interaction between generators and retailers, suggesting that positive or negative forward premia may be induced by retailers' appraisal of the market power of the generators in the spot market. The intuition is that when retailers forecast high demand (and prices) and expect that generators may use their market power to raise the spot price, they will buy futures contracts from generators (above expected spot price), which reduces the incentive of generators to raise spot prices. Consequently, we see positive a forward premium. When retailers forecast a low demand (and low spot prices), they have less incentive to buy futures contracts from generators and offer low strike prices. Generators have less incentive to enter those contracts and prefer raise prices in the spot market, so inducing a negative forward premium. Rudell et al. (2018) argue that financial traders cannot arbitrage away those forward premia because they lack market power in the spot market. In another framework, Pirrong and Jermakyan (2008) present a fundamentals-based model with the demand variable and a fuel price as the state variables. Given a specification of the dynamics of the state variables and the relevant boundary conditions, they apply partial differential equation solvers to value contingent claims. They use data from the PJM market and report large seasonal upward bias (peaks in July and August) in the forward price because of the extreme right skewness of spot electricity prices; this induces left skewness in the payoff of short futures positions and large risk premium is required to induce traders to sell power forward. Benth et al. (2008) relate the term structure of the forward premium to the net hedging demand of consumers and producers, producing a model that yields decreasing absolute values of forward premia (eventually getting negative) when time to maturity or delivery period length increases.

Regarding the empirical evidence on the forward premium Douglas and Popova (2008) confirm the negative impact of spot price variance and positive impact of price skewness on the forward premium for the PJM day-ahead forward market. However, Lucia and Torró (2011), Botterud et al.

(2010) for weekly contracts at the Nord Pool, Redl et al. (2009) for monthly contracts at the EEX and Nord Pool, and Furió and Meneu (2010) for monthly contracts in the Spanish electricity market, report partial, inverse (positive impact of volatility and negative impact of skewness) or no support to those effects. Bunn and Chen (2013) focus on the British market and report evidence on daily and seasonal sign reversals in the risk premium associated with demand cycles and fuel risk pass-through. Daskalakis and Markellos (2009) find a significant negative forward premium in the EEX, Nord Pool and PowerNext long-term electricity markets, and Redl et al. (2009) and Kolos and Ronn (2008) find a negative forward premium for monthly, quarterly and yearly contracts at the German market. In summary, current literature has documented positive, negative and zero risk premia. The empirical evidence suggests that the risk premium may vary throughout the hour of the day, among days of the week, between months or seasons, or over the year. Results differ from one market to another market, and within the same market over different periods, and whether ex-ante or ex-post measures are used. In this paper we posit a theoretical model explaining why the changing hedging needs of producers and retailers may help in explaining this diverse empirical evidence.

3. Methodology

We extend and generalize the standard equilibrium model of electricity prices by introducing green (renewable energy) producers into the equilibrium model and allowing for imperfect competition between them and the conventional (brown) generators. In doing so, we rely on the basic Bessembinder and Lemmon (2002) model but introduce key insights on the behaviour of sequential markets, based on Ito and Reguant (2016).

Consider N_p conventional producers with the same total cost function:

$$TC_C = F_C + \frac{a}{c}\left(Q_{P\_C}\right)^c \tag{1}$$

where F_C is the fixed cost and, Q_{P_C} denotes the total production. Thus, the marginal cost function for the conventional producer i is:

$$\frac{dTC_{C\_i}}{dQ_{P\_C\_i}} = a(Q_{P\_C\_i})^{c-1} \qquad (2)$$

Where c measures the convexity of the marginal cost curve. We expect c to be equal or greater than two, so that the marginal cost of the conventional producer increases along with generation at a rising rate. Positively skewed spot prices appear regardless of the power demand's distribution when $c \geq 2$.

Meanwhile, there are N_g green producers with homogeneous total cost function of the form:

$$TC_G = F_G + \frac{Q_{P\_G}^2}{2b_t} \qquad (3)$$

Then, the marginal cost function of the green producer j is:

$$\frac{dTC_{G\_j}}{dQ_{P\_G\_j}} = \frac{Q_{P\_G\_j}}{b_t} \qquad (4)$$

Re-arranging (4), we obtain the optimal amount of power production of the green producer j as :

$$Q_{P\_G\_j} = b_t \frac{dTC_{G\_j}}{dQ_{P\_G\_j}} \qquad (5)$$

where Q_{P_G} represents the total output from the green producer and, $b_t > 0$ is the slope of the supply curve at time t. Notice that b_t accounts for all possible factors affecting the production and higher b_t indicates better conditions for generating power using renewable sources. As (4) shows the marginal cost increases in the total output at a constant rate and better production conditions reduce the marginal cost. The green production is a function of the generating conditions and the marginal cost, see (5). So, the green producer j will produce if the price is above the marginal cost and total output depends on b_t.

Since b_t may change over time, b_1 is the slope of one renewable producer's supply curve in the forward market and b_2 in the spot market. Because is hard to store renewable inputs, like sunlight or wind, as well as the electricity itself, the real-time delivery of power using green resources is decided by the real-time production conditions. Therefore, the renewable producers submit offers in the forward market according to their expectations on the future production conditions, and adjust their positions based on the realized ones in the real-time market. Since these production conditions are difficult to predict, variation between expected production and realized production using renewable resources exposes the industry to uncertainty risk. Hence, we use the difference between the forecasted conditions, b_1, and the realized conditions, b_2, as a measure for the uncertainty risk in renewable productions. The smaller the difference, the closer the realized production conditions are to the forecasted ones, and the lower the volatility in renewable productions and, consequently, less uncertainty risk.

To account for the uncertainty risk, the production of one renewable producer in the forward and real-time (spot) market are:

$$Q^F_{G\_j} = b_1 P_F \tag{6}$$

$$Q^S_{G\_j} = b_2 P_W - b_2 P_F \tag{7}$$

Where $Q^F_{G\_j}$ and $Q^S_{G\_j}$ are the forward position and the spot position respectively of the green producer j , P_F is the forward price and is P_W the spot price. Following Ito and Reguant (2016), and depending of the values of b_1 and b_2 , the green producer will supply in the spot market more than its forward commitment if $P_W > P_F$, and commit less if $P_W < P_F$. When $P_W = P_F$, the green producer does not trade in the spot market. This setting motivates the renewable producers to participate in the forward market as they can benefit from price differences. Moreover, the total position is $Q_{G\_j} = Q^F_{G\_j} + Q^S_{G\_j}$ = $(b_1 - b_2)P_F + b_2 P_W$. Thus, the variation of renewable generation not only comes from the variation in prices but also is influenced by the uncertainty risk measure,

$(b_1 - b_2)$. We assume power markets are dominated by conventional producers because the renewable competitors have relatively small size. Thus, following Ito and Reguant (2016), we assume that the traditional generators face residual demand and set the spot price, while the green producers are price-takers.

According to the power market structure in most countries, the spot market is usually regarded as a balancing market which is used to price deviations in supply and demand from long-term contracts (Weron, 2006). Therefore, the volume traded in the spot power market is smaller than in the forward market. We denote the total demand as Q_D which is the sum of the forward demand Q_F and the spot demand ϵ , representing the demand shock which cannot be forecasted in advance, but may appear in real-time. So, the residual spot demand faced by the conventional producers in the spot market is calculated by subtracting the spot position taken by all green producers from the spot demand:

$$RD_s = \epsilon + (b_2 P_F - b_2 P_W) * N_g \tag{8}$$

Thus, a conventional producer i maximizes profits by solving the following problem for the optimal spot price P_W:

$$MAX\ \{P_W\} \quad \pi_i = P_W\left(\frac{\epsilon + (b_2 P_F - b_2 P_W) * N_g}{N_p}\right) + P_F Q_{C\_i}^F - F_C - \frac{a}{c}\left(Q_{C\_i}\right)^c$$

$$s.t \qquad Q_{C\_i} = \frac{\epsilon + (b_2 P_F - b_2 P_W) * N_g}{N_p} + Q_{C\_i}^F$$

Where π_i are the profits computed as revenues minus costs. The forward position is seen by the producer as sunk cost, since it was already committed. Thus, solving the problem by taking the first derivative of the profit function with respect to P_W, we get the optimal spot price P_W^* (see appendix A part i):

$$P_W^* = \frac{1}{2}(P_F + aQ_{C\_i}^{c-1} + \frac{\epsilon}{b_2 N_G}) \quad (9)$$

From equation (9), we can observe that optimal spot price depends on the forward price, the total conventional production, the cost of renewable production, the number of renewable producers, as well as the spot demand shock. Manipulating equation (9), we obtain the optimal conventional production of producer i :

$$Q_{C\_i} = \left(\frac{2P_W - P_F}{a} - \frac{\epsilon}{ab_2 N_G}\right)^{\frac{1}{c-1}} \quad (10)$$

Since the electricity delivery must be balanced, the total supply, which is the sum of the conventional positions and the renewable positions, must equal the total demand. We define parameter p to denote for the percentage of the conventional (brown) generation over the total demand. Together with expression (9), we have three equations as shown below, and three unknown parameters P_F, P_W, Q_D.

$$\begin{cases} 2P_W - P_F = aQ_{C\_i}^{c-1} + \dfrac{\epsilon}{b_2 N_G} & (10a) \\ Q_D = N_p Q_{C\_i} + N_g Q_{G\_j} \quad where\ Q_{G\_j} = (b_1 - b_2)P_F + b_2 P_W & (10b) \\ Q_D = \dfrac{N_p Q_{C\_i}}{p} & (10c) \end{cases}$$

Solving for P_W as a function of Q_{C_i} (see appendix A part ii), we get

$$P_W^* = \frac{N_p\left(\frac{1}{p} - 1\right)Q_{C_i} + a(b_1 - b_2)N_g Q_{C_i}^{c-1} + \left(\frac{b_1}{b_2} - 1\right)\epsilon}{(2b_1 - b_2)N_g} \quad (11)$$

Equation (11) gives the formula for deriving the optimal model-based spot price when the total individual conventional production is known. Notice that the amount of renewable production plays a role in setting the spot price.

Applying Taylor's expansion and the quadratic equation formula, we can obtain the individual conventional production as a function of P_W as displayed by expression (12) (see appendix A part iii),:

$$Q_{C\_i} = \alpha_1 + \alpha_2\left(\alpha_3^2 - \alpha_4 + \alpha_5 P_W\right)^{\frac{1}{2}} \quad (12)$$

Where

$$\alpha_1 = \frac{\frac{N_p(p-1)}{N_g p} + a(b_1 - b_2)(c-1)(c-3)E\left(Q_{C\_i}\right)^{c-2}}{a(b_1 - b_2)(c-1)(c-2)E\left(Q_{C\_i}\right)^{c-3}}$$

$$\alpha_2 = \frac{1}{a(c-1)(c-2)E\left(Q_{C\_i}\right)^{c-3}}$$

$$\alpha_3 = \frac{N_p(1-p)}{N_g p(b_1 - b_2)} + a(c-1)(3-c)E\left(Q_{C\_i}\right)^{c-2}$$

$$\alpha_4 = a(c-1)(c-2)E\left(Q_{C\_i}\right)^{c-3}\left(a(c-2)(c-3)E\left(Q_{C\_i}\right)^{c-1} + \frac{2\epsilon}{b_2 N_G}\right)$$

$$\alpha_5 = \frac{2a(c-1)(c-2)E\left(Q_{C\_i}\right)^{c-3}(2b_1 - b_2)}{b_1 - b_2}$$

Besides brown and green producers, we also consider N_r homogeneous retailers. As intermediates between the generators and final consumers, they benefit from the price difference between the purchase price and the retail price. From expression (10c), we can again re-write the individual retailer's demand Q_{R_n} as related to a single conventional production, Q_{C_i} as :

$$Q_{R\_n} = \frac{N_p Q_{C\_i}}{N_r p} \quad (13)$$

In the forward market, risk-averse participants lower their payoffs for having higher production(consumption) uncertainty. However, in our model, the renewable producers have no such concerns, as their supplies are satisfied first by design and their forward positions are publicly known. Thus, only the conventional producers and the retailers have objective functions which are linear in expectations and variances. As a result, the optimal forward position for such risk-averse players can be expressed as a function of the ex-ante forward premium, and the covariance between the "but-for-hedge" profit and the spot prices (see Hirshleifer and Subramanyam (1993), Bessembinder and Lemmon (2002)), which is defined by equation (14).

$$Q^F = \frac{P_F - E(P_W)}{A*VAR(P_W)} + \frac{COV(\rho, P_W)}{VAR(P_W)} \tag{14}$$

Define $\frac{A}{2}$ to be the coefficient on the variance of the profit in the objective function, and it can be viewed as the measure of absolute risk aversion. ρ is the profit function when no forward markets exist for the players to hedge risks. So, we define ρ_C, ρ_R for the conventional producers and the retailers respectively below:

$$\rho_{C\_i} = P_W Q_{C\_i} - F_C - \frac{a}{c}\left(Q_{C\_i}\right)^c \tag{15}$$

$$\rho_{R\_n} = P_R Q_{R\_n} - P_W Q_{R\_n} \tag{16}$$

Where P_R is the retail price; Q_{R_n} is the demand of retailer n. As the market should clear, we expect the sum of all forward positions to be zero. After derivation (see Appendix A part iv), we obtain the forward price as an equation of non-diversifiable risks as:

$$P_F = \left[\frac{N_r + N_p}{(N_r + N_p) + AN_g b_1 VAR(P_W)}\right] E(P_W) - \frac{A}{(N_r + N_p) + AN_g b_1 VAR(P_W)} \Big[P_R N_r cov\big(Q_{R\_n}, P_W\big) - N_g\, cov\big(P_w Q_{G\_j}, P_W\big) - \frac{a}{c} N_p cov\big(\left(Q_{C\_i}\right)^c, P_W\big)\Big] \tag{17}$$

With finite number of participants, there are three types of risks that cannot cancel out. The retail revenue risk for the retailers, the wholesale revenue risk for the green producers, and the production cost risk of the conventional producers. These three risk-related terms reflect the hedge pressures for the producers and retailers. Moreover, the forward price will be higher when the hedge pressures from the producers are higher than that from the retailers, and lower otherwise.

Using Taylor's expansion (see Appendix A part v) for the covariance terms, we could re-write the ex-ante forward premium as a function of the moments of the spot prices' distribution.

$$P_F = \beta_1 E(P_W) + \beta_2 VAR(P_W) + \beta_3 SKEWNESS(P_W) + \beta_4 KURTOSIS(P_W) \qquad (18)$$

Where

$$\beta_1 = \frac{N_r + N_p}{\left(N_r + N_p\right) + AN_g b_1 VAR(P_W)}$$

$$\beta_2 = -\frac{A}{\left(N_r + N_p\right) + AN_g b_1 VAR(P_W)} \left\{ \frac{\alpha_2 \alpha_5 N_p}{2} E(Y)^{-\frac{1}{2}} \left[\frac{P_R}{p} + \left(1 - \frac{1}{p}\right) E(P_W) - aE\left(Q_{C\_i}\right)^{c-2} \left((2-c)E\left(Q_{C\_i}\right) + (c-1)\alpha_1\right) \right] + N_p \left(1 - \frac{1}{p}\right) \left[\alpha_1 + \alpha_2 E(Y)^{\frac{1}{2}} \right] - \frac{aN_p(c-1)}{2} E\left(Q_{C\_i}\right)^{c-2} \alpha_2^2 \alpha_5 \right\}$$

$$\beta_3 = -\frac{A}{\left(N_r + N_p\right) + AN_g b_1 VAR(P_W)} \left\{ \frac{\alpha_2 \alpha_5 N_p}{8} E(Y)^{-\frac{3}{2}} \left[-\frac{P_R}{p} \alpha_5 + \left(1 - \frac{1}{p}\right)(4E(Y) - E(P_W)\alpha_5) + \alpha_5 aE\left(Q_{C\_i}\right)^{c-2} \left((2-c)E\left(Q_{C\_i}\right) + (c-1)\alpha_1\right) \right] \right\}$$

$$\beta_4 = \frac{A}{\left(N_r + N_p\right) + AN_g b_1 VAR(P_W)} \frac{\alpha_2 \alpha_5^2}{8} E(Y)^{-\frac{3}{2}} \left(N_p - \frac{N_p}{p}\right)$$

where

$$Y = \alpha_3^2 - \alpha_4 + \alpha_5 P_W$$

And, $\alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5$ are defined in equation (12). Comparing (18) with the equation (13) in Bessembinder and Lemmon (2002), there are similarities and dissimilarities. Whereas B&L posit that $\beta_2 < 0$ and $\beta_3 > 0$, the signs of β_2 and β_3 in (18) are not predetermined. Also, we find that the forward premium is affected by the kurtosis of the spot prices. Since we expect $p < 1$, the sign of β_4 is negative, suggesting that fat tails in the spot price distribution will lead to lower forward price.

To gauge the sign of β_2 and β_3, we perform simulations (see Appendix A, part viii) and find that the forward premium is negatively (positively) related to the variance of spot prices, and positively (negatively) related to the skewness of spot prices when the expected demand is low (high). To clarify this implication for β_3, B&L posit that under the setting of homogeneous conventional producers with convex marginal cost ($c > 2$), the prices will be positively skewed regardless of the demand. However, this may not be true anymore with the presence of green competitors in the market. Specifically, when the demand is low, and can be satisfied by the renewable supply which has much lower marginal cost[3] than that of the conventional producers, extremely low (or even negative) prices may occur (see Fanone et al., 2013 and Valitov, 2018). Then, the spot prices could be negatively skewed even when $c > 2$. Notice also that the forward premium increases when uncertainty risk of green production increases.

Next, we obtain the optimal forward position for the conventional producers and the retailers (Appendix A part vi and vii). The optimal forward position for the conventional producer i is given by

[3] According to the model, this will happen when the renewable production is lower or the generating conditions using green resources are very good.

$$Q_{C_i}^F = \Upsilon_1 + \frac{P_F - E(P_W)}{A * VAR(P_W)} + \Upsilon_2 \frac{SKEW(P_W)}{VAR(P_W)} + \Upsilon_3 \frac{KURTOSIS(P_W)}{VAR(P_W)} \tag{19}$$

Where

$$\Upsilon_1 = \Big\{\alpha_1 + \frac{\alpha_2}{2} E(Y)^{-\frac{1}{2}}(2E(Y) + E(P_W)\alpha_5) - \frac{a\alpha_2\alpha_5}{2} E\big(Q_{C\_i}\big)^{c-2} E(Y)^{-\frac{1}{2}}\Big((2-c)E\big(Q_{C\_i}\big) + (c-1)\alpha_1\Big) - \frac{a(c-1)}{2} E\big(Q_{C\_i}\big)^{(c-2)} \alpha_2^2 \alpha_5\Big\}$$

$$\Upsilon_2 = \Big\{\frac{\alpha_2\alpha_5}{8} E(Y)^{-\frac{3}{2}}(4E(Y) + E(P_W)\alpha_5) + \frac{a\alpha_2\alpha_5^2}{8} E\big(Q_{C\_i}\big)^{c-2} E(Y)^{-\frac{3}{2}}\Big((2-c)E\big(Q_{C\_i}\big) + (c-1)\alpha_1\Big)\Big\}$$

$$\Upsilon_3 = -\frac{\alpha_2\alpha_5^2}{8} E(Y)^{-\frac{3}{2}}$$

And

$$Y = \alpha_3^2 - \alpha_4 + \alpha_5 P_W$$

Also, $\alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5$ are defined in equation (12). Notice that the optimal forward position of the conventional producer is unlikely to be equal to its expected total production even when the forward price is an unbiased estimator of the expected spot price and the distribution of spot prices is normal. With the competition from the green producers in both markets, it is difficult for the traditional generators to commit all their expected production in the forward market. Notice also that in setting the optimal forward position of the conventional producer the kurtosis appears in the expression (19). Moreover, higher kurtosis of distribution of the spot power prices is linked with lower optimal futures purchase by the conventional producer because $\Upsilon_3 < 0$. This is consistent with previous discussion about the impact of kurtosis on the forward premium. Higher kurtosis in the spot prices will lead to lower forward premium suggesting net hedge pressure on the retailers' side and resulting in relatively smaller position by the producers and larger position by the retailers.

The optimal forward positions of homogeneous (fully diversified) retailers are just the opposite of that of the conventional producers. We allow for heterogeneous N_r retailers, each one covering partial demand. The sensitivity of each retailer's demand with respect to the total demand is :

$$Q_{R\_n} = \theta_n + \rho_n * \frac{Q_D}{N_r} + \xi_n$$

Where ρ_n is the power demand beta. If $\rho_n = 1$, the retailer n is fully diversified and takes as optimal forward position just the opposite of one conventional producer; If $\rho_n = 0$, the retailer n has non-systematic demand risk. If the retailer n's demand risk is systematic, $\rho_n \neq 0$. Therefore, we can derive the optimal forward position of retailer n. The results are reported below (see Appendix A part vii):

$$Q_{R\_n}^F = \varphi_1 + \frac{P_F - E(P_W)}{AVAR(P_W)} + \varphi_2 \frac{SKEW(P_W)}{VAR(P_W)} + \varphi_3 \frac{KURTOSIS(P_W)}{VAR(P_W)} \quad (20)$$

Where

$$\varphi_1 = \left\{\frac{P_R \rho_n N_p}{N_r p} \frac{\alpha_2 \alpha_5}{2} E(Y)^{-\frac{1}{2}} - \theta_n - \xi_n - \frac{\rho_n N_p}{N_r p}\left(\alpha_1 + \frac{\alpha_2}{2} E(Y)^{-\frac{1}{2}}(2E(Y) + E(P_W)\alpha_5)\right)\right\}$$

$$\varphi_2 = \left\{-\frac{P_R \rho_n N_p}{N_r p} \frac{\alpha_2 \alpha_5^2}{8} E(Y)^{-\frac{3}{2}} - \frac{\rho_n N_p}{N_r p}\left(\frac{\alpha_2 \alpha_5}{8} E(Y)^{-\frac{3}{2}}(4E(Y) - E(P_W)\alpha_5)\right)\right\}$$

$$\varphi_3 = \frac{\rho_n N_p}{N_r p} \frac{\alpha_2 \alpha_5^2}{8} E(Y)^{-\frac{3}{2}}$$

And

$$Y = \alpha_3^2 - \alpha_4 + \alpha_5 P_W$$

Also, $\alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5$ are defined in equation (12). The kurtosis of spot prices appears in equation (20), with $\varphi_3 > 0$. When the retailer has systematic demand risk ($\rho_n \neq 0$), higher kurtosis leads to higher optimal position taken by the retailers to hedge its revenue risk (i.e increasing its futures sale).

To gain intuition on how the optimal forward position of the conventional producer and the retailers would change with the risk factors, we simulate the optimal forward positions in Appendix A (ix). When expected demand level and demand risk are high (low), the brown producer responds by increasing (reducing) its futures position. For retailers we find the same effects.

4. Data

We focus on the day-ahead market and intra-day market of the Spanish Electricity Markets. All data used in this paper are retrieved from the website of OMIE (www.omie.es, the Iberian Energy Market Operator). The day-ahead market (the forward market) trades hourly electricity supply delivered next day. In the delivery day, six intra-day sessions are held consecutively in which market participants can adjust their positions up to four hours ahead of real time delivery. We choose the first session of the intra-day market as the spot market, because they hold the first session five hours after the day-ahead market is closed. Within such interval, we assume little information updating excepting information about demand and supply. Electricity price exhibits yearly, monthly, weekly, daily and hourly cycles. We choose the year 2017. In Appendix B part (i) and (ii), we give price statistics. We define seasons as Winter (December to February), Spring (March to May), Summer (June to August), and Autumn (September to November). Figure 7 shows the box plots of day-ahead prices.

[INSERT FIGURE 7 HERE]

The day-ahead prices show hourly cycle. There are two peaks, from 9:00 to 12:00, and from 19:00 to 21:00. The standard deviation of prices is higher during daytime, from 8:00 to 18:00. Average prices and price volatility are higher in Winter and lower in Spring. Day-ahead price distribution is negatively skewed in Spring, when the average price is low, but appear symmetric in other seasons.

Figure 8 shows the box plots of the prices of the first session of the intra-day market (spot market). Like the day-ahead prices, there are hourly and seasonal cycles. Because the interval between the day-ahead market and the first session of the intra-day market, the difference between the day-ahead prices and the spot prices are small. Spot price distributions are symmetric, but in Spring prices are left-skewed.

[INSERT FIGURE 8 HERE]

We also study average spot prices during on-peak hours and off-peak hours together with conventional production over the same hours. The on-peak hours are from 8:00 to 20:00, and the rest are off-peak hours. According to our model, a positive link between the spot price and the conventional production should appear. To compute the monthly average prices and productions, we first work out the daily average values both in on-peak hours and in off-peak hours. Then monthly average values are obtained from daily averages.

[INSERT FIGURE 9 HERE]

Figure 9 shows that the conventional production and the spot price are higher in the on-peak hours than they are in the off-peak hours.

5. Results

To obtain model-based prices, we need estimates of the cost parameters of both the conventional producer and the green producer, and the demand shock. We assume homogeneous green producers, and the cost parameters are the same for all renewable producers. Thus, we can estimate b_1 and b_2 by regarding all renewable units as one player and thus the slope of aggregate supply curve should be equal to the slope of individual supply curve if all green producers have the same cost function. According to REE (Red Electrica de España), renewable sources refer to solar thermal, solar PV, wind, hydro, renewable waste and other renewables. In OMIE, trading participants trade with an generation unit code. Though each unit code is unique, several unit codes may belong to the same company. The source of energy production in each unit is not disclosed by OMIE. Therefore, we hand-collected information about the companies using renewable sources according to the participants list provided by OMIE. We include a company as renewable producer if on their official website the company claims that renewable source is used to generate electricity. However, we are fully aware of the limitation of this way to identify renewable producers. For example, companies may use both conventional and renewable sources, and conventional companies may have affiliates producing electricity with renewable sources. But we do not include them as renewable producers because available data does not allow us to distinguish the units who use renewable sources from other conventional units owned by the same company. The effect of this lack of data granularity is to induce a downward bias in estimates of b_1 and b_2 . The reason is actual renewable units are likely more than the ones we have identified as such in our sample. We identify 43 companies as renewable providers out of 87 generators. The Spanish electricity market is concentrated because the top 4 companies have 80% of market share of generation (Iberian Data by EDP,2017). Following the approach of Ito and Reguant (2016), we estimate b_1 and b_2 as the slopes of the residual demand (demand minus the renewable supply). First, we obtain the supply and demand of each unit for each hour per day per market. Then we compute the residual demand which is the demand minus the supply by the renewable producers at each price level. In order to statistically test the difference between b_1 and b_2, we re-construct the data by combing the residual demands and the prices of the day-ahead market with those of the intraday market. We should also control for the total demand as demand curve may influence the residual demand curve. To solve this, we set the dependent variable by subtracting the total demand from the residual demand. Then, the regression we run per hour per day is:

$$Residual\ Demand_{p_i} - Total\ Demand_{p_i} = constant + b_1 * price_{p_i} + constant * MarketDummy_{p_i} + \phi_1 * price_{p_i} * MarketDummy_{p_i} + \xi_{p_i} \quad (21)$$

Where i represents market (either day-ahead market or intraday market), p represents different price levels of the bids and offers in one market, MarketDummy is a dummy variable equals to 0 if the data is from the day-ahead market and to 1 if the data is from the intraday market. b_1 is the coefficient of $price_{p_i}$, and b_2 equals to the sum of $b_1 + \phi_1$. If ϕ_1 is significant, that means the difference between b_1 and b_2 is significant. We run (21) for each hour each day and estimated b_1, b_2 are obtained accordingly. We provide basic descriptions of estimated b_1 and b_2 in Appendix B part iii Table B3. We may see that b_1 is on average four times larger than b_2. On average, b_1 is around 35, while b_2 is around 9[4]. Next, we estimate the demand shock, ε. According to our definition, ε should be the demand shock of the total demand, realized in the spot market. In other words, ε cannot be forecasted by players in the forward market. Total demand should be equal to the forward demand plus the spot demand. (Appendix B part iv, see Table B4 to TableB9). The regression is :

[4] Ito and Reguant (2016) assume that the total demand is inelastic, getting estimates with higher order of magnitude but report that b_1 is several times larger than b_2.

$$\ln(Total\ Demand)_{jh} = constant + \beta_1 * \ln(Forward\ Demand)_{jh} + \beta_2 * \ln(Renewable\ Spot\ Demand)_{jh} + \beta_3 * \ln(Planned\ Demand)_{jh} + \beta_4 * \ln(Forecasted\ Demand)_{jh} + \beta_5 * Week * Month + \beta_6 * Week * Hour + \beta_7 * Month * Hour + \beta_8 * Week + \beta_9 * Month + \beta_{10} * Hour + FE + \varepsilon_{jh} \quad (22)$$

Where total demand is the sum of the accepted demand bids in both markets. Forward demand is the accepted demand bids in the day-ahead market. Renewable spot demand is the demand bids from renewable producers in the intraday market. Planned demand is the scheduled demand submitted by all participants to OMIE before the trading in the day-ahead market. The forecasted demand is obtained from REE (the system operator) and is the forecast of real-time total demand of the Spanish peninsula. Dummy variables are Week (day of the week from Monday (1) to Sunday (7)), Month (month of the year from January (1) to December (12)), Hour as (hour of the day from 1:00 to 24:00), are ordinal variables used to control for weekly, monthly, and hourly cycles. We also include interactions between these ordinal variables to control for unobservable trends. This is a dated panel regression, with cross-sessions being Hour, so j represents Day, and h represents Hour. As there may exist unobservable factors across time are related with independent variables, we include fixed effects. We provide regression results and residuals statistics in Appendix B part v.

According to Table B11 (Appendix B part iv), demand shocks are positive in peak hours and negative during off-peak hours. The volatility of the shock is higher in peak hours than in off-peak hours, as expected. Next, we estimate a and c which are cost parameters of the conventional production. To obtain estimates of a and c for each hour in each season, we include ordinal variables named as Hour and Season. The regression is:

$$\ln\left(Q_{P_C}\right)_{jh} = constant + \delta_1 \ln\left(b_2(2P_W - P_F) - \varepsilon\right)_{jh} + \delta_2 constant * season * hour + \delta_3 \ln\left(b_2(2P_W - P_F) - \varepsilon\right) * season * hour + \xi_{jh} \quad (23)$$

Where season is an ordinal variable from 1 to 4 with 1 for winter (December to February), 2 for spring (March to May), 3 for summer (June to August), 4 for autumn (September to November); hour is also an ordinal variable from 1 to 24 represents the hour of the day. Q_{P_C} is the total conventional supply bids which are accepted in both markets. The explanatory variable, $b_2(2P_W - P_F) - \varepsilon$, is computed using market prices and estimated[5] b_2, ε. In the end, $c = \frac{1}{\delta_1} + 1$ and $a = \frac{e^{\frac{constant}{-\delta_1}}}{b_2}$. We provide basic descriptions on estimated c and a in Appendix B part v. With estimated parameters, now we can derive model-based prices. According to equation (11), we can obtain model-based spot prices by inserting estimated values into the equation. Table 1 shows the average difference between the model-based prices and the realized prices by hour.

[INSERT TABLE 1 HERE]

The model-based prices appear to be higher than the realized ones during peak-time, but lower on average during the off-peak time. However, t-statistics fail to reject the null hypotheses of zero average difference in all cases. Therefore, the evidence suggest that the model can replicate actual spot prices.

[5] As the parameters b_2, ε are average estimates, negative values for the explanatory variable may appear (in 25 cases out of 8760). Since this variable should be non-negative, we set negative value as missing value.

Next, we study if the forward premium is negatively (positively) related to the variance of spot prices, and positively (negatively) related to the skewness of spot prices when the expected demand is low (high). The model also suggest that the forward premium should be negatively related to the kurtosis of spot prices at all levels of expected demand, and should increases when the uncertainty of RES production over total production increases. We run a threshold regression where state variable defining the thresholds is the level of total demand. The regression we run is as follows

$$Forward\ Premium_t = constant + \Phi_1 variance_t(highdemand) +$$
$$+\Phi_2 variance_t(lowdemand) + \Phi_3 skewness_t(highdemand) + \Phi_4 skewness_t(lowdemand) +$$
$$\Phi_5 kurtsosis_t(highdemand) + \Phi_6 kurtosiss_t(lowdemand) +$$
$$\Phi_4 renew\ ableuncertainty_{t_h} + controls + \mu_{t_h} \quad (22)$$

Where *variance, skewness and kurtosis* are conditional values obtained by using sample moments of 30-day moving averages of intraday prices. The variable *renewableuncertainty* is the difference between estimated b_1 and estimated b_2 . *Controls* includes ordinal variables for hour, week, month, and season to control for hourly, weekly, monthly, and seasonally trend as well as lagged values of the dependent variable.

Table 2 gives the results by considering two thresholds of “low” and “high” demand.

[INSERT TABLE 2 HERE]

We may see that in when demand is low ("low state"), the coefficients of the variance (negative), skewness (positive) and kurtosis (negative) present the expected signs according to our model and are statistically significant at conventional levels. In the "high state" (high demand), the skewness (negative) and the kurtosis (negative) present the expected signs, but the variance presents a negative sign. The measure of uncertainty of renewables production presents a positive and significant impact on the forward premium, as expected. All other variables also present the expected signs. Therefore, the empirical results largely agree with the predictions of the theoretical model.

6. Conclusions

The importance of the study of the forward premium in electricity markets arises for its implications about the market efficiency of power derivatives markets, a significant concern to financial investors, utilities, power producers, retailers, regulators, and policymakers. In this paper, we develop an equilibrium model to price forward contracts for electricity introducing green producers besides the conventional (brown) producers. In doing so, we extend and refine the implications of the benchmark B&L model by including a richer market setup and a more realistic structure of the generating assets. We argue that the hedging activities market of participants may change according to the expected spot price, or to the fundamental variables such as expected demand.

We get the implication that the forward electricity price is a biased forecast of the future spot price. This bias depends on two elements. First, on the variance, skewness, and kurtosis of the distribution of spot prices. The impact of these moments can be positive or negative, depending on the level of expected demand. Second, by the uncertainty of green production, that has a positive relationship with the forward premium. We also get the optimal forward positions for brown producers and retailers. When expected demand level and demand risk are high (low), the brown producer responds by increasing (reducing) its futures position. For retailers we find the same effects.

Empirical evidence comparing model-based prices and market-observed prices by using hourly data of the Spanish market is largely consistent with the implications of the model. Regression analysis shows that the forward premium is related to the variance, asymmetry, and kurtosis of the distribution of spot prices, the sign depending on expected demand. Increases in the uncertainty of RES production increase the forward premium, as predicted.

Our findings help in reconciling the mixed empirical support received by earlier equilibrium models, and we give added insights about the hedging decisions of market participants. Therefore, we believe that the implications of our model are useful for practitioners and policymakers alike.

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Tables

Table 1: Differences between the model-based fitted prices and the realized spot prices

The table shows descriptive statistics, and t-statistics for the null hypothesis of zero difference for the average differences between the model-based fitted prices and the realized spot prices. Units are €/MWh. The sample is from 1 January 2017 to 31 December 2017.

HOUR	Mean	Std. Dev.	Obs.	T-stat	P-value
1	-1.700439	16.99846	365	-0.141471	0.443749
2	-1.413872	15.24023	365	-0.131200	0.447809
3	-0.416224	14.36878	365	-0.040966	0.483662
4	-0.662584	14.09458	365	-0.066482	0.473497
5	-2.035911	14.22437	365	-0.202414	0.419797
6	-3.285663	15.02272	365	-0.309307	0.378544
7	-5.814217	18.03774	365	-0.455852	0.324248
8	-5.465775	21.38411	365	-0.361473	0.358873
9	-0.872095	18.81843	365	-0.065538	0.473873
10	0.04753	18.77718	365	0.003580	0.498572
11	2.159637	18.11977	365	0.168556	0.433073
12	2.579151	17.81575	365	0.204733	0.418890
13	2.932957	17.22411	365	0.240815	0.404849
14	3.116797	17.07509	365	0.258143	0.398148
15	3.011083	16.70029	365	0.254984	0.399368
16	1.872595	16.61897	365	0.159351	0.436696
17	1.557062	16.75373	365	0.131435	0.447716
18	1.401681	18.05852	365	0.109770	0.456296
19	1.087808	19.48203	365	0.078965	0.468530
20	1.120782	20.09022	365	0.078895	0.468558
21	1.382585	20.14574	365	0.097056	0.461341
22	2.256196	19.70887	365	0.161894	0.435695
23	-5.226655	21.55694	365	-0.342888	0.365842
24	-4.42284	19.70893	365	-0.317361	0.375485
All	-0.282934	18.0692	8760	-0.022144	0.491166

Table 2: Threshold Regression results

The table shows the result sof a threshold regression where the state variable is the Total Demand. The sample is hourly data from 1 January 2017 to 31 December 2017.

Dependent Variable: PFPS				
Method: Threshold Regression				
Sample (adjusted): 16 8744				
Included observations: 8729 after adjustments				
Threshold type: Fixed number of globally determined thresholds				
Threshold variable: TOTALDEMAND				
Threshold value used: 33665.899				
HAC standard errors & covariance (Bartlett kernel, Newey-West fixed bandwidth = 11.0000)				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
TOTALDEMAND < 33665.899 -- 6409 obs				
HOUR	-0.250882	0.031501	-7.964370	0.0000
VARIANCE	-0.023775	0.001635	-14.54286	0.0000
SKEW	1.118339	0.238049	4.697938	0.0000
KURTOSIS	-0.628367	0.114377	-5.493816	0.0000
33665.899 <= TOTALDEMAND -- 2320 obs				
HOUR	-0.810647	0.053671	-15.10399	0.0000
VARIANCE	-0.010540	0.001792	-5.879957	0.0000
SKEW	-0.723635	0.363069	-1.993105	0.0463
KURTOSIS	-1.953685	0.304787	-6.409992	0.0000
Non-Threshold Variables				
B1B2	0.836597	0.026457	31.62120	0.0000
WEEK	0.689433	0.066157	10.42120	0.0000
MONTH	-0.585991	0.071378	-8.209724	0.0000
SEASON	-2.990647	0.212851	-14.05045	0.0000
PFPS(-1)	0.431010	0.015381	28.02144	0.0000
PFPS(-2)	-0.029307	0.012638	-2.318896	0.0204
PFPS(-3)	-0.029120	0.009388	-3.102017	0.0019
PFPS(-4)	0.002974	0.008387	0.354580	0.7229
PFPS(-5)	0.045386	0.010260	4.423558	0.0000
PFPS(-6)	0.039412	0.008830	4.463496	0.0000
PFPS(-7)	0.036873	0.009466	3.895156	0.0001
R-squared	0.624736	Mean dependent var		-0.045392
Adjusted R-squared	0.623961	S.D. dependent var		18.25988
S.E. of regression	11.19733	Akaike info criterion		7.671401
Sum squared resid	1092061.	Schwarz criterion		7.686800
Log likelihood	-33462.83	Hannan-Quinn criter.		7.676649
Durbin-Watson stat	1.611072			

Figures

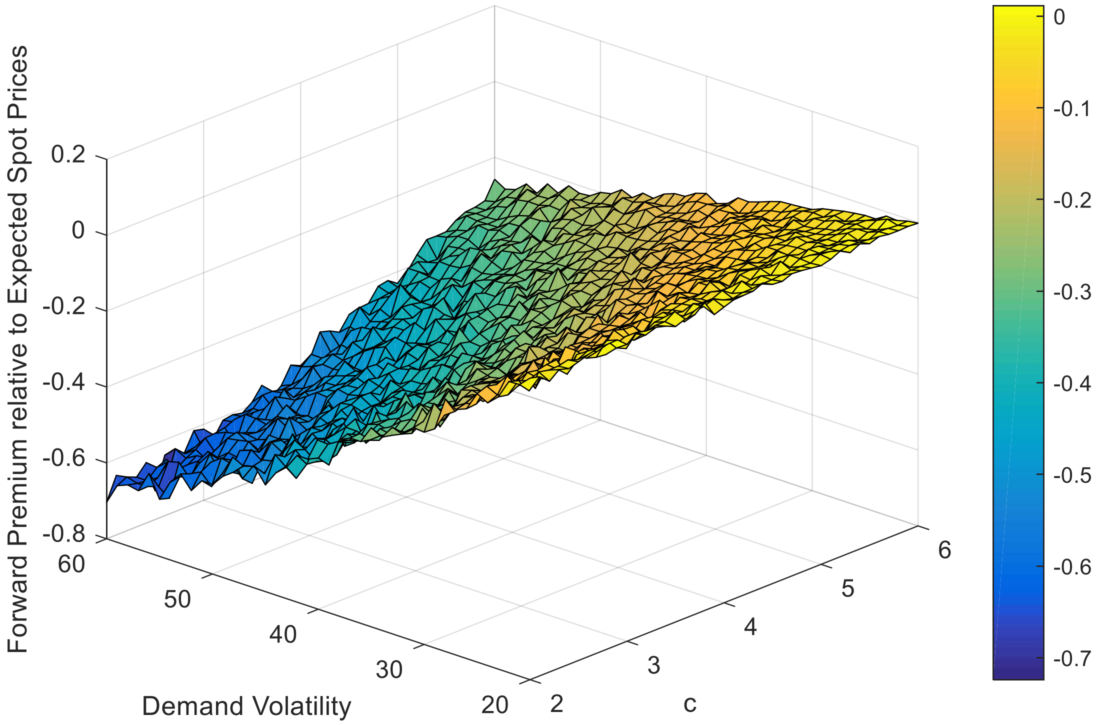


Figure 1 **Low Demand case: Forward Premium as a percentage to the expected spot price, as a function of demand volatility and conventional production cost convexity (c)**. Total demand is normally distributed with mean $E(Q_D) = 2000$ and standard deviation from 20 to 60. Demand shock is also normally distributed with mean $E(\epsilon) = 0$ and standard deviation $SD(\epsilon) = 30$. Q_{Ci} is set as 50% of Q_D. c changes from 2 to 6, and a is then set by expression (9). P_R is 100. Finally, the risk parameter $A = \frac{0.8}{2^c}$.

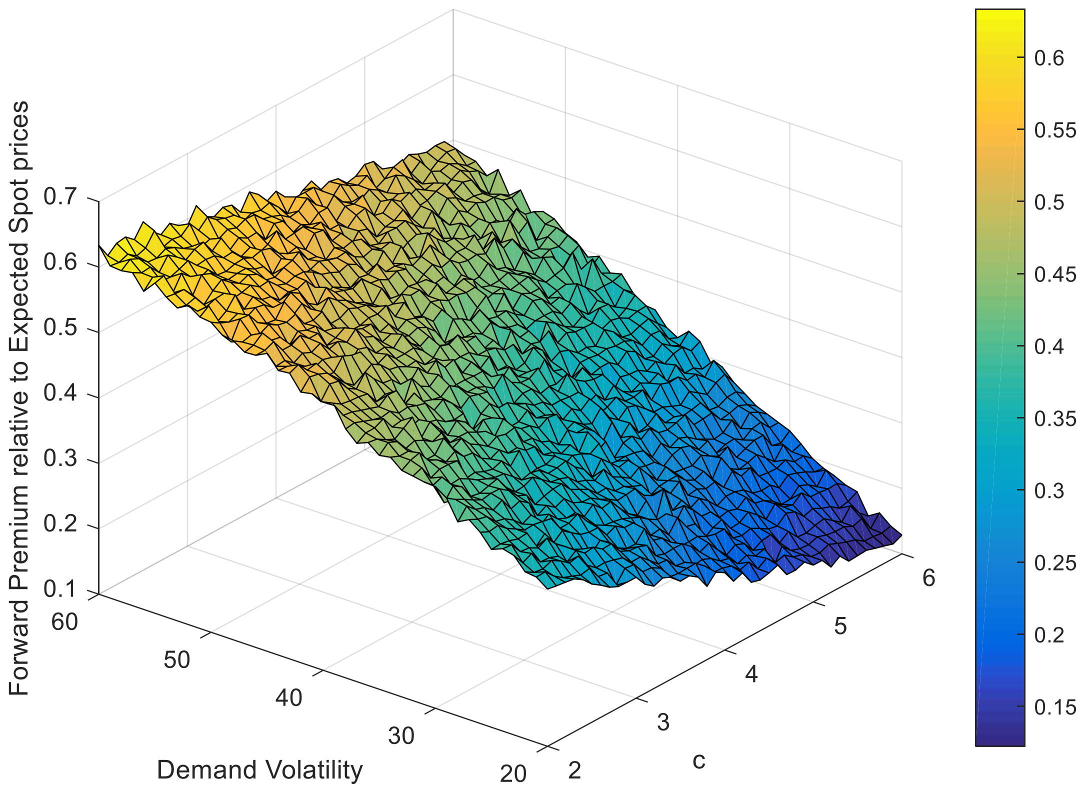


Figure 2 **High Demand case: Forward Premium as a percentage to the expected spot price, as a function of demand volatility and conventional production cost convexity (c)**. Total demand is normally distributed with mean $E(Q_D) = 6000$ and standard deviation from 20 to 60. Demand shock is also normally distributed with mean $E(\epsilon) = 0$ and standard deviation $SD(\epsilon) = 30$. Q_{Ci} is set as 50% of Q_D. c changes from 2 to 6, and a is then set by expression (9). P_R is 100. Finally, the risk parameter $A = \frac{0.8}{2^c}$.

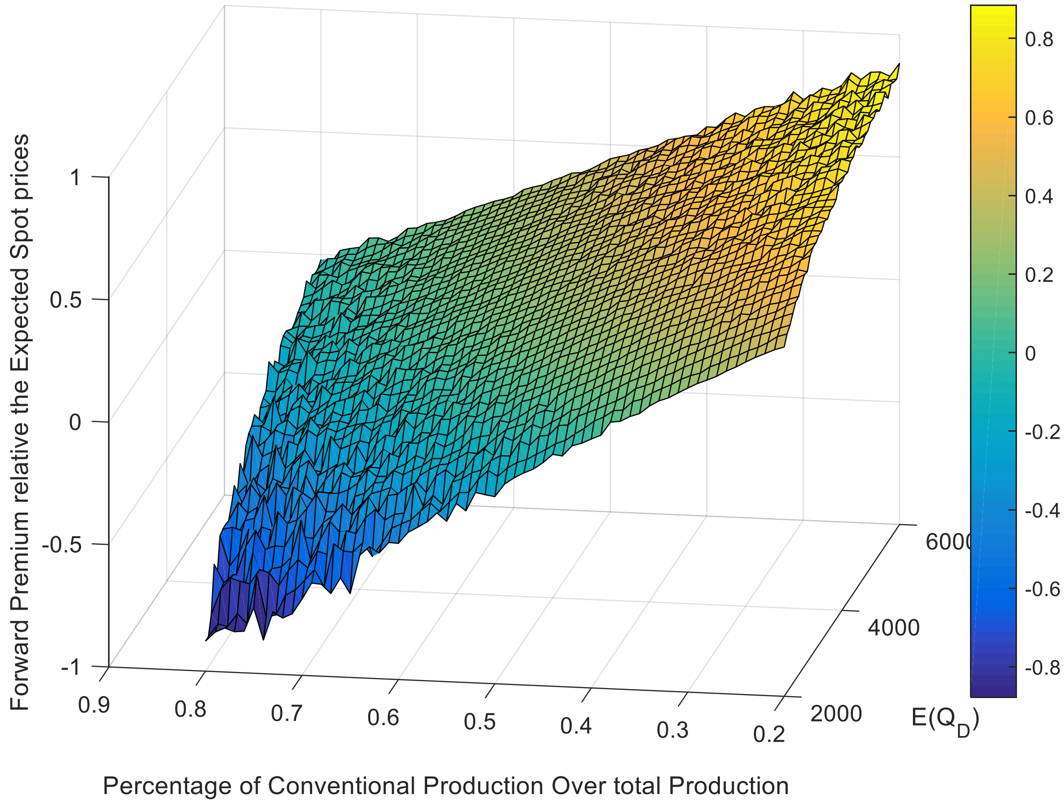


Figure 3 **Forward Premium as a percentage to the expected spot price, as a function of percentage of conventional production over total production and expected demand.** Total demand is normally distributed with mean $E(Q_D)$ from 2000 to 6000 and standard deviation $SD(Q_D) = 30$. Demand shock is also normally distributed with mean $E(\epsilon) = 0$ and standard deviation $SD(\epsilon) = 30$. Q_{Ci} is set from 80% to 20% of Q_D. c changes from 2 to 6, and a is then set by expression (9). P_R is 100. Finally, the risk parameter $A = \frac{0.8}{2^c}$.

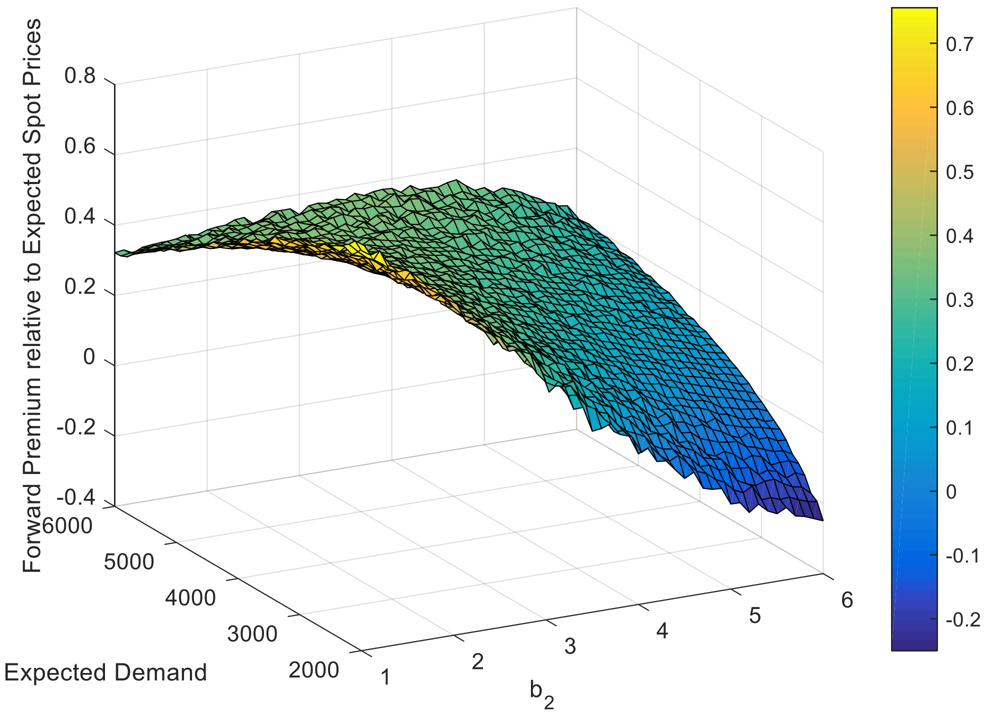


Figure 4 **Forward Premium as a percentage to the expected spot price, as a function of b_2 and expected demand**. Total demand is normally distributed with mean $E(Q_D)$ from 2000 to 6000 and standard deviation $SD(Q_D) = 30$. Demand shock is also normally distributed with mean $E(\epsilon) = 0$ and standard deviation $SD(\epsilon) = 30$. Q_{P_C} is set as 50% of Q_D. c is set as 4, and a is then set by expression (9). P_R is 100. b_1 is set as 8, and b_2 changes from 1 to 6. Finally, the risk parameter $A = \frac{0.8}{2^c}$.

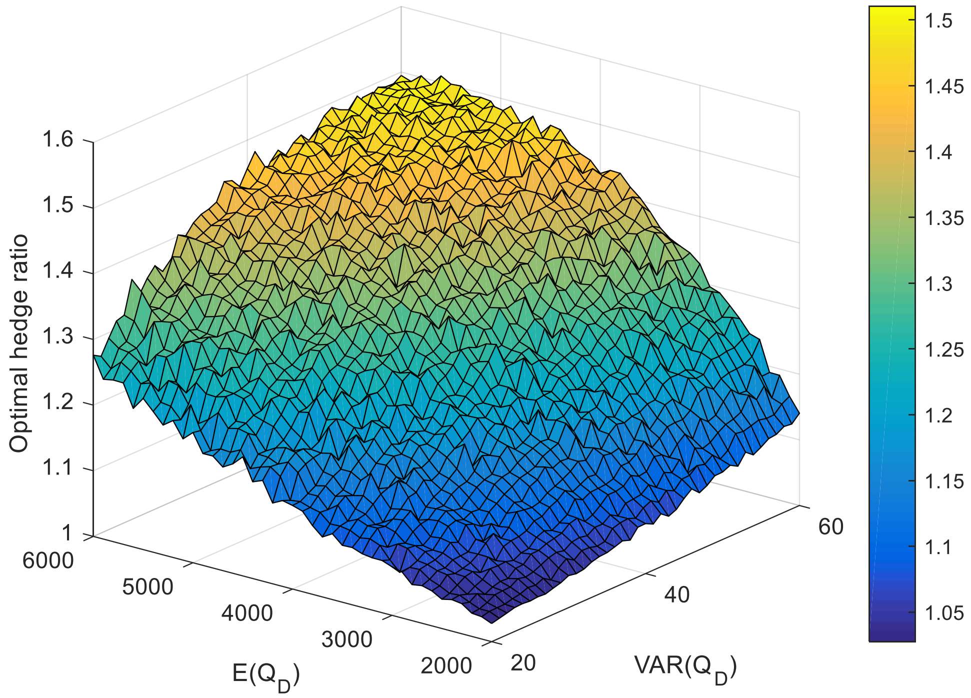
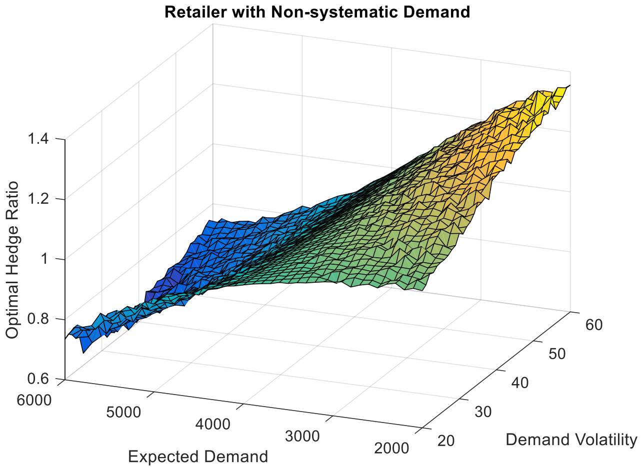


Figure 5 **optimal conventional hedge ratio (optimal hedge position over expected production), as a function of expected demand and demand volatility**. Total demand is normally distributed with mean $E(Q_D)$ from 2000 to 6000 and standard deviation from 20 to 60. Demand shock is also normally distributed with mean $E(\epsilon) = 0$ and standard deviation $SD(\epsilon) = 30$. Q_{Ci} is set as 80% of Q_D. c is set as 4, and a is then set by expression (9). P_R is 100. Finally, the risk parameter $A = \frac{0.8}{2^c}$.



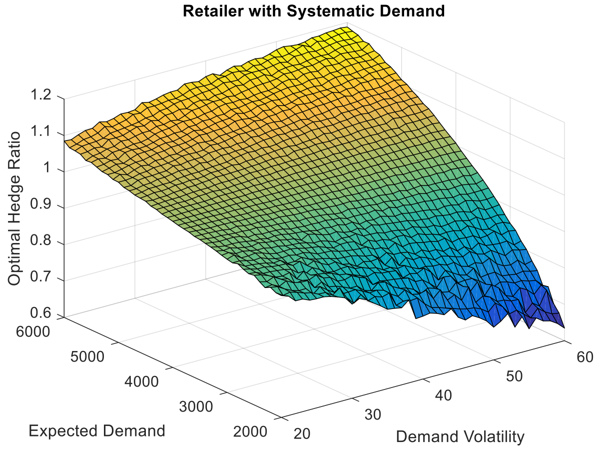


Figure 6 **optimal retailer (retailer with non-systematic local demand and retailer with systematic local demand) hedge ratio (optimal hedge position over expected demand), as a function of expected demand and demand volatility**. Total demand is normally distributed with mean $E(Q_D)$ from 2000 to 6000 and standard deviation from 20 to 60. Demand shock is also normally distributed with mean $E(\epsilon) = 0$ and standard deviation $SD(\epsilon) = 30$. Q_{P_C} is set as 80% of Q_D. c is set as 4, and a is then set by expression (9). P_R is 100. Finally, the risk parameter $A = \frac{0.8}{2^c}$.

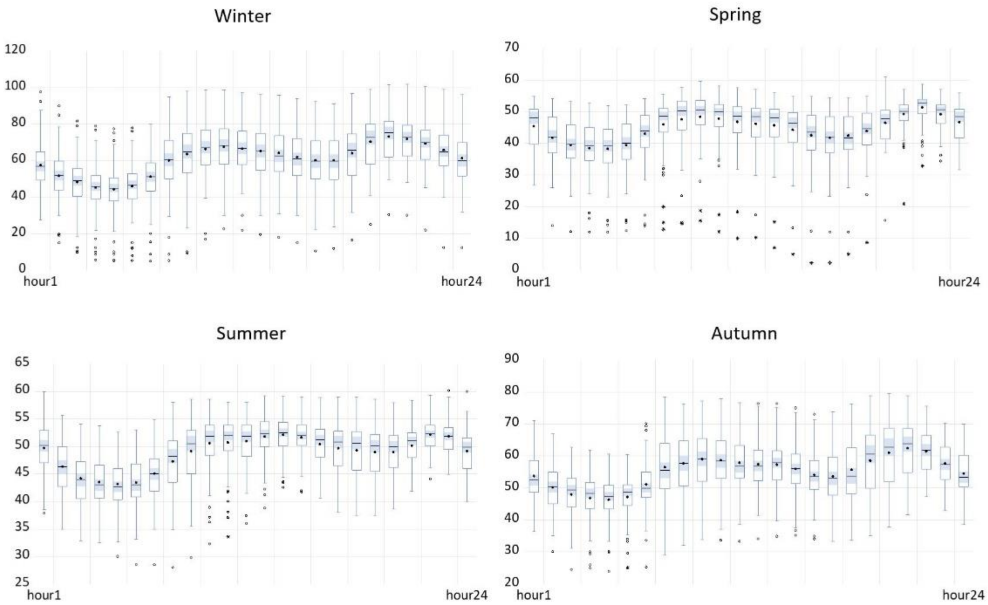


Figure 7 **Boxplot of day-ahead prices**

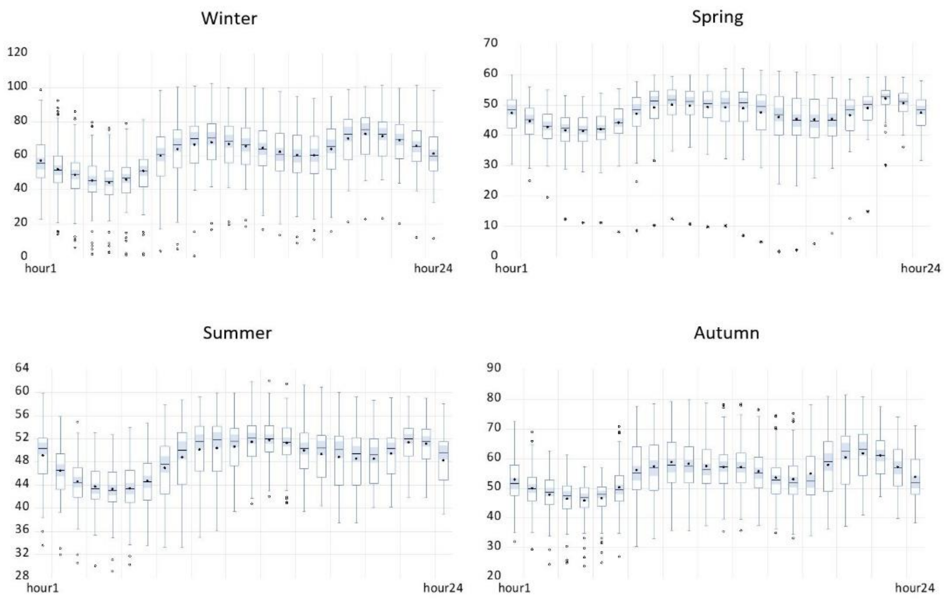


Figure 8 **Boxplot of intraday prices**

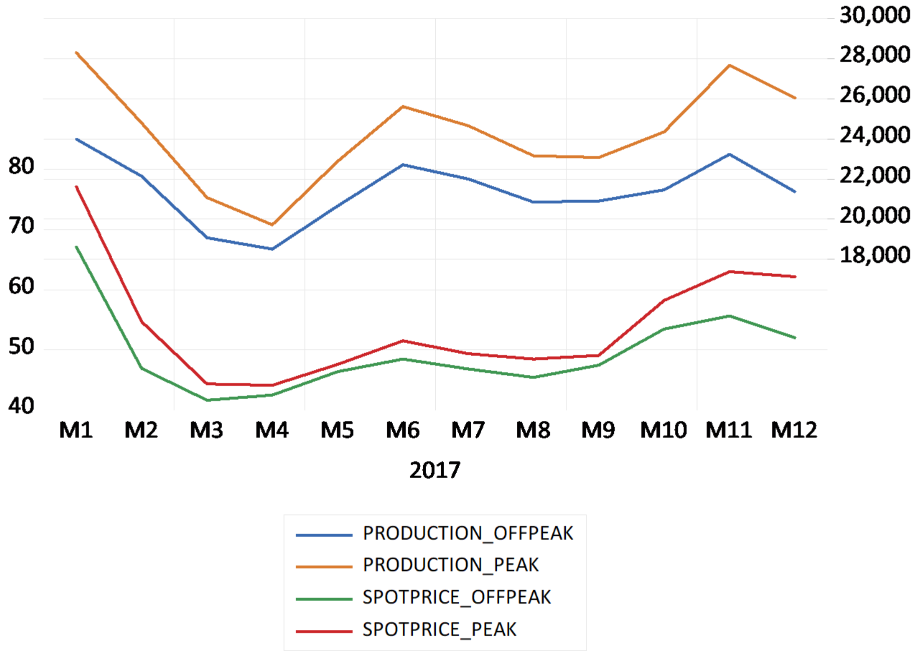


Figure 9 **Spot Prices (peak and off-peak) vs Conventional Production (peak and off-peak)**

Appendix A

(i)

$$\text{MAX} \qquad \pi_i = P_W\left(\frac{\epsilon + (b_2P_F - b_2P_W) * N_g}{N_p}\right) + P_F Q^F_{C\_i} - F_C - \frac{a}{c}\left(Q_{C\_i}\right)^c$$

$$\text{s.t} \qquad Q_{C\_i} = \frac{\epsilon + (b_2P_F - b_2P_W) * N_g}{N_p} + Q^F_{C\_i}$$

Taking the first derivative with respect to P_W,

$$P_W\left(\frac{-b_2 * N_g}{N_p}\right) + \left(\frac{\epsilon + (b_2P_F - b_2P_W) * N_g}{N_p}\right) - a\left(Q_{C_i}\right)^{c-1}\left(\frac{-b_2 * N_g}{N_p}\right) = 0$$

Rearranging the equation, we get

$$2P_W - P_F = aQ^{c-1}_{C\_i} + \frac{\epsilon}{b_2N_G}$$

And solving for the optimal spot price

$$P_W^* = \frac{1}{2}\left(P_F + aQ^{c-1}_{C\_i} + \frac{\epsilon}{b_2N_G}\right)$$

Which is text equation (9).

(ii)

We know the following equations hold

$$\begin{cases} 2P_W - P_F = aQ^{c-1}_{C\_i} + \dfrac{\epsilon}{b_2N_G} & \text{(a1)} \\ Q_D = N_pQ_{C\_i} + N_gQ_{G\_j} \quad \text{where } Q_{G\_j} = (b_1 - b_2)P_F + b_2P_W & \text{(a2)} \\ Q_D = \dfrac{N_pQ_{C\_i}}{p} & \text{(a3)} \end{cases}$$

Inserting (a3) into (a2), we get

$$\frac{N_pQ_{C\_i}}{p} = N_pQ_{C\_i} + N_g((b_1 - b_2)P_F + b_2P_W) \qquad \textbf{(a4)}$$

Multiplying (a1) on both sides with $(b_1 - b_2)N_g$, and sum with (a4), P_F can be eliminated. Leaving P_W as a function of Q_{C_i} shown in text equation (11)

$$P_W = \frac{N_p\left(\frac{1}{p} - 1\right)Q_{C\_i} + a(b_1 - b_2)N_gQ^{c-1}_{C\_i} + \left(\frac{b_1}{b_2} - 1\right)\epsilon}{(2b_1 - b_2)N_g} \qquad \textbf{(11)}$$

(iii)

Taylor's expansion helps to give the approximation of function F^z where z is a constant around the point E(F), such as

$$F^z = [E(F)]^z\left(1 - z + \frac{z(z-1)}{2}\right) + z(2-z)[E(F)]^{z-1}F + \frac{z(z-1)}{2}[E(F)]^{z-2}F^2$$

Thus, applying Taylor's expansion, we get

$$Q_{C_i}^{c-1} = \left(\frac{(c-2)(c-3)}{2}\right)E\left(Q_{ci}\right)^{c-1} + (c-1)(3-c)E\left(Q_{ci}\right)^{c-2} * Q_{Ci} + \frac{(c-2)(c-1)}{2}E\left(Q_{ci}\right)^{c-3} * Q_{Ci}^2 \quad \text{(iii-A)}$$

Then, replacing Q_{Ci}^{c-1} in text equation (11) with expression (iii-A), we get

$$\frac{a(b_1-b_2)}{2b_1-b_2} * \frac{(c-1)(c-2)}{2}E\left(Q_{ci}\right)^{c-3} * Q_{Ci}^2 + \left[\frac{N_p(1-p)}{N_g(2b_1-b_2)p} + \frac{a(b_1-b_2)}{2b_1-b2}(c-1)(3-c)E\left(Q_{ci}\right)^{c-2}\right]Q_{Ci} + \frac{(c-2)(c-3)}{2}E\left(Q_{ci}\right)^{c-1} * \frac{a(b_1-b_2)}{2b_1-b_2} + \frac{(b_1-b_2)\epsilon}{(2b_1-b_2)N_g b_2} - P_W = 0 \quad \textbf{(III-B)}$$

According to quadratic formula and considering $Q_{Ci} > 0$, we can get Q_{C_i} as a function of P_W as shown by text equation (12).

$$Q_{C\_i} = \alpha_1 + \alpha_2\left(\alpha_3^2 - \alpha_4 + \alpha_5 P_W\right)^{\frac{1}{2}} \quad \textbf{(12)}$$

Where

$$\alpha_1 = \frac{\frac{N_p(p-1)}{N_g p} + a(b_1-b_2)(c-1)(c-3)E\left(Q_{C\_i}\right)^{c-2}}{a(b_1-b_2)(c-1)(c-2)E\left(Q_{C\_i}\right)^{c-3}}$$

$$\alpha_2 = \frac{1}{a(c-1)(c-2)E\left(Q_{C\_i}\right)^{c-3}}$$

$$\alpha_3 = \frac{N_p(1-p)}{N_g p(b_1-b_2)} + a(c-1)(3-c)E\left(Q_{C\_i}\right)^{c-2}$$

$$\alpha_4 = a(c-1)(c-2)E\left(Q_{C\_i}\right)^{c-3}\left(a(c-2)(c-3)E\left(Q_{C\_i}\right)^{c-1} + \frac{2\epsilon}{b_2 N_G}\right)$$

$$\alpha_5 = \frac{2a(c-1)(c-2)E\left(Q_{C\_i}\right)^{c-3}(2b_1-b_2)}{b_1-b_2}$$

(iv)

The optimal forward position of conventional producers are:

$$Q_c^F = N_P \frac{P_F - E(P_W)}{A*VAR(P_W)} + N_P \frac{COV(\rho_p, P_W)}{VAR(P_W)} \qquad \textbf{(IV-A)}$$

The optimal forward position of retailers are:

$$Q_R^F = N_r \frac{P_F - E(P_W)}{A*VAR(P_W)} + N_r \frac{COV(\rho_R, P_W)}{VAR(P_W)} \qquad \textbf{(IV-B)}$$

And, the forward position of green producers are:

$$Q_G^F = N_g b_1 P_F \qquad \textbf{(IV-C)}$$

Since the forward market should clear, $Q_G^F + Q_R^F + Q_c^F = 0$ which gives:

$$\frac{P_F - E(P_W)}{A*VAR(P_W)}(N_P + N_r) + \frac{N_P COV(\rho_p, P_W) + N_r COV(\rho_R, P_W)}{VAR(P_W)} + N_g b_1 P_F = 0 \qquad \textbf{(IV-D)}$$

Rearranging equation (iv-D), we get

$$P_F = \left[\frac{N_r + N_p}{(N_r + N_p) + AN_g b_1 VAR(P_W)}\right] E(P_W) - \frac{A}{(N_r + N_p) + AN_g b_1 VAR(P_W)} \left[N_p cov(\rho_p, P_W) + N_r\, cov(\rho_R, P_W)\right] \qquad \textbf{(IV-E)}$$

As

$$\rho_{C\_i} = P_W Q_{C\_i} - F_C - \frac{a}{c}\left(Q_{C\_i}\right)^c \qquad \textbf{(15)}$$

$$\rho_{R\_n} = P_R Q_{R\_n} - P_W Q_{R\_n} \qquad \textbf{(16)}$$

Then,

$$\left[N_p cov\left(\rho_p, P_W\right) + N_r\, cov(\rho_R, P_W)\right] = \left[P_R N_r cov(Q_{R\_n}, P_W) - N_g\, cov\left(P_w Q_{G\_j}, P_W\right) - \frac{a}{c} N_p cov\left(\left(Q_{C\_i}\right)^c, P_W\right)\right] \qquad \textbf{(IV-F)}$$

Inserting (IV-F) into (IV-E), we get text expression (17)

(v)

As according to text equation (13),

$$Q_{R\_n} = \frac{N_p Q_{C\_i}}{N_r p} \qquad \textbf{(13)}$$

We can rewrite (iv-F) as

$$\left[N_p cov\left(\rho_p, P_W\right) + N_r\, cov(\rho_R, P_W)\right] = \frac{P_R N_p}{p} COV(Q_{Ci}, P_W) + \left(N_p - \frac{N_p}{p}\right) COV(P_W Q_{Ci}, P_W) - \frac{N_p a}{c} COV(Q_{Ci}^c, P_W) \qquad \textbf{(V-A)}$$

Thus, to derive text equation (18), we need to derive first $COV(Q_{Ci}, P_W)$, $COV(P_W Q_{Ci}, P_W)$ and $COV(Q_{Ci}^c, P_W)$.

Define

$$Y = \alpha_3^2 - \alpha_4 + \alpha_5 P_W$$

Q_{Ci} is given by equation (12), and applying Taylor's expansion,

$$Q_{C_i} = \alpha_1 + \alpha_2(\alpha_3^2 - \alpha_4 + \alpha_5 P_W)^{\frac{1}{2}} = \alpha_1 + \alpha_2\left\{\frac{3}{8}E(Y)^{\frac{1}{2}} + \frac{3}{4}E(Y)^{-\frac{1}{2}} * Y - \frac{1}{8}E(Y)^{-\frac{3}{2}} * Y^2\right\} = \alpha_1 + \alpha_2\left\{\left[\frac{3}{8}E(Y)^{\frac{1}{2}} + \frac{3}{4}E(Y)^{-\frac{1}{2}} * (\alpha_3^2 - \alpha_4) - \frac{1}{8}E(Y)^{-\frac{3}{2}}(\alpha_3^2 - \alpha_4)^2\right] + \left[\frac{3}{4}E(Y)^{-\frac{1}{2}} * \alpha_5 - \frac{1}{4}E(Y)^{-\frac{3}{2}}(\alpha_3^2 - \alpha_4)\alpha_5\right] P_W - \frac{1}{8}E(Y)^{-\frac{3}{2}}\alpha_5^2 P_W^2\right\} \quad \textbf{(V-B)}$$

Then,

$$COV(Q_{Ci}, P_W) = \alpha_2\left\{\left[\frac{3}{4}E(Y)^{-\frac{1}{2}} * \alpha_5 - \frac{1}{4}E(Y)^{-\frac{3}{2}}(\alpha_3^2 - \alpha_4)\alpha_5\right] VAR(P_W) - \frac{1}{8}E(Y)^{-\frac{3}{2}}\alpha_5^2 COV(P_W^2, P_W)\right\} \quad \textbf{(V-C)}$$

And,

$$COV(P_W Q_{Ci}, P_W) = \alpha_1 VAR(P_W) + \alpha_2\left\{\left[\frac{3}{8}E(Y)^{\frac{1}{2}} + \frac{3}{4}E(Y)^{-\frac{1}{2}} * (\alpha_3^2 - \alpha_4) - \frac{1}{8}E(Y)^{-\frac{3}{2}}(\alpha_3^2 - \alpha_4)^2\right] VAR(P_W) + \left[\frac{3}{4}E(Y)^{-\frac{1}{2}} * \alpha_5 - \frac{1}{4}E(Y)^{-\frac{3}{2}}(\alpha_3^2 - \alpha_4)\alpha_5\right] COV(P_W^2, P_W) - \frac{1}{8}E(Y)^{-\frac{3}{2}}\alpha_5^2 COV(P_W^3, P_W)\right\} \quad \textbf{(V-D)}$$

Also, according to Taylor's expansion

$$Q_{C_i}^c = \frac{(c-1)(c-2)}{2}E(Q_{Ci})^c + c(2-c)E(Q_{Ci})^{c-1} * Q_{Ci} + \frac{c(c-1)}{2}E(Q_{Ci})^{c-2} * Q_{Ci}^2$$

Where $Q_{Ci}^2 = \alpha_1^2 + \alpha_2^2(\alpha_3^2 - \alpha_4 + \alpha_5 P_W) + 2 * \alpha_1 * \alpha_2(\alpha_3^2 - \alpha_4 + \alpha_5 P_W)^{\frac{1}{2}}$

Thus, $COV(Q_{Ci}^c, P_W) = c(2-c)E(Q_{Ci})^{c-1} * COV(Q_{Ci}, P_W) + \frac{c(c-1)}{2}E(Q_{Ci})^{c-2}\alpha_2^2\alpha_5 VAR(P_W) + 2 * \alpha_1 * \alpha_2\left\{\left[\frac{3}{4}E(Y)^{-\frac{1}{2}} * \alpha_5 - \frac{1}{4}E(Y)^{-\frac{3}{2}}(\alpha_3^2 - \alpha_4)\alpha_5\right] VAR(P_W) - \frac{1}{8}E(Y)^{-\frac{3}{2}}\alpha_5^2 COV(P_W^2, P_W)\right\}$ **(V-E)**

Define $cov(P_W^2, P_W) = skew(P_W) * SD(P_W)^3 + 2E(P_W)Var(P_W)$, and

$cov(P_W^3, P_W) = kurtosis(P_W) * SD(P_W)^4 + 3E(P_W)skew(P_W) * SD(P_W)^3 + 3E(P_W)^2 Var(P_W)$,

We can re-write equation (V-C), (V-D), and (V-E) as follows:

$$\mathrm{COV}(Q_{Ci}, P_W) = \frac{\alpha_2\alpha_5}{2} E(Y)^{-\frac{1}{2}} \mathrm{VAR}(P_W) - \frac{\alpha_2\alpha_5^2}{8} E(Y)^{-\frac{3}{2}} \mathrm{SKEWNESS}(P_W) \quad \textbf{(V-F)}$$

$$\mathrm{COV}(P_W Q_{Ci}, P_W) = \left\{\alpha_1 + \frac{\alpha_2}{2} E(Y)^{-\frac{1}{2}} (2E(Y) + E(P_W)\alpha_5)\right\} \mathrm{VAR}(P_W) + \left\{\left[\frac{\alpha_2\alpha_5}{8} E(Y)^{-\frac{3}{2}} (4E(Y) - E(P_W)\alpha_5)\right] \mathrm{SKEWNESS}(P_W) - \frac{1}{8} E(Y)^{-\frac{3}{2}} \alpha_5^2 \mathrm{KURTOSIS}(P_W)\right\} \quad \textbf{(V-G)}$$

$$\mathrm{COV}(Q_{Ci}^c, P_W) = \left\{\frac{c\alpha_2\alpha_5}{2} E(Q_{Ci})^{c-2} E(Y)^{-\frac{1}{2}} \left((2-c)E(Q_{Ci}) + (c-1)\alpha_1\right) + \frac{c(c-1)}{2} E(Q_{Ci})^{c-2} \alpha_2^2 \alpha_5\right\} \mathrm{VAR}(P_W) + \left\{-\frac{c\alpha_2\alpha_5^2}{8} E(Q_{Ci})^{c-2} E(Y)^{-\frac{3}{2}} [(2-c)E(Q_{Ci}) + (c-1)\alpha_1]\right\} \mathrm{SKEWNESS}(P_W) \quad \textbf{(V-H)}$$

Finally, replacing (V-A) with (V-F), (V-G),(V-H), we can get text equation (18).

(vi)

To derive the optimal forward position of the conventional producer, we first need to derive the covariance term between the "but-for-hedge" conventional profit and the spot price as expression (VI-A) shows

$$\mathrm{cov}(\rho_p, P_W) = \mathrm{cov}(P_W Q_{Ci}, P_W) - \frac{a}{c} \mathrm{cov}((Q_{Ci})^c, P_W) \quad \textbf{(VI-A)}$$

As we have derived $\mathrm{cov}(P_W Q_{Ci}, P_W)$ and $\mathrm{cov}((Q_{Ci})^c, P_W)$ in last section, we can just insert equation (V-F) and (V-G) into (VI-A).

And, according to expression (14), we could have text expression (19).

(vii)

Like the derivation in part vi, we need to derive the covariance term between the "but-for-hedge" profit of the retailer and the spot price.

If we assume there is one retailer with partial demand risk in the market, and $N_r Q_{R\_n} = N_p Q_{Ci} + N_g Q_{G\_j}$. Applying the covariance properties, we get

$$\mathrm{COV}(\rho_{Rn}, P_W) = P_R \mathrm{COV}(Q_{Rn}, P_W) - \mathrm{COV}(P_w Q_{Rn}, P_W) = P_R * \frac{\rho_n}{N_R} * \frac{N_p}{p} [\mathrm{COV}(Q_{Ci}, P_W)] - \theta_n \mathrm{VAR}(P_W) - \xi_n \mathrm{VAR}(P_W) - \frac{\rho_n}{N_R} * \frac{N_p}{p} [\mathrm{COV}(Q_{Ci} P_W, P_W)] \quad \textbf{(VII-A)}$$

$\mathrm{COV}(Q_{Ci}, P_W)$ is given by expression (V-F), $\mathrm{COV}(Q_{Ci} P_W, P_W)$ is given by expression (V-G). Thus, we can derive the optimal forward position of the retailer as equation (20) states for both systematic and non-systematic retailer case.

(viii)

To gauge the sign of β_2 and β_3, we perform simulations. First, we set the cost factors of the renewable producer, b_1 *and* b_2, to be 8 and 5, following Hortaçsu and Puller (2008) and Ito and Reguant (2016) who find evidence that $b_1 > b_2$. Second, both the total demand and the demand shock in the spot market are assumed to be normally distributed. Specifically, we set the total demand to be at low level (high level) when its mean is 2000 (6000) and its standard deviation changes from 20 to 60 with intervals being 1. The demand shock follows distribution with mean zero and standard deviation to be 30. The retail price P_R is set as 100. In practice, the retail price charged by the retailer does not change frequently and thus it applies to the consumers under all circumstances. Fourth, we choose p as a percentage of the conventional production over the total production to be 80%. Fifth, the convexity measure of the conventional cost function c ranges from 2 to 6. Also, a is calculated according to equation (9) conditional on $Q_D = 2000$, $P_W = 40$, $\epsilon = 0$ and $p = 80\%$. This is to fix the spot price to be 40 when the demand is 2000 and the demand shock to be 0 in order to compare results across different simulation settings. Sixth, we set $N_p = N_r = N_g = 1$ to minimize the impact of numbers of players on the forward premium. Finally, similar to B&L we set the absolute risk aversion parameter, $A = \frac{0.8}{2^c}$. Note that A can be chosen discretionarily to scale the results.

The sign of β_2 and β_3 in (18) can be inferred by changing the cost parameter c and the volatility of the total demand. Thus, for each c and $std(Q_D)$, we generate 1000 realizations for the spot price based on expression (11). Then, the forward premium is derived according to equation (17). We report the bias in the forward price as a percentage of the expected spot prices as shown in Figure 1 and Figure 2.

Figure 1 displays the bias of forward price versus the cost and demand risk in the situation where the total demand is low. In agreement with B&L, forward premium decreases in variance and becomes more negative when $c = 2$, suggesting the sign of β_2 is negative. Also, the bias in the forward premium increases in skewness when c increases, indicating that the sign of β_3 is positive.

However, in Figure 2 where the demand is high, the results are different. With quadratic cost ($c = 2$) and green production fixed, the skewness of the spot prices remains constant. Instead of observing a decreasing trend of forward premium, the forward bias increases in demand risk, implying the β_2 is positive when the demand is at high level. This implies that the hedge pressure switches from the retailers' side to the producers' side in the case of high expected demand and rising demand volatility. As mentioned above, retailers are more concerned with low prices or low demand, while the conventional producers worry more about positive demand spikes due to their convex cost in production. Therefore, it is reasonable to expect the conventional producers having higher net hedge pressure when the demand has higher mean and volatility. Regarding the sign of β_3, we may observe a decreasing trend in c of the forward premium when the demand is high. This suggest that the net hedge pressure from the retailers' side is stronger than the producers' pressure in the case of high demand and higher skewness. As c becomes higher, the spot prices are more positively skewed.

[Insert Figure 1 Here]

[Insert Figure 2 Here]

We present the forward bias in relation with the percentage of conventional production over total demand and the expected demand in Figure 3.

[Insert Figure 3 Here]

From Figure 3, the higher the market share of the renewable production the higher the forward premium. This reflects higher hedge pressure of the conventional producers when their market share is shrinking due to the competition from the green generators.

Another renewable-related risk is the uncertainty risk. The unpredictable conditions for generating power using renewable resources expose the market to this uncertainty risk, which could potentially lead to more volatile prices. Thus, we simulate the forward bias versus the measure of this renewable production uncertainty risk, $|b_1 - b_2|$, and the expected demand. To better visualize the simulation results without losing generality, we set b_1 to be 8 and changing b_2 from 1 to 6. Thus, the higher the b_2 is, the smaller the difference between b_1 and b_2, the higher precision of the forecast on the generating conditions using green resources, then the less uncertainty risk in renewable production. Figure 4 shows the simulation results. We may see that the lower the uncertainty risk of the green generation, the lower the forward premium, suggesting smaller forward position of the retailers. As intermediates, the retailers have obligations to supply certain quantity of power to the final consumers. Therefore, lower uncertainty risk of the green production reduces this default risk for the retailers and leads to less buying in the forward market.

[Insert Figure 4 Here]

(ix)

To gain intuition on how the optimal forward position of the conventional producer and the retailers would change with the risk factors, we simulate the optimal forward positions. We compute forward premiums according to equation (17) and the procedure in Appendix A, part viii. Then, equation (19) is used to derive the optimal forward positions. We present the optimal hedge ratio, which is the simulated optimal forward position over the expected conventional production, instead of optimal position per se.

[Insert Figure 5 Here]

Figure 5 illustrates the implications of equation (19), based on $c = 4$ and normally distributed demand. When expected demand and demand risk are low, the brown producer responds to the decreasing bias in the forward price by reducing its futures purchases; when either the demand or the demand volatility increases, the producer optimally increases its futures purchases, as a reaction to the upward forward bias as well as to hedge its cost risk.

We assume two retailers: one with power beta zero, the other one with power beta two. Since the forward premium would change accordingly, we re-calculate the forward premium according to expression (17). And, the optimal forward position of each retailer is obtained using expression (20). Figure 6 combines two plots on the two retailers' optimal forward position with respect to their expected demand versus expected total demand and demand volatility. For both retailers, in most of the time, the higher the standard deviation of total demand, the higher the optimal forward position; Except when the retailer has systematic demand risk and the demand is low, the retailer chooses to decrease its forward position as a response to the low demand level. However, retailer with systematic local demand generally increases its forward position along with the rising expected demand, while the retailer with non-systematic local demand optimally decreases its forward position relative to its expected demand. This finding is consistent with the implications from B&L model (2002). Retailer with non-systematic local demand decreases its forward position as a respond to the upward bias in the forward price with respect to the expected spot price. However, the retailer with systematic demand concerns more about its revenue risk, thus it increases its forward position to hedge potential high expected spot price and price spikes.

[Insert Figure 6 Here]

Appendix B

(i)

	Winter																								
Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Average
Mean	57.54	51.76	48.32	45.31	44.22	45.89	51.26	60.11	63.56	66.35	67.50	66.52	65.29	64.22	61.99	60.17	60.11	64.10	70.42	73.19	71.95	69.35	65.83	61.34	60.68
Median	56.95	51.91	49.18	45.94	45.00	46.95	51.19	60.60	65.01	67.52	68.36	66.85	65.38	62.70	61.03	59.86	59.75	65.86	72.67	75.24	72.81	70.03	65.01	60.11	61.08
Maximum	97.70	90.00	81.69	78.98	77.50	78.00	80.10	95.01	98.01	98.61	98.61	97.35	96.50	96.00	94.01	92.84	91.19	96.69	99.18	101.70	101.99	100.67	99.18	96.19	93.24
Minimum	27.57	15.00	9.80	5.48	5.27	5.27	5.00	5.27	9.27	17.10	22.67	21.95	19.51	18.10	15.19	10.56	11.90	16.60	25.00	30.43	30.01	22.01	12.40	12.40	15.57
Std. Dev.	13.75	13.58	13.43	13.70	13.73	13.56	14.31	17.00	17.37	15.84	14.42	14.28	14.12	14.25	14.54	15.20	15.24	15.30	14.38	13.24	13.07	12.84	13.58	13.84	14.36
Skewness	0.39	-0.09	-0.45	-0.41	-0.42	-0.48	-0.50	-0.51	-0.55	-0.36	-0.21	-0.20	-0.20	-0.10	-0.12	-0.31	-0.36	-0.33	-0.36	-0.20	-0.10	-0.27	-0.37	-0.13	-0.28
Kurtosis	3.30	3.82	4.08	4.12	4.22	4.24	4.24	4.05	3.88	3.59	3.40	3.40	3.47	3.42	3.21	3.44	3.23	3.00	2.94	3.07	3.33	4.13	4.70	3.92	3.68
Probability	0.28	0.26	0.03	0.03	0.02	0.01	0.01	0.02	0.03	0.20	0.53	0.55	0.48	0.67	0.83	0.33	0.35	0.45	0.38	0.73	0.75	0.05	0.00	0.18	
Observations	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	
	Spring																								
Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Average
Mean	45.43	41.81	39.47	38.49	38.22	39.41	43.04	46.01	47.58	48.41	47.81	46.81	46.18	45.68	44.27	42.57	41.79	42.44	43.87	46.47	49.25	51.33	49.18	46.74	44.68
Median	48.14	42.18	39.65	39.23	39.28	40.12	43.98	48.67	50.36	50.54	50.00	48.60	48.45	48.06	46.53	43.64	41.91	41.67	44.58	47.72	50.20	52.77	50.61	48.49	46.06
Maximum	54.93	54.04	53.25	52.79	52.02	52.13	54.12	55.58	57.80	59.58	58.22	57.55	57.06	56.07	54.93	54.93	54.50	54.53	55.00	61.05	56.97	58.80	57.01	56.00	55.79
Minimum	27.04	14.00	12.16	12.00	12.00	12.40	13.90	12.89	14.69	15.61	12.12	10.00	10.29	7.09	5.00	2.30	2.30	5.01	8.70	15.67	21.00	32.96	34.41	31.67	14.38
Std. Dev.	6.90	7.70	7.91	8.23	8.22	8.46	8.09	8.30	8.40	7.60	7.50	7.45	7.67	8.00	8.22	8.71	8.84	8.40	7.18	6.30	5.16	4.58	4.88	5.63	7.43
Skewness	-0.70	-0.66	-0.60	-0.79	-0.93	-0.91	-1.36	-1.88	-1.80	-1.94	-2.16	-2.13	-1.88	-2.03	-1.93	-1.63	-1.47	-1.49	-1.50	-1.20	-2.10	-1.61	-0.98	-0.79	-1.44
Kurtosis	2.42	3.36	3.33	3.69	4.14	4.15	5.60	6.98	6.74	7.80	9.56	9.85	8.51	9.34	8.95	7.76	7.02	7.27	8.01	7.59	11.29	6.16	3.51	2.85	6.50
Probability	0.01	0.03	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	
Observations	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	

Table B1-1 statistics on seasonal day-ahead prices

Summer																									
Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Average
Mean	49.71	46.33	44.19	43.53	43.15	43.44	45.04	47.27	49.12	50.57	50.73	50.97	51.77	52.12	51.65	50.42	49.66	49.31	48.94	48.95	50.14	52.14	51.83	49.15	48.75
Median	50.15	46.27	43.94	43.02	42.67	43.03	45.00	48.25	50.55	51.88	51.99	51.83	52.26	52.55	51.95	51.27	50.80	50.66	50.03	49.99	51.05	52.24	51.84	49.87	49.29
Maximum	59.99	55.65	54.05	53.78	52.57	53.00	54.93	58.01	58.62	58.59	58.01	58.10	59.20	59.15	59.00	58.93	59.03	59.03	58.62	58.00	58.43	59.35	60.15	59.99	57.67
Minimum	37.86	35.00	32.89	32.50	30.00	28.50	28.50	28.00	29.77	32.29	33.58	35.99	38.80	42.53	41.72	40.60	37.99	37.49	37.47	38.60	41.91	44.09	44.99	40.00	36.29
Std. Dev.	4.75	4.65	4.71	4.62	4.62	4.70	4.85	5.64	5.78	5.10	4.82	4.39	4.07	3.60	3.55	4.10	4.65	4.81	4.55	4.18	3.75	3.04	3.19	3.86	4.42
Skewness	-0.38	-0.08	0.23	0.19	0.05	-0.10	-0.17	-0.67	-0.85	-1.24	-1.21	-1.07	-0.82	-0.59	-0.67	-0.59	-0.58	-0.52	-0.40	-0.31	-0.44	-0.02	0.20	-0.14	-0.42
Kurtosis	2.99	2.41	2.44	2.65	2.88	3.18	3.50	3.48	3.53	4.41	4.31	4.08	3.56	3.15	3.62	3.01	2.74	2.54	2.49	2.52	2.81	2.96	3.01	2.77	3.13
Probability	0.33	0.48	0.37	0.59	0.96	0.87	0.50	0.02	0.00	0.00	0.00	0.00	0.00	0.07	0.02	0.07	0.07	0.09	0.17	0.31	0.22	0.99	0.74	0.77	
Observations	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	
Autumn																									
Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Average
Mean	53.68	50.13	47.89	46.78	46.27	47.11	51.09	56.44	57.61	58.92	58.60	57.81	57.39	57.27	55.87	54.02	53.53	55.66	58.51	60.99	62.39	61.41	57.61	54.47	55.06
Median	52.40	50.25	49.29	48.32	47.33	48.59	49.98	55.52	57.76	59.19	58.44	56.69	56.86	57.81	55.99	53.51	52.98	53.70	60.51	62.69	63.76	61.84	57.28	53.31	55.17
Maximum	71.04	66.84	62.65	61.84	60.53	60.43	70.10	78.45	76.39	77.23	77.97	76.69	76.39	76.39	75.00	73.00	73.73	76.31	78.94	79.62	78.81	75.61	70.27	70.00	72.68
Minimum	36.36	30.00	24.47	24.88	23.85	25.00	25.23	29.00	32.00	33.80	33.60	33.25	34.05	34.81	35.15	33.96	33.25	33.59	35.15	37.80	41.53	47.30	42.90	38.50	33.31
Std. Dev.	7.68	6.99	6.97	6.83	6.74	6.24	7.69	9.86	9.98	9.11	8.48	8.19	7.56	7.37	7.35	7.81	8.35	9.59	10.65	9.91	7.98	6.40	6.72	6.98	7.98
Skewness	0.25	-0.08	-0.66	-0.99	-1.13	-0.90	0.00	-0.12	-0.19	-0.17	-0.16	-0.09	0.00	-0.10	-0.07	0.00	0.04	0.09	0.04	-0.21	-0.20	-0.02	-0.05	0.07	-0.19
Kurtosis	2.75	3.10	3.75	4.27	4.62	4.19	3.97	2.78	2.57	2.82	3.32	3.35	3.57	3.71	3.69	3.38	2.95	2.45	2.17	2.23	2.26	2.23	2.18	2.61	3.12
Probability	0.55	0.94	0.01	0.00	0.00	0.00	0.17	0.82	0.53	0.76	0.67	0.75	0.54	0.36	0.39	0.77	0.98	0.53	0.26	0.24	0.26	0.32	0.28	0.72	
Observations	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	

Table B1-2 statistics on seasonal day-ahead prices

(ii)

Winter																									
Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Average
Mean	57.16	52.06	48.70	45.38	44.19	45.95	51.06	59.98	63.87	66.57	67.84	66.88	65.63	64.59	62.31	60.37	60.18	63.97	70.10	72.76	71.40	69.13	65.70	61.28	60.71
Median	55.50	51.46	48.98	45.37	44.69	46.80	51.31	60.56	66.23	70.00	70.29	68.42	66.34	63.88	60.80	60.05	60.28	65.50	72.78	75.49	72.83	69.55	65.41	60.03	61.35
Maximum	98.70	92.44	85.99	79.60	76.18	79.04	81.10	98.37	100.31	101.18	102.49	100.00	99.77	99.77	97.73	95.00	93.78	94.71	99.18	100.70	101.50	99.67	101.35	98.51	94.88
Minimum	22.63	13.83	5.90	2.16	3.00	1.50	1.51	3.86	5.10	1.00	16.51	19.45	18.41	16.58	13.19	8.60	10.71	15.38	20.97	22.63	22.93	19.91	11.91	11.30	12.04
Std. Dev.	15.55	15.24	14.65	15.00	14.58	14.63	15.69	17.96	18.43	17.66	16.09	15.67	15.21	15.20	15.71	16.44	16.31	16.04	15.23	14.50	14.34	13.89	14.82	14.87	15.57
Skewness	0.31	0.03	-0.26	-0.38	-0.40	-0.48	-0.54	-0.46	-0.55	-0.65	-0.41	-0.31	-0.25	-0.13	-0.16	-0.37	-0.40	-0.44	-0.46	-0.45	-0.31	-0.24	-0.22	0.04	-0.31
Kurtosis	3.34	4.01	4.29	3.98	3.95	4.22	4.15	3.98	3.82	4.36	3.63	3.40	3.47	3.48	3.43	3.69	3.34	3.05	2.95	3.25	3.30	3.61	4.03	3.75	3.69
Probability	0.40	0.15	0.03	0.06	0.05	0.01	0.01	0.03	0.03	0.00	0.14	0.35	0.41	0.57	0.59	0.14	0.25	0.23	0.21	0.20	0.42	0.32	0.09	0.35	
Observations	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	
Spring																									
Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Average
Mean	44.53	42.08	39.88	38.40	37.97	38.83	42.06	45.38	47.27	48.39	47.87	47.02	46.37	45.91	44.40	42.73	42.05	42.44	43.61	46.19	48.83	51.06	48.75	46.02	44.50
Median	45.58	42.67	40.62	39.60	39.07	40.02	43.56	48.37	50.54	51.00	50.39	49.00	48.35	46.83	45.79	43.82	43.00	42.46	44.16	47.73	49.98	52.19	49.98	47.84	45.94
Maximum	55.50	55.51	53.62	52.15	52.15	52.13	55.38	56.34	59.95	59.58	58.28	57.31	57.50	57.23	56.14	55.93	55.54	55.54	55.46	60.56	58.82	58.90	56.92	54.47	56.29
Minimum	18.93	10.80	11.84	11.84	11.19	8.51	8.30	8.70	8.00	8.82	10.90	10.00	10.29	7.09	5.00	1.80	1.50	2.00	7.70	12.67	15.00	30.00	31.94	28.54	11.72
Std. Dev.	7.19	7.35	7.14	7.83	7.89	8.29	8.52	9.02	9.39	8.36	7.72	7.59	7.67	7.94	8.40	8.97	9.31	9.03	7.77	6.79	5.75	5.02	5.04	6.12	7.67
Skewness	-0.96	-0.99	-1.08	-1.35	-1.44	-1.61	-1.73	-1.90	-1.87	-2.23	-2.42	-2.31	-1.84	-2.00	-1.78	-1.60	-1.69	-1.70	-1.48	-1.26	-2.32	-1.88	-0.94	-0.82	-1.63
Kurtosis	4.18	5.40	5.45	5.73	6.09	7.03	7.45	7.60	7.56	10.11	11.64	11.25	8.81	10.13	8.81	8.09	8.50	8.71	7.73	7.76	14.29	8.14	3.77	2.93	7.80
Probability	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	
Observations	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	

Table B2-1 statistics on seasonal intraday prices

Summer																									
Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Average
Mean	49.13	46.48	44.59	43.76	43.32	43.46	44.71	46.96	48.83	50.14	50.40	50.66	51.49	51.80	51.30	49.99	49.35	48.86	48.60	48.54	49.48	51.40	51.19	48.28	48.45
Median	50.30	46.59	44.52	43.38	43.13	43.42	44.59	47.63	50.00	51.49	51.85	51.65	52.12	52.01	51.46	50.31	50.42	50.15	49.43	49.26	50.31	52.03	51.57	49.68	49.05
Maximum	59.84	55.90	54.96	53.13	52.70	54.03	54.79	57.93	58.72	59.21	59.99	59.96	61.95	62.03	61.50	61.30	60.96	60.10	59.25	58.69	59.19	59.35	59.05	58.01	58.44
Minimum	33.55	31.95	30.55	30.00	29.10	30.24	33.50	33.20	33.20	34.93	36.15	39.40	40.75	42.00	40.89	39.43	40.40	37.49	37.47	40.10	40.21	41.89	41.82	39.00	36.55
Std. Dev.	5.21	4.54	4.40	4.29	4.34	4.47	4.62	5.62	6.00	5.62	5.15	4.71	4.51	4.17	4.23	4.61	4.90	5.13	4.93	4.66	4.30	3.68	3.58	4.06	4.66
Skewness	-0.49	-0.39	-0.26	-0.38	-0.37	-0.30	-0.01	-0.35	-0.58	-0.78	-0.62	-0.50	-0.38	-0.29	-0.38	-0.15	-0.11	-0.11	-0.05	0.01	-0.18	-0.34	-0.17	-0.18	-0.31
Kurtosis	3.08	3.52	3.66	4.05	3.82	3.43	2.55	2.61	2.74	3.02	2.72	2.62	2.81	2.94	3.15	2.63	2.36	2.19	2.20	2.11	2.39	2.66	2.67	2.22	2.84
Probability	0.16	0.18	0.26	0.04	0.10	0.36	0.68	0.30	0.06	0.01	0.05	0.11	0.31	0.53	0.31	0.65	0.41	0.26	0.29	0.22	0.38	0.34	0.65	0.25	
Observations	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	
Autumn																									
Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Average
Mean	52.96	50.04	47.93	46.47	45.88	46.69	50.33	56.20	57.42	58.83	58.35	57.48	57.20	57.11	55.73	53.60	53.05	54.96	57.96	60.39	61.80	61.10	57.15	53.87	54.69
Median	51.66	49.93	48.78	47.66	47.10	48.00	49.61	55.12	56.94	57.80	57.51	56.39	57.33	57.13	55.14	52.92	52.15	52.50	58.89	62.48	63.31	61.06	57.00	52.04	54.52
Maximum	72.54	68.94	62.62	61.34	57.34	56.80	70.80	77.73	78.39	79.23	79.77	78.93	78.15	78.29	76.50	74.50	75.23	78.31	80.94	81.62	80.81	77.51	73.99	71.05	73.81
Minimum	32.09	29.50	24.47	24.88	23.85	25.00	27.00	30.50	33.10	35.78	35.60	37.50	35.53	35.81	37.55	35.05	33.25	34.19	36.54	37.29	41.00	47.28	40.00	38.43	33.80
Std. Dev.	8.02	7.12	7.02	6.86	6.61	6.37	7.95	10.37	10.65	9.83	9.24	8.91	8.36	8.21	7.98	8.42	8.78	9.96	11.02	10.51	8.46	6.84	7.49	7.83	8.45
Skewness	0.33	0.08	-0.55	-1.03	-1.27	-1.04	0.11	-0.02	-0.07	0.02	0.16	0.27	0.31	0.25	0.43	0.42	0.38	0.36	0.18	-0.12	-0.06	0.24	0.12	0.30	-0.01
Kurtosis	3.11	3.38	3.78	4.48	4.89	4.12	3.46	2.51	2.49	2.51	2.82	2.84	3.29	3.33	3.28	3.27	3.16	2.58	2.17	2.20	2.33	2.38	2.31	2.53	3.05
Probability	0.43	0.72	0.03	0.00	0.00	0.00	0.61	0.63	0.58	0.64	0.78	0.54	0.41	0.50	0.22	0.23	0.32	0.27	0.21	0.27	0.42	0.31	0.37	0.34	
Observations	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	

Table B2-2 statistics on seasonal intraday prices

(iii)

												b_1													
Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Average
Mean	29.98	28.87	28.69	28.28	27.52	27.23	27.98	31.30	36.60	38.02	39.97	40.53	40.94	41.13	41.15	40.47	40.30	40.30	40.11	40.61	40.53	40.48	33.10	31.35	35.64
Median	29.59	28.68	28.17	27.95	27.23	26.89	27.33	30.61	36.68	37.73	39.85	40.31	40.70	40.96	40.89	39.94	40.13	39.77	39.68	40.04	39.82	40.11	32.46	30.95	35.27
Maximum	44.57	44.55	42.65	42.08	41.25	41.43	43.93	46.01	55.55	55.75	56.65	57.18	56.32	56.88	56.76	56.88	56.90	62.27	59.66	62.72	63.37	62.41	53.77	51.26	52.95
Minimum	17.52	13.09	15.60	17.75	16.64	16.86	13.32	17.41	20.52	24.89	26.48	26.97	27.21	25.87	25.81	27.12	27.09	27.05	25.80	24.76	25.00	26.10	20.06	7.78	21.53
Std. Dev.	5.14	5.33	5.08	4.82	4.93	4.87	5.79	5.56	5.86	5.61	5.62	5.75	5.75	5.82	5.81	5.81	5.80	6.13	6.21	6.11	6.13	6.22	5.95	6.11	5.67
Skewness	0.17	0.17	0.39	0.29	0.30	0.34	0.42	0.19	0.21	0.31	0.10	0.11	0.15	0.11	0.12	0.25	0.26	0.36	0.27	0.28	0.38	0.29	0.48	0.26	0.26
Kurtosis	2.82	3.30	2.91	2.79	2.61	2.71	2.83	2.63	3.17	2.91	2.78	2.80	2.89	2.90	2.86	2.99	2.99	3.05	2.71	3.04	3.18	2.92	3.08	3.34	2.93
Probability	0.33	0.21	0.01	0.06	0.02	0.01	0.00	0.12	0.22	0.05	0.50	0.52	0.48	0.65	0.58	0.15	0.13	0.02	0.05	0.08	0.01	0.07	0.00	0.05	
Observations	365	365	365	365	365	365	365	365	365	365	365	365	365	365	365	365	365	365	365	365	365	365	365	365	
												b_2													
Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Average
Mean	8.31	7.95	7.99	7.89	7.87	8.17	8.92	9.71	10.14	10.32	10.44	10.37	10.25	10.16	10.04	9.99	10.16	10.62	11.10	11.48	11.37	10.66	9.67	9.22	9.70
Median	8.18	7.95	7.85	7.83	7.77	8.09	8.63	9.31	9.48	9.71	9.68	9.54	9.69	9.62	9.60	9.33	9.41	9.74	9.77	9.84	9.88	9.62	9.18	8.76	9.10
Maximum	17.48	18.90	20.14	21.16	22.78	22.95	21.42	27.27	29.84	29.71	30.15	28.14	29.33	28.16	26.45	26.15	25.40	28.89	39.08	38.87	37.07	31.89	24.05	18.97	26.84
Minimum	0.94	0.88	0.97	1.14	1.20	1.46	1.16	1.70	2.47	1.67	1.84	1.81	2.09	1.47	1.53	1.41	1.72	1.69	2.49	1.80	1.55	1.54	1.60	-15.56	0.86
Std. Dev.	3.01	2.85	3.03	3.01	2.93	3.11	3.25	3.55	4.13	4.30	4.27	4.13	3.90	3.83	3.68	3.77	3.79	4.48	5.37	6.00	6.01	4.98	3.64	3.37	3.93
Skewness	0.36	0.41	0.49	0.49	0.61	0.55	0.57	1.07	1.33	1.27	1.33	1.33	1.25	1.17	1.10	1.18	1.17	1.58	1.74	1.67	1.45	1.35	0.82	-0.61	0.99
Kurtosis	3.25	3.84	3.77	3.83	4.58	4.13	3.46	5.48	6.17	5.83	6.17	5.95	6.07	5.78	5.13	5.11	5.02	6.34	7.24	6.38	5.49	5.39	4.24	10.48	5.38
Probability	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Observations	365	365	365	365	365	365	365	365	365	365	365	365	365	365	365	365	365	365	365	365	365	365	365	365	

Table B3 statistics on estimated b_1 and b_2

(iv)

Date Description	Full description	source	whether accepted bids
Total demand	Forward demand plus Intraday demand	OMIE	yes
Renewable spot demand	Demand by renewable producer in intraday market	OMIE	yes
Forward demand	Forward demand in day-ahead market	OMIE	yes
Planned demand	Forecasted total demand by planned schedule	OMIE	
Forecast demand	Forecasted total demand by REE	REE	

Table B4 Data information for regression (20)

Winter																									
Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Average
Mean	28679.59	26144.32	24682.68	23873.34	23440.60	24043.09	26118.05	29019.71	30277.82	32679.76	34587.01	35230.09	35311.45	35387.56	34670.89	33621.53	33176.48	33058.64	34827.93	35864.60	36214.99	36007.23	34145.70	31255.68	31346.61
Median	28805.90	26237.15	24684.55	24000.85	23136.10	24196.70	26805.90	29734.95	30012.05	32439.70	35038.15	35295.25	36109.50	35724.85	34841.35	33621.70	33206.75	32733.65	34645.60	35885.90	36184.15	36096.70	33795.55	31093.55	31430.27
Maximum	33332.40	31960.10	31330.60	30921.70	30464.50	30805.10	32314.00	39993.50	42451.70	44186.00	45218.00	45584.50	45185.60	45310.50	44797.80	44561.60	44028.30	43850.20	46064.00	47168.20	48079.40	44514.50	41915.90	37237.30	40469.81
Minimum	21009.60	17644.30	17919.90	16263.70	15533.30	15895.70	16403.40	16639.00	16953.50	20447.10	22076.70	22409.30	23194.80	24197.90	23839.90	19899.80	19883.00	18859.10	23918.90	24633.10	24618.10	24526.80	23795.70	22116.20	20528.28
Std. Dev.	2853.86	3162.97	3075.97	3418.96	3412.01	3448.93	3739.26	5025.14	5452.99	5503.05	5302.04	5049.74	4906.62	4612.80	4541.95	4861.87	4947.49	5230.14	5235.14	5316.94	4916.92	3891.89	3440.43	2936.89	4345.17
Skewness	-0.47	-0.50	-0.16	-0.23	-0.20	-0.39	-0.68	-0.37	-0.05	-0.06	-0.25	-0.28	-0.36	-0.29	-0.31	-0.40	-0.36	-0.27	0.00	-0.16	-0.06	-0.30	-0.21	-0.39	-0.28
Kurtosis	2.66	2.74	2.55	2.34	2.44	2.59	2.72	2.59	2.56	2.28	2.33	2.46	2.59	2.66	2.78	2.99	2.79	2.61	2.05	2.15	2.35	3.09	3.23	3.39	2.62
Probability	0.16	0.14	0.56	0.30	0.42	0.23	0.03	0.26	0.69	0.37	0.27	0.31	0.28	0.42	0.45	0.30	0.35	0.42	0.19	0.21	0.44	0.50	0.65	0.25	
Observations	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	
Spring																									
Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Average
Mean	25668.35	23684.57	22632.73	22006.90	21723.19	22061.73	23250.44	25345.08	26723.61	28662.84	30121.78	30471.04	30773.22	30901.35	30419.28	29760.01	29312.31	28658.57	28178.28	28504.49	29688.48	30825.76	29306.80	27183.98	27327.70
Median	26277.60	24004.85	22754.70	22073.65	22010.20	22284.25	23979.15	26551.00	28315.05	30707.40	31584.40	31663.35	32057.95	32102.80	31379.60	30753.55	30324.65	29876.00	29035.25	29212.10	30450.35	31716.65	29824.00	27545.50	28186.83
Maximum	29004.10	27408.70	27430.70	27435.20	27383.80	27555.80	26791.30	30385.60	32501.50	34122.20	35340.90	35868.30	36507.20	36227.30	35677.60	35393.60	35065.40	34951.30	33886.70	33871.10	34586.80	34733.20	33246.10	30697.40	32336.33
Minimum	20765.70	18948.90	18161.70	17485.30	17525.00	17567.90	18104.80	18131.60	18369.80	19874.00	21525.10	21809.30	21162.30	21933.60	22530.20	21694.90	20502.50	20155.90	19288.40	20281.70	21627.10	24533.30	23755.50	21861.10	20316.48
Std. Dev.	1786.86	1923.73	1986.34	2009.00	2047.84	2044.50	2244.29	3364.12	3941.77	4028.90	3635.70	3401.14	3615.06	3463.44	3281.83	3471.96	3553.73	3666.39	3430.32	3137.34	3160.76	2651.19	2093.36	1826.27	2906.91
Skewness	-0.84	-0.53	-0.11	0.04	0.04	-0.19	-0.71	-0.69	-0.51	-0.69	-0.90	-0.89	-0.84	-0.82	-0.72	-0.58	-0.65	-0.55	-0.62	-0.48	-0.55	-0.61	-0.51	-0.57	-0.56
Kurtosis	3.19	2.53	2.29	2.47	2.50	2.71	2.44	2.27	2.12	2.22	2.62	2.79	2.69	2.73	2.59	2.26	2.48	2.38	2.59	2.33	2.29	2.13	2.54	2.89	2.50
Probability	0.00	0.07	0.34	0.58	0.61	0.65	0.01	0.01	0.03	0.01	0.00	0.00	0.00	0.00	0.01	0.03	0.02	0.05	0.04	0.07	0.04	0.01	0.09	0.08	
Observations	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	

Table B5-1 statistics on total demand

Summer																									
Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Average
Mean	29230.84	27189.68	25839.65	24929.30	24488.49	24444.46	25373.84	26616.28	28589.96	30910.07	32886.21	33792.11	34789.43	35233.79	35470.33	35124.26	34958.51	34692.63	34092.48	33470.74	33028.43	32769.92	32568.36	30949.39	30893.30
Median	29312.95	27279.35	26099.90	25099.15	24679.25	24591.50	25692.90	27263.75	29405.85	31589.00	33651.65	34693.65	35731.35	36371.45	36622.70	36340.45	36083.55	35799.70	35144.35	34389.20	33573.20	33880.55	33063.25	31340.15	31570.78
Maximum	33123.10	30481.20	29035.70	28236.40	27832.70	27918.20	29190.50	32697.40	36376.70	38375.90	39989.80	40850.30	42188.40	42551.90	42616.00	42369.70	42191.60	41816.90	40857.70	39942.20	39130.50	39053.20	37847.10	35433.80	36671.12
Minimum	25296.80	23095.50	21869.20	20930.30	20588.30	20080.70	19728.30	19495.90	20052.80	21525.30	23175.70	24627.30	25747.20	26754.50	27177.20	26833.00	25968.90	25613.30	25705.40	25549.60	25821.60	24058.00	23923.90	26535.10	23756.41
Std. Dev.	1882.62	1694.17	1754.23	1808.30	1747.31	1861.30	2299.44	3317.44	3963.29	4198.91	4014.57	3916.21	4059.15	4073.82	3856.65	3976.52	4130.69	4142.66	3778.84	3486.44	3182.37	3509.94	2824.81	2171.14	3152.12
Skewness	0.00	-0.15	-0.24	-0.20	-0.14	-0.17	-0.50	-0.44	-0.30	-0.38	-0.57	-0.54	-0.49	-0.44	-0.44	-0.40	-0.42	-0.41	-0.39	-0.36	-0.36	-0.57	-0.57	-0.10	-0.36
Kurtosis	2.24	2.32	2.29	2.22	2.28	2.26	2.40	2.25	2.10	2.09	2.45	2.44	2.33	2.18	2.33	2.25	2.18	2.17	2.18	2.27	2.34	2.49	3.13	2.24	2.31
Probability	0.33	0.35	0.24	0.23	0.32	0.28	0.08	0.08	0.11	0.07	0.05	0.06	0.07	0.06	0.09	0.10	0.07	0.07	0.08	0.13	0.17	0.05	0.08	0.31	
Observations	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	
Autumn																									
Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Average
Mean	27022.21	25021.63	24028.64	23396.63	23072.08	23347.20	25139.71	28273.47	30060.01	31715.71	32879.36	33379.26	33812.42	33945.05	33283.57	32645.38	32240.35	32451.28	33100.19	33659.05	34584.56	34087.69	31545.40	29026.71	30071.57
Median	27184.90	25168.40	24117.30	23551.70	23191.90	23481.80	25280.00	28381.70	30141.80	32658.30	33609.60	34402.60	35083.20	35174.10	34563.30	33853.00	33532.90	33595.00	33173.60	33391.60	34789.00	34486.90	31645.10	28761.60	30550.80
Maximum	33038.90	32406.70	30750.80	29123.70	29055.60	30038.50	32323.50	37073.00	40019.40	41721.80	42166.70	41512.70	41571.80	41543.40	40786.90	40245.90	39562.40	40395.80	43126.10	43340.50	42908.70	41263.30	37800.70	34795.00	37773.83
Minimum	22994.60	19437.80	19785.80	19540.30	19443.70	18725.40	19114.80	19234.60	19707.60	21076.50	22358.00	23275.70	22702.90	23448.20	23617.50	23217.80	22461.00	23002.80	23870.10	23796.20	25191.70	21245.60	21392.90	24927.60	21815.38
Std. Dev.	1991.50	2082.83	2007.78	1890.48	1883.42	2178.84	2796.20	4548.98	5357.19	5221.54	4912.42	4504.74	4377.80	4163.83	3959.16	4124.26	4231.83	4415.02	4828.49	5007.62	4491.47	4002.71	3078.97	2456.61	3688.07
Skewness	0.23	0.32	0.47	0.42	0.65	0.51	0.02	-0.02	-0.14	-0.14	-0.23	-0.36	-0.56	-0.62	-0.59	-0.57	-0.60	-0.40	-0.03	0.08	-0.01	-0.58	-0.12	0.54	-0.07
Kurtosis	3.10	4.36	3.91	3.58	4.02	3.48	2.80	2.22	2.16	2.29	2.56	2.56	2.62	2.64	2.66	2.50	2.38	2.22	2.33	2.18	2.29	3.55	3.23	2.77	2.85
Probability	0.65	0.01	0.04	0.14	0.01	0.09	0.93	0.31	0.23	0.33	0.46	0.25	0.07	0.04	0.06	0.05	0.03	0.09	0.43	0.26	0.38	0.05	0.81	0.10	
Observations	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	

Table B5-2 statistics on total demand

Winter																									
Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Average
Mean	26758.78	24466.54	23155.90	22413.90	22062.68	22611.36	24450.60	27042.68	28239.80	30510.31	32354.01	33075.03	33165.70	33292.39	32640.20	31677.90	31228.49	30998.52	32551.36	33476.95	33893.50	33862.86	32240.02	29531.92	29404.23
Median	26917.15	24487.60	23214.70	22468.55	21892.20	22748.15	24994.30	27749.60	27602.45	30050.45	32407.50	33313.80	33557.70	33396.15	32649.05	31622.50	31630.60	31005.35	32475.00	33636.05	34184.25	34116.80	32038.65	29494.20	29485.53
Maximum	31555.00	30388.70	29504.80	29183.60	28775.80	29847.20	31230.70	36770.60	39112.60	40910.40	41694.50	42081.50	41997.60	41906.80	41197.10	40679.40	40115.00	39149.40	40996.30	41965.50	42818.50	40444.90	38139.30	34559.50	37292.70
Minimum	19362.30	16424.20	16247.80	14818.90	14506.90	14666.60	15339.80	15459.80	15780.60	18540.70	20515.60	21371.80	22170.90	22966.40	22274.50	18576.80	18398.40	17447.30	22859.30	22714.30	22768.30	22619.20	22077.10	20440.30	19097.83
Std. Dev.	2694.22	3014.13	2951.01	3289.57	3298.09	3336.15	3557.40	4702.12	5173.50	5236.04	5005.98	4748.64	4635.57	4337.16	4265.97	4511.04	4599.15	4862.22	4801.15	4932.27	4602.57	3691.04	3312.84	2837.97	4099.83
Skewness	-0.54	-0.41	-0.14	-0.20	-0.18	-0.34	-0.64	-0.41	-0.01	-0.03	-0.27	-0.33	-0.38	-0.31	-0.33	-0.45	-0.43	-0.37	-0.11	-0.26	-0.21	-0.38	-0.34	-0.51	-0.32
Kurtosis	2.90	2.79	2.71	2.44	2.54	2.69	2.78	2.55	2.46	2.15	2.23	2.37	2.49	2.55	2.61	2.93	2.75	2.50	1.93	2.06	2.19	2.90	2.99	3.31	2.58
Probability	0.11	0.26	0.73	0.41	0.54	0.35	0.04	0.20	0.57	0.25	0.19	0.21	0.21	0.34	0.33	0.22	0.22	0.22	0.11	0.12	0.21	0.34	0.43	0.12	
Observations	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	
Spring																									
Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Average
Mean	23599.50	21742.48	20780.69	20192.15	19963.25	20271.34	21227.91	23060.51	24478.03	26373.81	27907.68	28328.33	28662.55	28801.54	28375.35	27788.79	27392.08	26762.53	26269.78	26490.24	27584.21	28706.77	27316.88	25282.73	25306.63
Median	24159.90	22088.50	21061.50	20398.80	20149.00	20423.05	21645.70	24308.30	25823.05	28075.75	29267.45	29344.10	29728.65	29832.30	29325.75	28747.60	28315.35	27792.25	27046.20	27305.25	28403.45	29709.85	27782.50	25642.05	26099.01
Maximum	26582.20	25884.30	25416.90	25299.60	25090.50	25087.40	24612.60	27045.40	29833.40	31523.20	32459.80	32913.20	33712.40	33996.20	33210.30	33515.80	33561.90	33389.10	31791.80	31401.10	32052.20	32366.90	30788.00	28882.80	30017.38
Minimum	19041.40	17201.10	16601.70	15698.40	15659.40	15958.30	16124.40	15861.40	16379.60	18012.30	19146.90	20004.50	19960.40	20546.80	20591.10	19875.50	19214.00	18932.20	18415.60	18671.40	19454.10	22373.60	21631.90	19397.60	18531.40
Std. Dev.	1766.20	1890.73	1959.97	1982.60	2012.96	2008.30	2208.22	3113.46	3733.58	3842.60	3478.40	3240.11	3445.64	3311.76	3162.57	3309.33	3412.16	3506.53	3271.79	2986.37	3032.11	2614.43	2105.73	1840.25	2801.49
Skewness	-0.67	-0.39	-0.09	-0.02	-0.05	-0.28	-0.69	-0.73	-0.46	-0.66	-0.88	-0.87	-0.80	-0.78	-0.68	-0.56	-0.58	-0.48	-0.51	-0.46	-0.64	-0.67	-0.59	-0.69	-0.55
Kurtosis	2.78	2.45	2.26	2.42	2.43	2.57	2.49	2.34	2.04	2.15	2.58	2.75	2.57	2.61	2.53	2.25	2.40	2.26	2.39	2.27	2.33	2.23	2.62	3.16	2.45
Probability	0.03	0.17	0.33	0.52	0.52	0.39	0.02	0.01	0.03	0.01	0.00	0.00	0.01	0.01	0.02	0.03	0.04	0.06	0.07	0.07	0.02	0.01	0.05	0.03	
Observations	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	

Table B6-1 statistics on forward demand

Summer																									
Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Average
Mean	26988.51	25074.54	23822.60	22934.52	22571.25	22524.83	23364.48	24533.75	26358.24	28597.30	30590.21	31485.74	32421.33	32850.46	33072.82	32813.97	32694.70	32475.88	31887.67	31364.66	30932.65	30617.40	30418.92	28831.67	28717.84
Median	27209.65	25135.50	24046.85	23168.15	22755.05	22623.35	23571.50	24948.30	26802.70	29115.85	31201.50	32193.25	33300.45	34120.15	34161.65	33904.15	33847.80	33699.15	32868.25	32220.50	31497.00	31483.00	30756.60	28942.15	29315.52
Maximum	30639.40	28208.20	26773.30	25836.10	25597.70	25784.20	26998.50	30260.50	33499.50	35743.50	37295.20	38075.20	39358.20	39794.90	39707.30	39610.80	39466.10	39154.60	38183.30	37438.10	36931.00	37012.60	35975.30	33349.60	34195.55
Minimum	22979.70	20969.10	19845.50	19077.80	18746.40	18575.50	18461.50	17976.70	18570.10	19892.80	21597.30	22932.80	23838.70	24756.20	25146.40	24826.40	24369.30	23948.60	23896.80	24016.80	24107.10	21952.10	21565.50	24317.20	21931.93
Std. Dev.	1889.51	1692.74	1664.21	1698.06	1648.02	1728.93	2167.90	3111.10	3759.76	4019.89	3833.95	3755.19	3907.45	3949.60	3768.99	3867.26	3970.13	3969.06	3653.82	3373.58	3158.17	3542.18	2887.89	2199.58	3050.71
Skewness	-0.13	-0.26	-0.28	-0.22	-0.18	-0.20	-0.45	-0.37	-0.24	-0.33	-0.53	-0.50	-0.46	-0.40	-0.42	-0.39	-0.37	-0.39	-0.38	-0.34	-0.33	-0.52	-0.56	-0.05	-0.35
Kurtosis	2.18	2.28	2.23	2.15	2.27	2.24	2.35	2.23	2.07	2.06	2.41	2.40	2.29	2.13	2.26	2.21	2.13	2.15	2.17	2.21	2.27	2.44	3.17	2.30	2.27
Probability	0.24	0.22	0.18	0.17	0.28	0.25	0.09	0.11	0.12	0.08	0.06	0.07	0.08	0.07	0.09	0.10	0.08	0.07	0.09	0.12	0.16	0.07	0.08	0.39	
Observations	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	
Autumn																									
Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Average
Mean	24849.73	23090.93	22228.01	21658.11	21390.55	21595.26	23035.97	25617.45	27189.15	28725.27	29930.54	30577.00	31029.15	31243.24	30613.50	30068.10	29620.11	29555.32	29805.11	30228.95	31106.94	30840.96	28841.13	26666.97	27479.48
Median	24902.10	23249.50	22292.30	21741.70	21304.60	21589.10	22950.20	25700.60	27413.20	29402.70	30304.50	31170.30	32050.70	32259.20	31528.90	31089.30	30676.10	30642.70	30068.10	30213.80	31420.50	31514.80	28868.00	26450.30	27866.80
Maximum	30712.60	29289.30	28368.80	27164.30	26995.20	27877.00	29237.50	33768.80	35869.70	37488.40	38270.20	38266.80	38498.70	38463.30	37673.30	37096.90	36432.10	36529.30	38821.60	39652.70	39843.70	37741.00	35024.60	32464.30	34647.92
Minimum	20265.00	17994.70	17791.10	17185.60	16830.60	16725.00	16715.30	16770.90	17068.60	18717.80	20261.50	21546.80	20693.90	22009.40	21609.50	21275.30	20746.10	21024.30	21612.70	22039.40	22917.10	19541.00	19605.00	22234.70	19715.89
Std. Dev.	1901.32	1968.96	1978.48	1898.08	1912.07	2207.70	2597.74	4017.79	4683.04	4647.13	4369.14	4068.63	3976.95	3796.32	3621.61	3738.15	3798.85	3813.38	4080.23	4241.00	3801.19	3592.00	2890.61	2290.46	3328.78
Skewness	0.33	0.34	0.43	0.38	0.51	0.43	-0.08	-0.07	-0.18	-0.20	-0.30	-0.38	-0.58	-0.62	-0.60	-0.60	-0.65	-0.54	-0.05	0.09	0.04	-0.56	-0.07	0.42	-0.10
Kurtosis	3.37	3.96	3.71	3.45	3.78	3.41	2.93	2.31	2.22	2.32	2.64	2.65	2.75	2.71	2.72	2.56	2.45	2.36	2.52	2.42	2.59	3.71	3.32	2.87	2.91
Probability	0.33	0.07	0.09	0.22	0.04	0.18	0.95	0.39	0.25	0.31	0.39	0.27	0.07	0.05	0.06	0.04	0.02	0.05	0.64	0.50	0.72	0.03	0.79	0.26	
Observations	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	

Table B6-2 statistics on forward demand

Winter																									
Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Average
Mean	158.52	144.04	145.61	155.68	158.75	158.45	150.43	137.51	154.89	180.09	188.01	189.61	183.10	182.65	178.61	174.26	179.71	169.31	164.09	171.71	170.91	169.08	158.09	152.77	165.66
Median	126.65	101.65	100.35	121.75	125.50	122.25	127.10	106.65	126.50	158.90	168.65	170.40	149.25	152.55	152.95	149.25	149.55	142.40	132.45	142.30	131.80	132.80	123.40	122.80	134.91
Maximum	524.60	532.30	787.10	466.50	481.00	458.10	551.40	457.50	519.50	682.50	643.10	609.20	591.60	626.80	653.80	694.50	666.40	665.90	622.00	635.70	688.80	687.90	665.90	684.00	608.17
Minimum	38.00	38.40	32.20	33.90	33.20	33.20	30.60	25.20	17.10	39.00	37.50	47.60	32.90	30.20	21.80	23.20	30.80	26.60	29.60	29.40	29.80	33.40	18.20	22.00	30.58
Std. Dev.	110.49	103.74	120.02	102.27	110.48	110.35	105.57	97.03	101.62	111.67	112.53	112.34	112.47	115.54	112.02	114.52	122.50	112.99	104.12	113.85	122.29	121.30	109.74	109.00	111.19
Skewness	1.46	1.51	2.54	1.11	1.04	1.02	1.57	1.26	1.15	1.45	1.17	1.25	1.22	1.26	1.18	1.36	1.28	1.45	1.29	1.39	1.66	1.55	1.57	1.75	1.40
Kurtosis	4.71	4.98	11.63	3.64	3.17	3.26	5.74	4.07	3.99	6.37	4.76	4.79	4.45	4.90	5.23	6.25	4.91	6.07	5.60	5.16	6.18	6.33	6.88	8.12	5.47
Probability	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Observations	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	
Spring																									
Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Average
Mean	163.14	146.01	147.73	144.61	140.18	137.54	137.41	152.73	163.20	185.11	191.25	186.53	182.77	186.63	177.78	175.08	170.21	176.99	171.72	167.55	187.49	191.09	175.85	170.92	167.90
Median	134.70	118.80	116.05	121.35	123.15	117.75	117.20	132.75	138.40	160.55	167.25	160.85	147.90	163.80	156.50	156.80	140.90	147.60	143.60	152.35	177.75	169.50	167.90	161.30	145.61
Maximum	582.60	397.00	494.40	454.10	447.80	386.60	406.40	483.00	525.40	593.90	641.00	636.90	708.60	679.90	720.30	710.30	683.60	642.10	617.10	546.20	513.90	606.10	478.70	415.60	557.15
Minimum	48.80	32.00	28.30	35.40	31.20	19.80	34.80	30.40	33.80	28.40	29.20	28.00	22.80	22.10	22.50	22.30	25.50	32.40	31.60	29.10	26.30	27.60	24.40	24.70	28.81
Std. Dev.	88.25	85.08	95.15	88.91	80.14	78.56	73.95	87.54	97.86	107.38	111.66	104.01	108.82	107.62	104.31	101.44	106.90	103.86	109.59	96.72	99.71	109.03	87.97	81.25	96.49
Skewness	1.52	1.09	1.32	1.36	1.20	0.98	1.39	1.49	1.35	1.21	1.27	1.37	1.76	1.64	1.81	1.91	1.96	1.77	2.00	1.39	0.78	1.32	0.98	0.69	1.40
Kurtosis	6.90	3.55	4.32	4.56	4.39	3.28	5.17	5.40	4.76	4.67	5.46	6.04	8.05	7.31	9.51	10.00	8.48	7.29	7.67	5.46	3.39	4.94	3.92	3.18	5.74
Probability	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.02	
Observations	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	

Table B7-1 statistics on renewable spot demand

Summer																									
Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Average
Mean	303.17	272.12	256.49	266.33	249.21	242.89	254.98	247.30	272.90	288.47	310.26	310.15	312.14	322.87	313.23	324.63	325.99	326.45	317.51	289.11	314.98	316.96	301.99	290.26	292.93
Median	302.85	259.55	236.70	239.05	225.60	223.50	224.50	225.95	271.55	271.80	283.60	287.10	299.80	291.20	294.00	302.00	312.15	306.30	293.40	277.10	301.70	295.45	293.85	288.30	275.29
Maximum	596.70	584.30	747.70	745.60	722.90	660.00	627.70	916.80	1138.00	1150.00	1120.00	1121.60	1047.90	967.50	888.10	862.60	826.50	789.00	771.80	752.00	810.20	1007.00	872.50	526.10	843.85
Minimum	73.90	69.40	59.50	77.30	75.30	60.30	53.10	67.60	94.50	74.30	73.90	63.80	46.40	45.90	62.30	65.90	65.30	65.30	50.20	47.50	50.10	53.30	44.50	58.10	62.40
Std. Dev.	124.65	123.10	127.25	135.80	128.94	130.12	129.68	131.34	140.79	141.37	154.03	154.87	156.30	165.30	156.61	160.29	160.27	153.46	150.53	143.45	153.42	159.83	140.91	121.43	143.49
Skewness	0.23	0.47	1.05	1.24	1.28	0.97	0.84	1.75	2.66	2.68	1.92	1.80	1.37	1.20	1.12	0.99	0.92	0.77	0.68	0.72	0.64	1.15	0.89	0.08	1.14
Kurtosis	2.54	2.73	4.40	4.61	5.10	3.82	3.25	9.03	16.75	16.55	10.08	9.94	7.28	5.12	4.85	4.21	4.14	3.79	3.48	3.23	3.31	5.52	4.78	2.25	5.86
Probability	0.44	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.04	0.00	0.00	0.32	
Observations	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	
Autumn																									
Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Average
Mean	274.79	251.71	239.04	234.97	233.42	239.58	243.55	293.13	309.23	346.25	357.58	373.76	386.74	392.42	374.56	378.41	379.20	412.60	437.49	444.07	448.46	429.71	398.90	358.65	343.26
Median	243.50	226.20	203.10	213.40	230.10	228.50	193.00	278.10	275.80	322.60	321.00	347.00	369.10	380.90	352.80	362.60	327.50	386.80	391.20	458.10	438.00	406.20	397.00	352.20	321.03
Maximum	715.20	758.30	557.10	590.80	640.00	646.90	882.30	830.20	755.60	918.80	940.40	988.70	975.30	969.20	986.10	985.50	1167.50	1090.00	1094.00	1134.60	1159.60	885.10	1005.30	946.50	900.96
Minimum	54.50	37.70	63.40	52.10	28.10	39.40	38.50	29.20	34.60	60.40	57.70	71.90	78.70	81.40	78.20	69.70	63.30	44.40	34.80	33.30	26.90	26.20	38.20	40.30	49.29
Std. Dev.	147.02	142.53	123.82	122.95	122.57	126.33	152.56	165.57	171.68	189.46	188.11	195.67	204.10	200.10	189.88	201.19	216.05	234.87	251.98	246.72	219.45	213.53	200.59	173.71	183.35
Skewness	0.95	1.03	0.76	0.83	0.72	0.93	1.54	0.92	0.54	0.71	0.85	0.75	0.71	0.68	0.78	0.91	1.16	0.64	0.45	0.37	0.36	0.23	0.53	0.64	0.75
Kurtosis	3.50	3.96	2.74	3.12	3.28	3.92	5.68	3.86	2.55	3.14	3.38	3.20	3.20	3.30	3.53	3.73	4.57	2.87	2.50	2.63	3.25	2.40	3.15	3.63	3.38
Probability	0.00	0.00	0.01	0.01	0.02	0.00	0.00	0.00	0.08	0.02	0.00	0.01	0.02	0.03	0.01	0.00	0.00	0.04	0.13	0.28	0.34	0.34	0.12	0.02	
Observations	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	

Table B7-2 statistics on renewable spot demand

Winter																									
Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Average
Mean	36404.46	34064.11	32860.89	32636.26	32549.85	32439.19	33156.07	35976.54	38638.90	41034.78	42748.33	43247.96	43181.78	43312.71	42573.48	41798.03	41091.51	40874.75	42789.03	44911.33	45944.31	45588.20	43060.05	39609.57	39603.84
Median	36585.05	34166.20	32885.15	32925.45	32954.75	32735.40	33291.60	37157.75	40633.60	43367.75	44592.15	44523.35	44174.75	44107.00	42894.60	42422.40	42062.00	41832.00	43083.35	45620.90	46421.35	45924.25	43106.45	39760.90	40301.17
Maximum	41722.90	38815.30	37595.30	36895.70	36708.80	37305.30	39151.80	41432.20	45013.50	47486.70	48769.20	49027.50	49158.30	48684.50	47656.30	46920.20	46353.30	46710.60	49546.10	50774.70	51702.00	51056.80	47729.00	44501.20	45029.88
Minimum	30351.90	27966.10	26680.00	25681.50	25521.30	25559.50	25823.00	26315.20	26825.90	28501.60	30244.20	30853.50	31678.20	32613.40	33090.40	32516.80	31610.10	29857.70	32907.80	35046.40	36308.60	36831.20	36040.30	33320.60	30506.05
Std. Dev.	2035.42	2076.04	2190.43	2255.16	2205.66	2236.47	2552.70	3811.94	4942.35	5000.69	4528.60	4146.48	4022.71	3735.81	3434.82	3624.86	3733.20	3903.88	3906.33	3596.13	3430.04	3259.38	2786.34	2277.75	3320.55
Skewness	-0.52	-0.34	-0.27	-0.60	-0.56	-0.40	-0.40	-0.61	-0.57	-0.68	-0.78	-0.75	-0.65	-0.65	-0.62	-0.57	-0.56	-0.52	-0.39	-0.55	-0.54	-0.50	-0.51	-0.54	-0.55
Kurtosis	3.91	3.55	3.09	3.61	3.47	3.43	3.26	2.23	2.02	2.24	2.67	2.85	2.64	2.76	2.71	2.42	2.35	2.40	2.38	2.66	2.83	2.84	2.83	3.14	2.85
Probability	0.03	0.23	0.57	0.03	0.06	0.22	0.26	0.02	0.01	0.01	0.01	0.01	0.03	0.04	0.05	0.05	0.04	0.07	0.16	0.09	0.11	0.15	0.14	0.11	
Observations	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	
Spring																									
Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Average
Mean	33005.20	31115.97	30094.46	29524.48	29225.30	29247.92	30065.10	32360.07	34963.08	37266.87	38634.56	39055.01	39404.76	39329.18	38631.68	38038.21	37502.78	36902.77	36250.62	36833.12	38489.41	39765.35	37950.88	35169.99	35367.78
Median	33375.85	31239.70	30126.85	29592.30	29289.50	29312.85	30647.35	33675.10	36723.85	39059.50	40094.15	40360.25	40837.90	40364.65	39771.50	39161.65	38725.15	38191.50	37446.00	37400.35	38880.25	40351.80	38427.70	35467.55	36188.47
Maximum	35983.80	34899.50	34313.00	34230.40	34176.10	33914.20	33274.50	36652.40	40087.80	42826.50	44079.40	44253.70	44147.70	43580.60	43031.40	42882.20	43225.00	42031.70	40494.60	42641.90	45351.00	44800.40	42479.30	39653.30	40125.43
Minimum	27837.30	25908.30	25064.00	24329.50	24176.20	24122.30	24106.60	23642.70	24941.40	27042.70	28340.80	29563.30	30223.00	30526.70	29609.50	28881.70	28316.60	27889.40	27763.40	27573.70	28638.10	32486.90	31566.00	28879.60	27559.57
Std. Dev.	1773.55	1842.04	2075.07	2150.94	2183.36	2158.29	2125.34	3216.41	4110.66	4270.32	3920.65	3573.74	3485.47	3308.20	3199.21	3295.91	3319.70	3310.96	3146.55	3405.91	3791.03	3041.64	2307.40	1933.15	2956.06
Skewness	-0.67	-0.33	-0.01	0.04	0.01	-0.09	-0.77	-0.85	-0.83	-0.90	-0.93	-0.90	-0.92	-0.95	-0.96	-0.90	-0.81	-0.80	-0.74	-0.56	-0.46	-0.63	-0.71	-0.79	-0.64
Kurtosis	2.86	2.79	2.65	2.70	2.71	2.68	2.86	2.62	2.39	2.60	2.85	2.82	2.78	2.95	2.99	2.79	2.68	2.50	2.40	2.64	2.74	2.77	3.21	3.80	2.78
Probability	0.03	0.41	0.79	0.83	0.85	0.77	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.07	0.18	0.04	0.02	0.00	
Observations	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	

Table B8-1 statistics on planned demand

Summer																									
Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Average
Mean	35800.83	33585.81	32186.39	31341.64	30893.87	30791.07	31502.62	33013.41	35344.42	38132.71	40071.64	41167.40	42235.81	42755.75	42550.06	42075.60	41821.42	41505.38	40902.73	40441.79	40240.96	40601.60	40067.35	37900.68	37788.79
Median	36222.75	33947.20	32368.15	31522.60	31039.80	30986.20	31951.80	33728.10	36467.30	39313.05	41171.15	42311.40	43497.60	44091.05	43819.10	43164.25	42808.80	42651.45	41948.70	41420.30	41388.10	41257.50	40386.40	38092.65	38564.81
Maximum	39145.70	36564.10	34928.80	34463.80	34224.50	34302.70	35180.90	37992.30	41651.10	44597.50	46369.30	47264.90	48648.40	49095.20	48958.80	48863.70	48684.30	48230.00	47292.40	46586.40	46213.10	46059.10	44987.80	42037.10	43014.25
Minimum	31530.70	29986.60	28752.50	27745.70	27090.10	26633.10	26463.00	26488.20	26923.70	28834.10	30761.70	32218.40	33130.20	33624.00	33384.60	33021.30	33347.40	32968.20	33213.60	33616.90	33652.80	34058.20	34622.50	32895.50	31040.13
Std. Dev.	1797.98	1561.51	1499.03	1522.68	1519.52	1587.73	1999.50	2825.96	3706.06	4110.44	4013.35	3923.56	4085.27	3982.72	3899.29	4030.48	4117.95	4115.73	3788.51	3426.85	3165.03	2786.13	2347.56	2022.14	2993.12
Skewness	-0.32	-0.37	-0.26	-0.27	-0.26	-0.38	-0.62	-0.63	-0.66	-0.74	-0.77	-0.76	-0.70	-0.67	-0.60	-0.53	-0.49	-0.50	-0.48	-0.42	-0.41	-0.37	-0.22	-0.21	-0.48
Kurtosis	2.26	2.28	2.26	2.48	2.63	2.75	2.67	2.49	2.39	2.51	2.62	2.60	2.47	2.44	2.39	2.30	2.16	2.18	2.18	2.20	2.28	2.38	2.48	2.56	2.42
Probability	0.16	0.13	0.21	0.34	0.46	0.29	0.04	0.03	0.02	0.01	0.01	0.01	0.01	0.02	0.03	0.04	0.04	0.04	0.05	0.08	0.10	0.16	0.41	0.50	
Observations	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	
Autumn																									
Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Average
Mean	32884.63	31151.92	30216.87	29743.71	29488.09	29465.89	30531.66	33098.01	34964.84	36839.15	38258.80	38976.23	39573.78	39804.35	39115.90	38477.52	37930.20	37480.45	37640.13	38334.05	40089.99	40174.22	37621.73	34974.25	35701.52
Median	32945.80	31187.10	30234.30	29793.20	29628.30	29566.70	31043.50	34077.80	36185.40	38349.30	39414.90	40161.70	40864.00	40959.30	40174.00	39556.50	39114.40	38806.00	38099.60	38666.40	40585.30	40562.40	37849.40	34944.90	36365.43
Maximum	37252.50	36783.80	35929.20	35313.40	35220.20	35209.90	35655.80	40132.40	42950.00	44918.00	46009.80	45819.50	45935.20	45804.00	44892.30	44277.00	43583.10	43867.20	46738.00	48003.80	49023.60	48372.00	45247.80	40384.10	42388.44
Minimum	29420.40	27798.00	26812.30	25904.20	25400.20	25178.30	25179.30	25304.80	25616.20	27560.60	28951.70	30537.90	31365.80	31943.00	31613.50	30664.50	30060.80	28538.80	28745.00	29778.80	32872.40	34202.40	32407.90	30350.20	29008.63
Std. Dev.	1813.97	1662.80	1697.23	1792.63	1831.48	1830.05	2068.54	3395.52	4198.59	4240.80	3879.53	3604.36	3596.35	3374.82	3160.41	3388.02	3496.68	3697.37	3878.17	3882.39	3486.80	3044.81	2555.25	2062.62	2984.97
Skewness	0.02	0.32	0.42	0.40	0.40	0.32	-0.43	-0.46	-0.53	-0.63	-0.72	-0.74	-0.78	-0.78	-0.72	-0.71	-0.71	-0.66	-0.23	0.07	0.00	0.09	0.42	0.39	-0.22
Kurtosis	2.57	3.52	3.87	3.78	3.94	3.75	3.25	2.54	2.41	2.60	2.88	2.73	2.54	2.58	2.58	2.43	2.36	2.35	2.75	2.92	2.94	2.96	3.56	3.43	2.97
Probability	0.70	0.28	0.06	0.09	0.06	0.16	0.22	0.13	0.06	0.04	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.58	0.96	0.99	0.94	0.15	0.22	
Observations	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	

Table B8-2 statistics on planned demand

Winter																									
Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Average
Mean	147005.3	181617.3	179862.7	160151.7	161457.4	135386.2	132465.5	147433.0	148462.0	147776.4	157098.4	154396.5	156492.2	169906.1	171100.5	161675.7	142856.7	142585.7	151496.6	149984.3	156579.9	171449.1	168502.2	153363.4	156212.7
Median	151224.0	206090.5	198565.0	187151.5	173095.5	145697.0	139552.5	157151.0	175905.5	166918.5	162960.0	164034.5	171486.5	195151.0	181134.5	169124.5	156116.0	150890.0	167222.0	170919.0	163070.5	192792.0	181141.0	159904.5	170304.0
Maximum	217593.0	239035.0	218528.0	213673.0	209789.0	186068.0	195997.0	189863.0	192622.0	199205.0	230706.0	232678.0	230358.0	233535.0	227479.0	211305.0	201584.0	192131.0	203337.0	199695.0	218674.0	228717.0	225579.0	232989.0	213797.5
Minimum	11831.0	1539.0	14129.0	1884.0	1441.0	12176.0	1268.0	1495.0	13569.0	1516.0	15132.0	1842.0	13617.0	18279.0	1964.0	2005.0	1914.0	1892.0	1851.0	1342.0	12914.0	1527.0	17306.0	14655.0	6962.0
Std. Dev.	51873.5	60497.4	48902.2	62599.6	45375.8	40869.9	52780.8	44130.8	56935.9	54121.9	51903.5	57231.2	59283.4	65763.2	52113.4	48273.0	54488.1	42468.0	54278.5	54571.5	48653.1	60276.4	49617.2	54049.2	52960.7
Skewness	-1.4	-1.8	-2.3	-1.6	-2.1	-2.1	-1.4	-2.1	-1.7	-1.8	-1.5	-1.4	-1.5	-1.5	-1.9	-2.0	-1.6	-2.1	-1.7	-1.7	-1.7	-1.8	-2.0	-1.3	-1.7
Kurtosis	4.6	5.7	7.9	4.2	7.6	7.0	4.1	7.0	4.3	4.9	5.2	4.6	4.3	4.0	6.6	6.8	4.3	7.2	5.0	4.8	5.8	5.2	6.6	4.5	5.5
Probability	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Observations	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	
Spring																									
Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Average
Mean	157364.5	187688.4	160774.3	156677.0	161732.0	154929.5	161807.3	137848.7	148580.0	135344.8	155655.1	179172.2	166531.7	161466.5	162030.3	161591.7	167447.6	154439.9	157282.4	150742.1	145013.3	163431.8	167164.8	185444.5	160006.7
Median	165192.0	196773.5	167415.0	164240.5	177153.5	178203.0	174206.5	149823.0	152313.0	151173.0	166708.0	201803.5	178497.0	171091.0	173949.0	168588.0	183197.5	177938.5	170182.0	151952.0	151951.5	173932.5	190456.5	206192.5	172622.2
Maximum	217147.0	246889.0	212366.0	212452.0	206613.0	211653.0	196685.0	189792.0	190705.0	197764.0	198136.0	234638.0	215124.0	222154.0	232843.0	220528.0	216045.0	198797.0	205209.0	196389.0	200102.0	217798.0	236793.0	230739.0	212806.7
Minimum	149.0	14737.0	1754.0	12801.0	1583.0	13381.0	13561.0	11973.0	1377.0	1273.0	14286.0	2242.0	13831.0	14905.0	156.0	1486.0	14789.0	196.0	193.0	13091.0	1403.0	1438.0	15888.0	1598.0	7003.8
Std. Dev.	56737.7	52899.0	45678.9	49359.3	45688.2	57305.8	36786.2	50395.5	38598.2	58349.1	44855.7	64490.1	50516.6	53199.4	59992.7	51912.6	52204.1	54952.5	51337.3	36687.4	46836.9	54507.2	65846.5	52153.1	51303.8
Skewness	-1.5	-1.6	-1.9	-1.8	-2.2	-1.7	-2.7	-1.7	-2.3	-1.4	-2.1	-1.7	-2.2	-1.8	-1.6	-1.8	-1.9	-1.9	-2.0	-2.1	-1.8	-1.8	-1.4	-2.3	-1.9
Kurtosis	4.6	6.0	7.0	5.8	8.0	4.5	11.3	4.6	9.0	3.5	7.2	4.9	7.0	5.6	4.7	6.0	6.2	5.2	6.0	8.9	6.1	5.8	3.8	7.9	6.2
Probability	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Observations	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	

Table B9-1 statistics on forecasted demand

Summer																									
Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Average
Mean	163465.1	175292.4	183225.7	162903.7	144301.1	153761.6	143116.9	147909.3	155222.1	161389.8	155870.2	156326.1	151824.0	169416.0	167783.3	170487.8	140350.7	146866.8	151594.5	161629.6	153191.2	162595.1	154116.6	136480.9	157046.7
Median	174103.5	197771.5	196743.0	180011.5	153006.5	165935.0	149504.5	166715.0	175138.0	170803.5	168122.0	173723.0	162367.0	188860.5	179239.0	182163.5	152491.5	154172.5	158075.5	180453.5	182542.5	176043.0	172785.0	148289.0	171210.8
Maximum	233054.0	235473.0	220346.0	211088.0	200125.0	210291.0	187239.0	195034.0	191891.0	204342.0	204755.0	225503.0	229377.0	225311.0	210327.0	220039.0	204058.0	197614.0	201417.0	201954.0	207562.0	218498.0	219713.0	195857.0	210452.8
Minimum	1824.0	2018.0	14238.0	2023.0	12539.0	1477.0	13391.0	1435.0	14163.0	1713.0	1377.0	171.0	2158.0	14431.0	15618.0	2028.0	1567.0	12692.0	1803.0	1354.0	1846.0	1397.0	13387.0	1323.0	5665.5
Std. Dev.	61688.1	65163.3	39895.8	51500.0	49712.5	55583.0	44086.9	52067.1	46341.1	46400.9	48504.8	61651.8	63207.1	54928.3	37487.6	51663.3	54523.5	48301.6	48301.1	46450.1	62823.7	52900.7	53098.9	52854.5	52047.3
Skewness	-1.4	-1.6	-2.5	-2.0	-1.7	-1.7	-2.0	-1.9	-2.2	-2.3	-2.0	-1.5	-1.3	-1.9	-2.7	-2.1	-1.5	-1.8	-1.9	-2.3	-1.5	-1.8	-1.7	-1.4	-1.9
Kurtosis	4.2	4.4	10.8	6.4	5.1	5.0	6.4	5.5	7.0	7.8	6.6	4.1	3.5	5.9	11.4	7.1	4.2	5.7	6.1	7.9	3.8	5.9	5.0	4.1	6.0
Probability	0	0	0	0	0	0	0	0	0	0	0	0	0.000003	0	0	0	0	0	0	0	0	0	0	0	
Observations	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	
Autumn																									
Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Average
Mean	173163.3	164440.6	150914.5	148297.6	157137.1	160557.5	130067.9	134625.2	128772.9	156122.2	185570.7	161677.6	176409.2	161040.4	141311.5	161910.2	161936.9	156801.8	134948.9	139378.9	153691.2	165843.2	178099.0	150777.0	155562.3
Median	195725.0	175591.0	169342.0	160022.0	180074.0	175826.0	137888.0	148663.0	145743.0	161295.0	204375.0	180101.0	189967.0	176056.0	152793.0	173989.0	181281.0	176388.0	148274.0	145539.0	163317.0	180238.0	207759.0	167327.0	170732.2
Maximum	227704.0	235779.0	216259.0	206082.0	208077.0	203353.0	182222.0	195031.0	194329.0	197805.0	228578.0	216859.0	235249.0	225866.0	188841.0	214798.0	206409.0	201799.0	187503.0	197161.0	217756.0	224462.0	230772.0	204541.0	210301.5
Minimum	14683.0	1638.0	1943.0	1624.0	1892.0	1874.0	1816.0	11575.0	1255.0	12977.0	2194.0	1594.0	13505.0	15451.0	188.0	1404.0	14021.0	14748.0	1442.0	1562.0	1743.0	15062.0	2213.0	1232.0	5734.8
Std. Dev.	57349.0	62662.7	62514.2	57120.3	55032.2	48943.0	40677.8	53178.6	55946.7	41113.2	51300.8	55313.4	59512.3	55702.9	42927.6	51498.7	51921.0	50559.9	48124.1	49692.9	55091.6	61725.9	60837.5	56626.5	53557.2
Skewness	-1.8	-1.4	-1.4	-1.5	-1.8	-2.2	-2.0	-1.4	-1.3	-2.1	-2.3	-1.9	-1.8	-1.7	-2.2	-2.0	-2.0	-1.9	-1.9	-1.6	-1.6	-1.5	-1.8	-1.5	-1.8
Kurtosis	5.4	4.3	3.6	4.1	5.1	7.0	6.6	3.9	3.3	7.9	8.2	5.7	5.4	5.1	7.1	6.4	6.0	5.8	5.3	5.0	4.8	4.2	5.3	4.4	5.4
Probability	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Observations	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	

Table B9-2 statistics on forecasted demand

Dependent Variable: LOG(TOTALDEMAND)
Method: Panel Least Squares
Date: 04/05/19 Time: 20:15
Sample: 1/01/2017 12/31/2017
Periods included: 365
Cross-sections included: 24
Total panel (balanced) observations: 8760

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LOG(FORWARDDEMAND)	0.981297	0.002889	339.6871	0.0000
LOG(RENEWDEMANDSPOT)	0.006939	0.000329	21.10828	0.0000
LOG(PLANNEDDEMAND)	-0.043002	0.004110	-10.46171	0.0000
LOG(FORECASTD)	0.001402	0.001312	1.068266	0.2854
WEEK*MONTH	-0.000106	2.90E-05	-3.650269	0.0003
WEEK*HOUR	-0.000126	1.46E-05	-8.625433	0.0000
MONTH*HOUR	9.58E-05	8.43E-06	11.37198	0.0000
WEEK	0.000833	0.000280	2.976064	0.0029
MONTH	-0.000184	0.000170	-1.078744	0.2807
C	0.674800	0.026240	25.71627	0.0000

Effects Specification

Cross-section fixed (dummy variables)

R-squared	0.990200	Mean dependent var	10.28812
Adjusted R-squared	0.990164	S.D. dependent var	0.188877
S.E. of regression	0.018732	Akaike info criterion	-5.113404
Sum squared resid	3.062206	Schwarz criterion	-5.086741
Log likelihood	22429.71	Hannan-Quinn criter.	-5.104319
F-statistic	27556.02	Durbin-Watson stat	1.216709
Prob(F-statistic)	0.000000		

Table B10 results for regression (20)

Winter																									
Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Average
Mean	9942.9	11803.6	13210.1	10173.5	11363.8	8414.5	7407.3	12029.6	10268.4	8295.1	10481.1	7473.7	14964.3	11386.2	7721.2	9663.4	7030.7	8355.5	12396.5	9834.6	9674.6	12355.1	11815.5	10402.3	10269.3
Median	-251.5	-181.2	-294.2	-299.7	-394.8	-334.2	-274.1	-27.8	23.7	-67.5	-55.0	-163.6	-160.5	-170.5	-217.5	-339.3	-355.7	-195.2	40.6	157.2	-5.4	-72.0	-256.6	-320.0	-175.6
Maximum	177019.0	213827.0	206797.0	189138.0	192372.0	147434.0	155537.0	183929.0	183184.0	189798.0	170984.0	151482.0	230358.0	208541.0	197341.0	167261.0	169123.0	156302.0	199735.0	168971.0	203573.0	224083.0	190325.0	173889.0	185458.5
Minimum	-895.4	-1006.1	-1281.4	-1253.3	-1284.2	-1200.2	-1211.8	-1065.7	-1060.9	-1009.9	-1186.7	-1209.2	-1152.8	-1212.8	-1319.9	-1221.8	-1287.7	-1363.8	-1190.9	-1270.5	-1502.3	-1982.7	-1798.7	-1727.5	-1279.0
Std. Dev.	38000.5	45730.5	50907.0	42771.9	44515.1	33282.4	31244.6	45280.3	41707.2	37784.3	39469.1	30784.2	56671.5	46809.9	35279.8	37433.6	32491.8	34663.6	46774.2	36855.8	39767.9	50737.7	45558.0	40577.0	41045.7
Skewness	3.5	3.6	3.5	3.9	3.5	3.5	3.9	3.5	3.9	4.4	3.5	3.9	3.5	3.9	4.5	3.5	4.4	3.9	3.5	3.5	4.0	3.9	3.5	3.5	3.8
Kurtosis	13.7	14.5	13.1	16.0	13.5	13.3	16.7	13.1	16.0	20.7	13.2	16.4	13.1	16.0	21.5	13.3	20.9	16.1	13.2	13.6	17.4	16.0	13.1	13.4	15.3
Probability	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Observations	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	
Spring																									
Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Average
Mean	125.2	107.5	73.2	72.0	31.6	51.7	236.6	368.3	297.6	235.5	87.0	15.8	-15.2	-38.1	-62.2	-112.1	-146.9	-174.5	-129.5	-31.1	20.5	26.2	-48.9	-74.8	38.1
Median	68.8	38.7	46.0	45.4	2.4	6.0	213.5	297.3	270.7	234.0	33.0	-28.1	-9.4	-48.4	-88.2	-141.0	-201.1	-189.8	-153.6	-45.1	36.3	99.0	-79.1	-70.8	14.0
Maximum	1468.3	1678.6	1719.8	1372.5	1243.9	1114.1	1131.9	1844.5	1791.1	1726.7	1400.1	1629.1	1619.0	1599.6	1628.6	1578.0	1464.4	1346.7	1712.3	2119.9	2124.1	2311.8	1079.6	981.9	1570.3
Minimum	-642.3	-606.5	-534.0	-792.7	-965.5	-843.3	-646.7	-602.1	-689.7	-739.1	-980.8	-976.3	-986.6	-1102.3	-1166.9	-1056.9	-1027.6	-1033.7	-1041.4	-1079.4	-1077.0	-1174.5	-1156.9	-1046.6	-915.4
Std. Dev.	468.0	450.7	393.5	377.1	388.4	365.5	414.7	522.6	541.7	507.9	503.4	494.5	468.3	459.0	440.1	441.2	446.7	428.3	432.9	511.7	549.2	564.7	483.7	465.3	463.3
Skewness	0.8	1.3	1.4	0.6	0.4	0.5	0.0	0.3	0.4	0.5	0.3	0.5	0.4	0.3	0.4	0.6	0.6	0.5	0.7	0.8	0.5	0.5	0.1	0.1	0.5
Kurtosis	3.4	5.0	6.2	3.8	3.6	3.4	2.3	2.7	2.7	2.9	2.6	3.1	3.3	3.6	4.2	4.1	3.7	3.6	5.3	5.2	4.2	4.8	2.7	2.4	3.7
Probability	0.00	0.00	0.00	0.01	0.15	0.07	0.40	0.35	0.20	0.14	0.31	0.19	0.31	0.27	0.02	0.01	0.03	0.07	0.00	0.00	0.01	0.00	0.81	0.43	
Observations	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	

Table B11-1 statistics on residuals from regression (20)

Summer																									
Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Average
Mean	67.1	31.1	-10.2	-14.3	-75.8	-71.8	-38.1	8.2	76.0	69.3	-48.7	-85.6	-61.0	-78.0	-87.4	-186.3	-238.2	-290.0	-284.5	-334.2	-345.8	-277.6	-298.8	-281.9	-119.0
Median	81.8	-27.7	-58.7	-60.3	-111.0	-112.5	-73.8	-17.4	-19.4	100.5	-97.6	-95.9	-78.9	-58.6	-84.6	-222.3	-276.9	-324.0	-273.1	-310.3	-370.5	-259.7	-362.0	-304.3	-142.4
Maximum	1016.0	1525.5	934.2	941.5	617.0	782.2	740.8	801.3	1100.6	1070.7	899.9	935.5	843.6	905.6	1020.9	740.5	719.7	667.5	929.1	695.4	888.2	1020.0	1469.4	1202.2	936.1
Minimum	-692.3	-771.8	-650.2	-597.0	-698.1	-882.5	-732.1	-635.3	-786.5	-974.1	-920.3	-1032.6	-967.7	-1093.4	-1037.6	-1174.6	-1244.6	-1308.7	-1295.3	-1124.5	-1140.9	-1380.0	-1212.6	-1019.1	-973.8
Std. Dev.	373.2	351.0	317.2	298.8	276.7	292.1	291.8	320.2	386.2	404.0	379.6	405.4	400.9	417.6	404.8	416.4	424.1	424.3	411.4	391.8	412.9	489.9	488.8	438.1	384.0
Skewness	0.3	1.0	0.6	0.8	0.4	0.5	0.2	0.3	0.5	0.3	0.4	0.4	0.3	0.0	0.1	0.1	0.0	0.0	0.2	0.2	0.2	0.2	0.7	0.6	0.4
Kurtosis	2.8	5.5	3.1	4.0	3.1	3.9	3.1	2.6	2.9	2.9	2.8	2.9	2.7	2.9	2.7	2.5	2.5	2.4	3.1	2.8	3.0	3.1	3.9	3.4	3.1
Probability	0.36	0.00	0.05	0.00	0.34	0.03	0.67	0.44	0.13	0.40	0.29	0.37	0.44	0.97	0.78	0.63	0.57	0.53	0.66	0.74	0.68	0.69	0.01	0.05	
Observations	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	
Autumn																									
Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Average
Mean	147.6	-22.8	-118.5	-139.4	-190.0	-148.5	91.6	479.7	591.8	610.4	506.5	300.5	247.4	130.8	120.4	53.5	109.6	374.5	751.0	847.5	844.8	605.0	139.0	-140.0	258.0
Median	78.6	-61.2	-156.2	-237.6	-201.4	-128.9	15.0	347.9	477.6	469.1	376.4	216.6	170.3	25.5	102.0	-47.3	62.1	144.3	573.1	716.2	788.4	657.8	133.0	-143.6	182.4
Maximum	1631.0	1296.9	1202.7	991.1	1170.7	1239.1	1719.1	2707.8	2843.3	2719.3	2565.9	2694.6	1829.4	1771.0	1958.1	1916.8	1966.3	2751.5	2665.0	2722.9	2892.3	2370.5	2086.9	1284.8	2041.5
Minimum	-823.7	-824.3	-818.8	-746.8	-822.8	-896.4	-914.1	-682.2	-616.0	-576.4	-833.0	-1008.7	-1076.2	-1155.7	-1225.6	-1179.3	-1145.5	-1027.2	-840.4	-837.4	-872.4	-970.0	-1106.5	-1538.2	-939.1
Std. Dev.	506.3	403.0	374.4	395.7	385.0	417.9	512.4	714.5	800.7	789.8	784.8	703.1	640.4	605.8	565.2	559.5	590.6	860.6	980.4	990.8	989.6	786.4	617.0	509.2	645.1
Skewness	0.5	0.6	0.8	0.6	0.8	0.6	0.5	1.4	1.0	1.0	0.9	0.9	0.6	0.6	0.5	0.5	0.5	0.7	0.4	0.2	0.2	0.2	0.6	0.4	0.6
Kurtosis	3.1	3.7	4.0	3.0	3.8	3.4	3.2	4.8	3.4	3.5	3.3	4.0	2.9	3.1	3.3	3.4	3.2	3.0	2.0	2.0	1.9	2.4	3.6	3.7	3.2
Probability	0.12	0.02	0.00	0.05	0.00	0.05	0.10	0.00	0.00	0.00	0.00	0.00	0.07	0.06	0.17	0.14	0.15	0.02	0.04	0.08	0.07	0.32	0.02	0.13	
Observations	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	

Table B11-2 statistics on residuals from regression (20)

(v)

	Winter	Spring	Summer	Autumn	Average
1	1.42E-07	1.8E-07	1.93E-07	1.6406E-07	1.69955E-07
2	1.44E-07	2.32E-07	2.66E-07	1.9196E-07	2.08591E-07
3	1.47E-07	2.99E-07	3.67E-07	2.2518E-07	2.59659E-07
4	1.48E-07	3.81E-07	5.01E-07	2.6072E-07	3.22447E-07
5	1.44E-07	4.7E-07	6.62E-07	2.9282E-07	3.92193E-07
6	1.29E-07	5.36E-07	8.09E-07	3.0387E-07	4.44606E-07
7	1.07E-07	5.65E-07	9.12E-07	2.9106E-07	4.68837E-07
8	8.98E-08	5.98E-07	1.04E-06	2.8055E-07	5.00948E-07
9	8.17E-08	6.89E-07	1.28E-06	2.9408E-07	5.85637E-07
10	7.27E-08	7.78E-07	1.54E-06	3.02E-07	6.74335E-07
11	6.81E-08	9.23E-07	1.96E-06	3.2599E-07	8.20042E-07
12	6.43E-08	1.1E-06	2.51E-06	3.5472E-07	1.00943E-06
13	6.04E-08	1.32E-06	3.21E-06	3.8468E-07	1.24297E-06
14	5.7E-08	1.58E-06	4.11E-06	4.1856E-07	1.5406E-06
15	5.53E-08	1.94E-06	5.42E-06	4.6839E-07	1.96954E-06
16	5.41E-08	2.4E-06	7.18E-06	5.2756E-07	2.54086E-06
17	5.14E-08	2.89E-06	9.27E-06	5.7852E-07	3.19867E-06
18	4.74E-08	3.38E-06	1.16E-05	6.1483E-07	3.91064E-06
19	4.28E-08	3.86E-06	1.42E-05	6.3977E-07	4.6899E-06
20	3.89E-08	4.46E-06	1.76E-05	6.7154E-07	5.68319E-06
21	3.56E-08	5.17E-06	2.18E-05	7.0857E-07	6.93326E-06
22	3.35E-08	6.17E-06	2.79E-05	7.6905E-07	8.71244E-06
23	3.45E-08	8.05E-06	3.89E-05	9.1219E-07	1.19798E-05
24	3.62E-08	1.07E-05	5.54E-05	1.1029E-06	1.68096E-05
Average	7.86E-08	2.44E-06	9.53E-06	4.6181E-07	

Table B12-1 estimated a

	Winter	Spring	Summer	Autumn	Average
1	2.971799	2.947658	2.941454	2.958364	2.954819
2	2.977099	2.928817	2.916409	2.950229	2.943139
3	2.982399	2.909976	2.891364	2.942094	2.931458
4	2.987699	2.891135	2.866319	2.933959	2.919778
5	2.992999	2.872294	2.841274	2.925824	2.908098
6	2.998299	2.853453	2.816229	2.917689	2.896418
7	3.003599	2.834612	2.791184	2.909554	2.884737
8	3.008899	2.815771	2.766139	2.901419	2.873057
9	3.014199	2.79693	2.741094	2.893284	2.861377
10	3.019499	2.778089	2.716049	2.885149	2.849697
11	3.024799	2.759248	2.691004	2.877014	2.838016
12	3.030099	2.740407	2.665959	2.868879	2.826336
13	3.035399	2.721566	2.640914	2.860744	2.814656
14	3.040699	2.702725	2.615869	2.852609	2.802976
15	3.045999	2.683884	2.590824	2.844474	2.791295
16	3.051299	2.665043	2.565779	2.836339	2.779615
17	3.056599	2.646202	2.540734	2.828204	2.767935
18	3.061899	2.627361	2.515689	2.820069	2.756255
19	3.067199	2.60852	2.490644	2.811934	2.744574
20	3.072499	2.589679	2.465599	2.803799	2.732894
21	3.077799	2.570838	2.440554	2.795664	2.721214
22	3.083099	2.551997	2.415509	2.787529	2.709534
23	3.088399	2.533156	2.390464	2.779394	2.697853
24	3.093699	2.514315	2.365419	2.771259	2.686173
Average	3.032749	2.730987	2.653437	3.032749	

Table B12-2 estimated c