Electricity futures prices in an emissions constrained economy: Evidence from European power markets

George Daskalakis[*], Lazaros Symeonidis[**], Raphael N. Markellos[†]

[*]Norwich Business School, University of East Anglia, Norwich NR4 7TJ, UK,

Tel.: +44 (0)1603 592309, Fax: +44 (0)1603 593343, E-mail: g.daskalakis@uea.ac.uk

(Corresponding author)

[**]Norwich Business School, University of East Anglia, Norwich NR4 7TJ, UK,

Tel.: +44 (0)1603 597332, Fax: +44 (0)1603 593343, E-mail: l.symeonidis@uea.ac.uk

[†]Norwich Business School, University of East Anglia, Norwich NR4 7TJ, UK,

Tel.: +44 (0)1603 597395, Fax: +44 (0)1603 593343, E-mail: r.markellos@uea.ac.uk

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ABSTRACT. We investigate the economic factors that drive electricity risk premia in the European emissions constrained economy. Our analysis is undertaken for monthly baseload electricity futures for delivery in the Nordic, French and British power markets. We find that electricity risk premia are significantly related to the volatility of electricity spot prices, demand and revenues, and the price volatility of the carbon dioxide (CO_2) futures traded under the EU Emissions Trading Scheme (EU ETS). This finding has significant implications for the pricing of electricity futures since it highlights for the first time the role of carbon market uncertainties as a main determinant of the relationship between spot and futures electricity prices in Europe. Our results also suggest that for the electricity futures under scrutiny prices are determined rationally by risk-averse economic agents.

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1. INTRODUCTION

A large number of countries worldwide, including many parts of the US, Europe and Australia, have liberalized their wholesale electricity sector over the last 20 years.[1] In such a setting, electricity futures markets serve a variety of key functions and thus their role is central. On the one hand, they facilitate hedging, speculation and arbitrage, increase liquidity and consequently improve price discovery and market efficiency (see, e.g., Sioshansi, 2002; Deng and Oren, 2006). On the other hand, they allow electricity producers and consumers, such as distributors and retailers, to reach better planning, operation and investment decisions (see, for example, Botterud et al., 2010; Furió and Meneu, 2010). Indirectly, they also provide useful insights for policy makers (e.g., Borenstein et al., 2002; Bunn and Gianfreda, 2010).

Our purpose in this paper is to examine the pricing of electricity futures in the European emissions constrained economy. This is still a highly controversial issue despite its importance and the widespread use of futures with underlying physical electricity for more than a decade now. The reason is that electricity cannot be economically stored in large amounts. As a result, the usual cost-of-carry model of Kaldor (1939), Working (1948) and Telser (1958) for relating spot and futures commodity prices is not applicable in the case of electricity (see, e.g., Pilipović, 1998; Vehviläinen, 2002; Eydeland and Wolyniec, 2003; Geman, 2005).

The usual approach followed in the electricity pricing literature is to derive futures prices on the basis of an empirically consistent continuous-time process of spot prices (e.g., Lucia and Schwartz, 2002; Bierbrauer et al., 2007; Wilkens and Wimschulte, 2007; Nomikos and Soldatos, 2008). This method however entails two significant complications: First, electricity spot prices exhibit a highly complex and idiosyncratic behaviour that is characterized by high levels of volatility, strong mean-reversion, periodicities at various time frames and spikes (see, e.g., Knittel and Roberts, 2005; Geman and Roncoroni, 2006). Therefore, the stochastic differential equation that accurately describes them is also complex and does not lead to closed-

[1] For a discussion on electricity market reform trends and policies adopted in different parts of the world see, among others, Mork (2001), Xu (2004) and Sioshansi and Pfaffenberger (2006).

form solutions (e.g., Burger et al., 2004). Second, accurate pricing of electricity futures requires a far from straightforward estimation of the market price of electricity spot price risk (e.g., Pirrong and Jermakyan, 2008; Weron, 2008).

We avoid these intricacies by concentrating on the determinants of electricity futures prices. Our objective in particular is to study the economic factors that give rise to risk premia in electricity futures prices. In this approach, traced back to the classical hedging-pressure literature (Keynes, 1930; Hicks, 1939 and Cootner, 1960, among others), commodity futures prices are considered to consist of two parts: the expected spot price of the underlying at the futures contract maturity and a positive risk premium (see, for example, Breeden, 1980; Hazuka, 1984). This premium reflects the compensation that risk-averse market participants, the hedgers, are willing to pay to less risk-averse investors, the speculators, in order to eliminate their spot price risk (e.g., French, 1986; Fama and French, 1987). The focus is then to understand the behaviour of the risk premium and most important to uncover its driving factors.

Along this direction, we examine the ability of four economic measures of risk in explaining risk premia in the case of 68 monthly baseload electricity futures for delivery in the Nordic, French and British power market, respectively (i.e. a total of 204 contracts). The period under consideration is from May 2005 to December 2011. The first three risk factors are directly related to electricity market uncertainties. These are the volatility of electricity spot prices, demand and revenues (i.e., the product of spot prices and demand). Their inclusion in our analysis is motivated by the theoretical equilibrium model for electricity day-ahead prices of Bessembinder and Lemmon (2002) and the empirical study of Longstaff and Wang (2004) for the day-ahead risk premia in the Pennsylvania-Jersey-Maryland (PJM) market in the US. The fourth risk factor is the price volatility of the carbon futures traded under the EU ETS (see Daskalakis et al., 2011, *inter-alia*, for a description of the scheme). We justify this on the basis of the carbon risk that electricity producers face in the European emissions constrained economy.

This allows us to make contributions in at least three different directions: First, we extend the electricity futures pricing and risk management literature (e.g., Benth et al., 2008; Pirrong and Jermakyan, 2008; Redl et al., 2009; Botterud et al., 2010). Our results indicate that electricity risk premia for the futures contracts under scrutiny are significantly related to the four risk factors considered. This finding is robust under different specifications for the test regressions and also when the estimations are performed across markets. Moreover, by analysing the hedging behaviour of electricity producers and consumers along the lines of Benth et al.'s (2008) model we are able to provide an intuitive understanding for the direction of the established relationships. In this manner, we empirically identify the main economic drivers of futures electricity risk premia, explain on a theoretical setting the way in which these factors impact electricity risk premia, and consequently enhance our understanding of the relationship between spot and futures electricity prices in Europe. These insights are of fundamental importance for pricing and hedging relevant derivative instruments under the risk premium approach.

Second, we shed further light on the interrelations between the EU ETS and the European deregulated wholesale electricity markets (e.g., Linares et al., 2006; Mansanet-Bataller et al., 2007; Fezzi and Bunn, 2009; Kirat and Ahamada, 2011). We find that carbon market uncertainties are a main driver of electricity risk premia in Europe, even when controlling for the potential effect of the price volatility of the main fuels used for power generation (coal, natural gas and oil). For example, ranking the four risk factors based on the number of statistically significant coefficients obtained reveals that carbon risk is the most important driver of electricity risk premia, followed by electricity spot price risk, electricity revenue risk and electricity demand risk, respectively. Moreover, the inclusion of the carbon risk factor in the test equation increases considerably the explanatory ability of our model. Most important, we observe a consistent inverse association between electricity risk premia and the carbon risk factor. This implies that power producers provide consumers with a carbon related premium (in the form of a discount in electricity futures prices) for motivating them to buy electricity through the futures market. In turn, this finding highlights a previous unidentified role of electricity futures markets in Europe: they provide a platform for power producers to manage their carbon risk.

Third, we contribute to the literature that studies electricity markets and their operation (e.g., Bessembinder and Lemmon, 2002; Anderson and Hu, 2008; Furió and Meneu, 2010; Lucia and Torró, 2011). Since electricity risk premia respond to economic measures of risk, we can infer that the prices of Nordic, French and British electricity futures are the result of a rational price generating process.[2]

The literature investigating electricity risk premia is extensive (e.g., Shawky et al., 2003; Diko et al., 2006; Kolos and Ronn, 2008; Pietz, 2009). To the best of our knowledge however, Longstaff and Wang (2004) is the only study that examines the economic factors that give rise to electricity risk premia.[3] These authors provide evidence that risk premia in the PJM day-ahead market are related to electricity spot price, demand and revenue uncertainty. We differentiate from them in two main respects: First, we concentrate on the risk premia of electricity futures rather than day-ahead prices. This is far from trivial since the day-ahead power market serves a fundamentally different role than the futures one. While the former is used for planning purposes and the optimal organization and operation of the electricity market, the latter serves as a hedging platform for market participants (e.g., Geman, 2005). Consequently, the economic factors that give rise to risk premia in these two types of market may also differ. Second, we include in our analysis the price volatility of the carbon futures as an additional risk factor that drives electricity risk premia in Europe. Thus, we also examine for the first time the potential impact of EU ETS market uncertainties on futures electricity risk premia and prices.

[2] By Nordic, French and British electricity futures we hereafter mean the contracts for delivery in the Nordic, French and British power market, respectively.

[3] Other researchers attempt to explain risk premia on the basis of physical and operational (market specific) variables. Examples include: power plant availability, wind power production, gas storage inventories, reservoir levels and hydroelectric capacity (e.g., Douglas and Popova, 2008; Botterud et al., 2010; Furió and Meneu, 2010; Lucia and Torró, 2011; Viehmann, 2011; Huisman and Kilic, 2010).

2. ELECTRICITY RISK PREMIA AND ECONOMIC RISK MEASURES

The pricing relationship for an electricity futures contract under the risk premium approach is the following:

$$F_{t,T} = E_t(S_T) + RP_t \quad (1)$$

In this specification, $F_{t,T}$ is the price at time t of a futures contract written on physical electricity that matures at time T, $E_t(S_T)$ is the expectation at time t for the electricity spot price at the futures maturity, and RP_t is the risk premium at time t. Substituting the expectation in Equation (1) by the observed spot electricity price at the contract's maturity, and re-arranging, we obtain the relationship of the so-called realized (or ex-post) risk premium (e.g., Weron, 2008):

$$RP_t = F_{t,T} - S_T \quad (2)$$

Our objective is to examine whether the realized risk premium, as estimated by Equation (2), is associated with economic risk factors related to electricity and carbon market uncertainties.

The norm in the asset pricing and commodity pricing literature is to express such measures of risk in terms of second moments. For the purposes of our analysis thus we use the volatility of electricity spot prices, demand and revenues, and the price volatility of the carbon futures traded under the EU ETS. Spot price risk, demand risk and revenue risk are commonly investigated as potential drivers for risk premia in the non-storable commodity pricing literature (see Longstaff and Wang, 2004 for a discussion). Moreover, these have been identified as significant drivers for the day-ahead electricity risk premia in both a theoretical and empirical setting (Bessembinder and Lemmon, 2002 and Longstaff and Wang, 2004, respectively). Here, we examine for the first time whether this is the also case for the risk premia observed in electricity futures prices. We include the latter in our analysis on the basis of the carbon risk that electricity producers face in the European emissions constrained economy.

To be more specific, since 2005, when the EU ETS became operational, power producers in Europe are subject to an annual cap on the volume of CO_2 they can emit into the atmosphere. This is allotted to them in the form of carbon permits, the so-called European emission allowances (EUAs), with each EUA giving the right to emit one tonne of CO_2. Should they wish to emit more, that is, produce more electricity than the amount justified by their emissions cap, they should turn to the EU ETS market in order to buy any lacking permits and avoid the penalties set. In contrast, if they abate emissions and emit less than their cap they can sell the surplus permits and use the proceeds to finance their operation and investments.

Naturally, since the goal of the EU ETS is to reduce aggregate CO_2 emission levels, power producers are short of permits (Ellerman and Joskow, 2008). As a result, they are exposed to a carbon risk associated with both the volume and price of EUAs that they will need in order to be environmentally compliant (see, e.g., Daskalakis et al., 2009).[4] This risk can be substantial due to the EU ETS policy-related uncertainties that can have a dramatic effect on the supply, demand and consequently price of EUAs (see, also, Daskalakis and Markellos, 2009). For example, the emission caps set in Phase I (2005-2007) of the EU ETS were too generous resulting in a market crash during April/May 2006 (e.g., Alberola et al., 2008). As a consequence, stricter caps were adopted in Phase II (2008- 2012) in order to ensure the achievement of the EU emission reduction targets agreed upon in the Kyoto protocol.

Thus, in a rational expectations framework, and assuming risk-averse economic agents, one would expect for this carbon risk to be priced in the electricity futures market. Hence, our underlying hypothesis that we put to test here is that carbon market uncertainties represent one of the main economic risk factors driving electricity risk premia in Europe.[5]

[4] We should note that EUA prices represent opportunity costs that, as expected, pass-through to consumers (e.g., Zachmann and Von Hirschhausen, 2008; Kirat and Ahamada, 2011). However, this carbon cost pass-through cannot fully compensate power producers for the carbon risk they face. The main reason is that even though different generation technologies produce different levels of emissions, the carbon cost pass-through in competitive electricity prices is determined only by the emission intensity of the marginal production plant (see Sijm et al., 2006 for a comprehensive discussion). This means that the carbon cost pass-through is not representative of the actual carbon cost for each electricity producer. In addition, since the cost pass-through rate depends on the elasticity of demand, carbon costs are not always fully passed on to consumers. According to Sijm et al. (2006) for example, the carbon cost pass-through rate in Europe varies between 60% and 100%.

[5] Daskalakis and Markellos (2009) point out that due to the carbon cost pass-through, and since the electricity risk premium is defined as the difference between the electricity futures price and the expected spot electricity price at the contract’s maturity, electricity risk premia in Europe should be positively

3. EMPIRICAL APPLICATION

3.1 Data Description

We undertake our analysis for Nordic, French and British electricity futures. This will allow us to study the potential effect of local market conditions on electricity risk premia and their driving factors. The period under consideration is from 3 May 2005 to 31 December 2011. This includes Phase I of the EU ETS and the first three years of Phase II. Due to liquidity considerations we focus on futures with baseload rather than peakload electricity as their underlying. Moreover, although electricity futures can have yearly, quarterly or monthly deliveries, we concentrate on futures with monthly deliveries only. The reason is that yearly futures are cascaded at maturity to corresponding positions in quarter futures, and in turn at expiry, to monthly futures that span the same delivery period as the quarter contract (see Wilkens and Wimschulte, 2007 for a similar task).

Thus, our analysis is performed for a total of 204 baseload electricity futures (68 Nordic, 68 French and 68 British) for delivery during the months November 2005 (NOV05 contract hereafter) to December 2007 (DEC07) and July 2008 (JUL08) to December 2011 (DEC11). Electricity futures with delivery prior to November 2005 (i.e., the contracts MAY05 to OCT05) are excluded from the analysis due to the limited number of price observations available either for the electricity futures and/or for carbon futures. We also disregard any contracts expiring in Phase II of the EU ETS if their trading was initiated in Phase I (i.e., the contracts JAN08 to JUNE08). This is justified on the basis of the EUA intertemporal trading ban from 2007 to 2008 that the EU member states had imposed. As discussed in Daskalakis et al. (2011), among others, a direct consequence of this policy was that EUAs issued for compliance in Phase I of the EU ETS were essentially a different asset from those issued in Phase II. Indeed, recent empirical

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related to EUA prices. The authors verify this for the French, German and Nordic power markets and, more recently, Furió and Meneu (2010) show that this is also the case for the Spanish electricity market. We differentiate from these studies by focusing on EU ETS market uncertainties (rather than EUA prices) and their potential impact on futures electricity risk premia and prices.

evidence suggests that carbon price fundamentals in Phase I differed from those in Phase II (Creti et al., 2012). Therefore, in order to account for these findings we choose to carry out our analysis separately for the two EU ETS phases. However, since power producers were short of EUAs in both phases (see Ellerman and Joskow, 2008), we expect our results to exhibit a similar qualitative picture.

Our electricity dataset consists of daily spot and futures prices quoted in € per Megawatt hour (€/MWh) in the case of the Nordic and French contracts and in £/MWh for the British contracts. The daily load is measured in Gigawatt hours (GWh). All electricity price data are obtained from Bloomberg. Electricity load is obtained from Nord Pool for the Nordic area, the UK National Grid for the British contracts, and Réseau de Transport d'Electricité (RTE), the transmission system operator in France, for the French contracts. The Nordic electricity futures in our analysis refer to contracts traded at NASDAQ OMX Commodities. These are cash settled against Nord Pool's day-ahead baseload index (system price). French and British electricity futures refer to physically settled contracts traded in the European Energy Exchange (EEX) and the Intercontinental Exchange (NYSE ICE), respectively. In the case of the French futures the reference price is the day-ahead baseload electricity index (Phelix Base) published in the European Power Exchange (EPEX). For the British futures we use as reference price the day-ahead baseload index from the APX Power UK (APX UK Base). We should note that our analysis is not sensitive to the settlement of the electricity futures (i.e., financial vs. physical). The reason is that financial electricity futures can be combined with physical delivery of electricity (and physical electricity futures with cash settlement) by simply placing a buy (sell) bid in the spot market that corresponds to the future's position during the contract's delivery month. The choice of the contracts is thus based solely on data availability and liquidity considerations.

[Figure 1 about here]

Figure 1 depicts the evolution of baseload spot prices for Nord Pool, EPEX and APX Power UK during the whole period under consideration. A simple visual inspection of this figure reveals the three stylized facts of spot electricity prices, namely: mean reversion, periodicities and spikes (see, also, Geman and Roncoroni, 2006). The summary statistics of the electricity data presented in Tables 1-3 reveal two common features of spot power prices: the highly non-Gaussian and positively skewed nature of the underlying distribution and the high variability. The stationarity properties of electricity spot prices are examined through three unit root tests: the Augmented Dickey-Fuller test (Dickey and Fuller, 1979), the Philips-Peron test (Philips and Peron, 1988) and the Kwiatkowski-Philips-Schmidt-Shin test (Kwiatkowski et al., 1992). The results, presented in Table 4, suggest that at conventional significance levels electricity spot and logarithmic spot prices are stationary.

[Tables 1-4 about here]

Figure 2 plots the aggregated electricity futures price curve for the contracts under study. Electricity futures prices exhibit similar patterns as spot prices thus implying a close relationship between the spot and the futures market. As can be inferred from Tables 1-3 however, futures prices exhibit on average smaller variation compared to spot prices, fewer extreme observations (lower kurtosis), and, an empirical distribution that is closer to the normal (see, e.g., Lucia and Schwartz, 2002 for similar conclusions).

[Figure 2 about here]

Figure 3 presents the daily electricity load in the Nordic, French and British power markets. As seen in this figure, demand is consistently higher (lower) during the winter (summer) months as a result of increased (decreased) heating needs. This pattern is also in line with the periodicities observed in spot electricity prices (Figure 1).

[Figure 3 about here]

For the purposes of our analysis we also collect daily carbon futures prices from Bloomberg. We use futures rather than spot EUA data as it has been shown that the price discovery of the carbon permits takes place in the futures market (Chevallier, 2010). For Phase I (Phase II) of the EU ETS the carbon price series is constructed by rolling over from the carbon futures contract with December 2006 (2008) maturity traded in NYSE ICE to the one expiring in December 2007 (2011). Figure 4 presents the evolution of carbon futures prices and logarithmic returns for both phases of the EU ETS. Descriptive statistics are found in Table 5.

[Figure 4 about here]

The main observation from Figure 4 is the extreme carbon price variation in two different periods within Phase I of the EU ETS: First, during April/May 2006 when carbon permits plummeted to a third of their value; second, in the latter part of 2007 when the permits were trading at a value of only a few cents. This behaviour has been extensively discussed in the literature (e.g., Ellerman and Buchner, 2008; Alberola and Chevallier, 2009; Parsons et al., 2009) and is attributed to the combined effect of the generous emission caps provided to the emission intensive firms in Phase I of the EU ETS and the EUA intertemporal trading ban imposed from 2007 to 2008.

[Table 5 about here]

3.2 Realized Risk Premia

We estimate through Equation (2) the daily-realized risk premium for each electricity futures contract under study. In all cases we use the electricity futures price observed in the market today for $F_{t,T}$. The choice of S_T is based on the manner in which the actual settlement of the contracts takes place: for the Nordic futures we use the arithmetic average of Nord Pool's system price realized during the delivery month; for both French and British futures we use the value of the Phelix Base index and APX UK Base index, respectively, two business days prior to each contract's expiry. Summary statistics are presented in Tables 6-8. For examining whether the mean realized risk premia are significantly different than zero at standard levels we perform a simple two-sided *t*-test. The computed *t*-statistics, based on Newey and West (1987) heteroskedasticity and autocorrelation consistent (HAC) covariances, indicate that this is the case for the majority of contracts under study (62, 61 and 60 out of 68 Nordic, 68 French and 68 British futures, respectively).

[Tables 6-8 about here]

Figure 5 plots the mean values of the realized risk premia for all futures contracts under scrutiny. Two interesting results are revealed from this figure. First, in contrast to other commodity markets electricity risk premia are not strictly positive (see, e.g., Shawky et al., 2003; Diko et al., 2006; Hadsell and Shawky, 2006; Kolos and Ronn, 2008 for similar conclusions). In fact, approximately half of the statistically significant risk premia are negative in the case of the Nordic futures (30 out of 62) and about a third in the case of both the French and the British contracts (23 out of 61 and 20 out of 60, respectively). Second, risk premia for the futures maturing during the autumn/winter months, that is, when increased demand is observed (see, also, Figure 3), are generally higher than those found in the contracts expiring in the spring/summer months.

[Figure 5 about here]

This seasonality is consistent with the model of Bessembinder and Lemmon (2002) according to which in periods of expected low power demand and demand uncertainty the forward electricity price is a downward biased predictor of the future spot price, and vice versa. Moreover, these findings are in line with the model of Benth et al. (2008) for the sign and pattern of electricity risk premia that is based on the temporal dimension in the relative appetite of electricity producers and consumers for risk diversification. To be more specific, these authors argue that electricity consumers are primarily interested in hedging their electricity spot price risk in periods of expected high power demand. In contrast, electricity producers are mainly interested in hedging their electricity revenue risk in periods of expected low power demand for better planning and investment decisions. In the former case, electricity consumers, as hedgers, are willing to pay a premium to power producers in order to motivate them in taking the short futures positions (i.e., act as speculators). In the latter case, electricity producers are the hedgers and hence willing to provide a discount to power consumers in order to motivate them in taking the long futures positions. In this manner, a positive, or relatively higher, risk premium is expected for electricity futures with delivery in periods of expected high power demand and a negative, or relatively smaller, premium when the delivery of electricity concerns a period of expected low power demand (see, also, Pietz, 2009; Botterud et al., 2010).

3.3 Risk Factors

Our objective is to examine whether the realized risk premia for the Nordic, French and British electricity futures under scrutiny are associated with four economic measures of risk: electricity spot price volatility, electricity demand volatility, electricity revenue volatility and carbon price volatility. Following Longstaff and Wang (2004), we construct these risk factors through a univariate AR(p)-GARCH(1,1) model:

$$r_t = c + \zeta \cdot \sum_{i=1}^{p} r_{t-p} + e_t \quad (3)$$

$$h_t = \omega + \alpha \cdot e_{t-1}^2 + \beta \cdot h_{t-1} \quad (4)$$

Equation (3) is the conditional mean equation that follows a p-order autoregressive process, with p selected on the basis of the Schwarz Bayesian Criterion (SBC), and Equation (4) is the conditional variance. Moreover, $e_t \sim N(0, h_t)$ are the residuals from Equation (3), while r_t represents daily carbon returns in the case of the carbon risk factor and daily logarithmic prices for the electricity market related risk factors. Finally, h_t is the conditional variance for each of the four series.

Constructing the carbon risk factor is straightforward: we fit the above model on carbon returns (with $p = 1$ on the basis of the SBC); the carbon risk factor is then simply the square root of the conditional variance obtained through Equation (4). In the case of the electricity market related risk factors however, we first need to address a complication. Electricity prices, load, and consequently revenues, exhibit seasonal behaviour (e.g., Knittel and Roberts, 2005). Thus, we need to deseasonalize each series by regressing it against a time trend, dummy variables for weekly and monthly periodicities and a cosine function for the annual cycle (see Lucia and Schwartz, 2002 and Bierbrauer et al., 2007 for a similar task):

$$Y_t = a + b \cdot t + \sum_{i=1}^{6} \gamma_i \cdot D_i + \sum_{i=1}^{11} \delta_i \cdot M_i + \varphi \cdot cos\left[2 \cdot \pi \cdot \left(\frac{t+\tau}{365}\right)\right] + \widetilde{Y_t} \quad (5)$$

In Equation (5), Y_t is the logarithm of electricity spot price, electricity demand and electricity revenue, respectively, t is a time trend, D_i are day of week dummies, M_i are monthly dummies, α, b, γ_i, q_i, φ and τ are constant parameters for estimation, and $\widetilde{\mathrm{Y}_\mathrm{t}}$ are the residuals that correspond to the deseasonalized series. We estimate Equation (5) by non-linear least squares with Newey and West (1987) HAC covariances. Each of the three electricity risk factors is then given by the square root of the conditional variance estimates obtained from fitting the above AR(*p*)-GARCH(1,1) model (given by Equations (3) and (4)) on the relevant deseasonalized series $\widetilde{\mathrm{Y}}_{\mathrm{t}}$ (with $p = 7$ on the basis of the SBC).

[Tables 9-11 about here]

3.4 Estimation Results and Discussion

We estimate separately for each electricity futures contract under scrutiny the following regression:

$$RP_{it} = c_i + \alpha_i \cdot \sigma_{S,t} + \beta_i \cdot \sigma_{L,t} + \gamma_i \cdot \sigma_{R,t} + \delta_i \cdot \sigma_{C,t} + \varepsilon_{it} \quad (6)$$

In Equation (6), RP_{it} is the realized premium of contract i on day t; $\sigma_{S,t}$, $\sigma_{L,t}$, $\sigma_{R,t}$ and $\sigma_{C,t}$ is the volatility of the electricity spot price, electricity load, electricity demand and carbon futures logarithmic returns, respectively; ε_{it} is an *i.i.d.* error term. We use logarithmic returns of carbon futures since previous research (see Daskalakis et al., 2009) has found evidence of a unit root in price levels. Moreover, to allow for a direct comparison across the different coefficients, we standardize all variables prior to estimation by subtracting the mean and dividing with the standard deviation (see, e.g., Hong and Yogo, 2012 for a similar task). In this manner, the parameters express the change in the risk premium for a change of one standard deviation in each risk factor. For example, a coefficient of 0.5 for the electricity spot price risk factor implies that a shock in electricity spot price volatility with a magnitude of one standard deviation will result in a change of 0.5 standard deviations (or 0.5% equivalently) for the realized risk premium. The estimation of all 204 regressions is undertaken using ordinary least squares (OLS) with Newey and West (1987) corrected standard errors. The results reported in Tables 9-11 allow us to draw four important conclusions:

First, electricity risk premia respond to the economic risk factors considered. To be more specific, out of the 68 Nordic, 68 French and 68 British futures under consideration, the coefficient for the carbon risk factor is statistically significant at standard levels for 43, 45 and

41 contracts, respectively. In the case of the electricity spot price risk factor, a statistically significant coefficient at standard levels is obtained for 38 Nordic futures, 41 French futures and 38 British futures. Moreover, demand risk (revenue risk) is significant driver for the electricity risk premia in 28 (25) Nordic futures, 17 (28) French futures and 21 (26) British futures. For examining whether the coefficients of the risk factors, for each of the 204 regressions, are jointly significant, we test the hypothesis $\alpha_i = \beta_i = \gamma_i = \delta_i = 0$ using a standard Wald test. The *p*-values for these tests provide evidence of a significant relationship between risk premia and the four risk factors for 59 Nordic futures and 58 both French and British contracts. Based on these findings, we can infer that Nordic, French and British electricity futures prices are determined by rational risk-averse economic agents.[6]

Second, carbon risk is a highly significant driver of electricity risk premia for the futures under scrutiny. In fact, by ranking the risk factors on the basis of the number of contracts for which a statistically significant coefficient is obtained we find that carbon risk is the most important driver of electricity risk premia, followed by electricity spot price risk, electricity revenue risk and electricity demand risk, respectively. To further assess the importance of the carbon risk factor, we re-estimate Equation (6) for every contract excluding $\sigma_{C,t}$ from the test regression. This is done in order to compare the in-sample explanatory power as measured by the adjusted coefficient of determination ($\bar{R}^2$) for each contract with and without the carbon risk factor. As seen in the last column of Tables 9-11, in the case of the contracts where a statistically significant coefficient for the carbon risk factor has been obtained, there is an improvement in the $\bar{R}^2$ of approximately 10.5% on average in the case of both the Nordic and British futures and 14.5% in the case of the French contracts. These results highlight for the

[6] In order to further ensure the robustness of our results we re-estimate all regressions using lagged one-period risk factors. The motivation is on the one hand, to check any in-sample predictive ability of the risk factors considered, and on the other hand, to deal with potential endogeneity issues. Moreover, we estimate contract-by-contract pooled OLS regressions, and also a system of seemingly unrelated regressions (SUR), in order to investigate whether our results are consistent across markets. In all cases, the obtained results (available upon request) provide a similar qualitative picture as before.

first time the role of EU ETS market uncertainties as a main determinant of the relationship between spot and futures electricity prices in Europe.[7]

Third, a comparison of our results with those of Longstaff and Wang (2004) for the day-ahead risk premia in PJM reveals that the electricity market related risk factors driving electricity risk premia are the same in both the day-ahead and the futures electricity market. This indicates that although the day-ahead market serves a different role than the futures one electricity prices in both types of market are determined by the same fundamentals.

Finally, the results are qualitatively similar in both EU ETS phases and consistent across the different, with respect to market of delivery, electricity futures considered. The former is to be expected since electricity producers were short of EUAs in both phases of the EU ETS. The latter, however, seems at first glance to be somewhat counterintuitive considering the different characteristics of the power markets where the delivery of the futures under study takes place. For example, the Nordic power market has a considerable share of hydropower in its energy mix, the French of nuclear power and the British of natural gas power. One might argue thus that carbon risk should be a less significant driving factor for electricity risk premia in the case of Nordic and French futures relative to the British contracts. Our results suggest that this is not the case. A plausible explanation can be based on the marginal pricing of competitive electricity prices, the cross-border interconnections and the market coupling mechanisms adopted in 2010 within Central West Europe (CWE) (Belgium, Netherlands, Luxemburg, France and Germany) and between CWE and the Nordic region.[8]

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[7] We should note that carbon prices are primarily determined by the prices of the main fuels used for power generation, i.e., coal, natural gas and oil (e.g., Aatola et al., 2013). Thus, it might be the case that our carbon risk factor is simply a proxy for the variation in coal, natural gas and oil prices, respectively. For examining whether this is indeed the case, we re-estimate all regressions by including the volatility of coal prices, the volatility of natural gas prices and the volatility of oil prices in the test equation. Our results (available upon request) indicate that carbon price volatility is a distinct risk factor driving electricity risk premia and provide a similar qualitative picture as before.

[8] Market coupling mechanisms facilitate power market integration by optimizing the allocation of cross-border capacities through auctions. As a result, any price differences between two or more areas are minimized (for more details see EPEX Spot at http://www.epexspot.com/en/market-coupling).

Turning our focus to the sign of the statistically significant coefficients, we find that electricity risk premia are in general positively related to electricity spot price volatility; negatively related to the volatility of both carbon prices and electricity revenues; while with respect to electricity demand volatility the signs are mixed. In order to understand these findings we need to consider in detail the hedging behaviour of the main market players along the lines of Benth et al.'s (2008) model.

Consider an electricity consumer that wishes to hedge electricity spot price risk during a period of expected high power demand. This would require entering into a long electricity futures position. As a result, the electricity spot price risk would be transferred to the power producer that holds the corresponding short futures position. Therefore, the electricity producer requires a premium in order to assume this risk. In turn, this implies that the coefficient of the risk factor related to electricity spot price uncertainty should be positive. This should also be the case for the risk measure associated with electricity demand risk since the delivery of electricity is for a period of expected high power demand. Through the short electricity futures position, however, the power producer secures cash flows and hence removes any revenue uncertainty faced. Moreover, knowing the exact amount of electricity that has to be generated in the future allows the power producer to manage carbon risk. This is achieved by simply buying the number of carbon permits that correspond to the amount of electricity sold through the futures contract immediately upon entering into the short futures position. Consequently, the electricity producer should provide the consumer with a discount for eliminating electricity revenue risk and carbon risk. Hence, the coefficient related to these two risk factors should be negative.

With a similar line of reasoning we can explain the signs of the coefficients for the four risk factors under scrutiny in the case when an electricity producer wishes to hedge revenue risk in periods of expected low power demand. This would require entering into a short electricity futures position. As a result the electricity revenue risk would be transferred to the power consumer that holds the corresponding long futures position. Therefore, the electricity consumer requires a discount in order to assume this risk. In turn, this implies that the coefficient of the risk measure related to electricity revenue uncertainty should be negative. This should also be the case for the risk measure associated with electricity demand risk since the delivery of electricity is for a period of expected low power demand. Through the long electricity futures position, however, the electricity consumer removes any electricity spot price uncertainty faced. Consequently, the electricity consumer should provide the producer with a premium for eliminating electricity spot price risk. Hence, the coefficient for the corresponding risk factor should be positive. Finally, as far as the coefficient of the carbon risk factor is concerned, the arguments presented above also hold in this case and therefore it should again be negative.

4. CONCLUDING REMARKS

We investigate the pricing of electricity futures in the European emissions constrained economy. Our objective is to understand the relationship between spot and futures electricity prices. To this end, we study the economic risk factors that drive risk premia for the case of monthly baseload electricity futures for delivery in the Nordic, French and British power markets. We find that electricity risk premia respond to both electricity and carbon market uncertainties. On the basis of Benth et al.'s (2008) model we are also able to provide an intuitive understanding of the direction of the established relationships. Our analysis is thus of relevance and importance not only for electricity producers and consumers but also for a wide range of other market stakeholders, including, energy traders, speculators and funds. Moreover, our findings provide a clear policy implication. The inverse association observed between electricity risk premia and the carbon risk factor suggests that power producers provide electricity consumers with a discount that is proportional to carbon price volatility as compensation for eliminating their carbon risk. Consequently, increased volatility in the carbon market results in increased hedging costs for power producers. European environmental policy makers should therefore take actions to reduce EU ETS market uncertainties as these have significant but unnecessary cost implications for electricity producers. A way to achieve this is to provide transparent information regarding the emissions reductions achieved to date on a regular (e.g., yearly) basis along with preliminary estimates on the level of the future emissions cap. A natural extension of our work is to study the potential impact of the EU ETS on both the day-ahead electricity risk premia and the optimal hedging decisions in the electricity futures market.

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Table 1. Descriptive statistics of electricity prices and load in the Nordic power market

Contract	# Obs.	Mean	Median	Maximum	Minimum	Std. Dev.	Skewness	Kurtosis
NOV05	126	37.621	37.925	44.830	33.520	2.256	0.498	3.215
DEC05	130	39.750	39.650	46.510	34.630	2.153	0.520	3.583
JAN06	130	41.428	41.275	46.800	37.050	1.867	0.509	4.121
FEB06	131	41.339	41.150	48.800	37.480	1.723	1.006	5.983
MAR06	128	39.091	37.825	49.000	34.400	3.224	1.145	3.452
APR06	129	40.598	37.900	58.250	34.000	6.063	1.151	3.285
MAY06	125	41.565	40.470	55.350	32.750	6.539	0.482	1.884
JUN06	123	42.585	41.130	54.700	33.300	6.192	0.360	2.073
JUL06	123	43.517	42.850	52.800	35.300	5.000	0.177	1.864
AUG06	122	48.914	49.115	58.740	39.700	4.646	0.009	2.010
SEP06	125	54.190	52.250	82.000	40.800	8.599	1.359	4.775
OCT06	123	56.897	54.900	81.750	40.900	9.210	0.582	2.736
NOV06	128	60.258	60.225	85.000	42.500	9.191	0.299	2.554
DEC06	130	63.174	62.850	84.950	38.350	9.848	-0.106	2.728
JAN07	128	63.028	65.690	86.500	37.100	12.955	-0.575	2.431
FEB07	129	58.009	65.300	88.500	28.550	17.486	-0.343	1.719
MAR07	126	46.180	43.075	70.000	25.850	15.283	0.149	1.444
APR07	127	36.515	31.300	61.500	23.050	12.059	0.680	2.104
MAY07	123	29.159	26.850	44.630	21.900	6.302	0.830	2.399
JUN07	121	25.828	24.800	36.230	19.700	3.869	1.027	3.360
JUL07	123	23.767	23.680	27.650	19.450	1.885	-0.158	2.270
AUG07	123	26.239	26.000	32.000	19.550	2.562	-0.360	3.122
SEP07	126	28.100	28.555	34.500	21.600	2.677	-0.297	3.082
OCT07	124	30.262	30.140	36.250	25.800	2.177	0.594	3.285
NOV07	129	39.030	37.830	52.400	34.300	3.604	1.643	5.302
DEC07	131	45.066	43.600	55.250	39.800	3.815	0.762	2.373
JUL08	124	38.501	39.250	50.000	27.100	6.209	0.143	1.893
AUG08	125	46.065	44.550	61.300	33.300	7.194	0.245	1.746
SEP08	125	53.886	56.030	68.900	39.250	8.050	-0.180	1.977
OCT08	129	60.264	60.750	73.250	45.350	7.213	-0.265	2.190
NOV08	130	65.532	65.800	77.500	51.750	6.095	-0.276	2.378
DEC08	130	65.876	67.915	78.500	45.350	8.135	-0.707	2.613
JAN09	128	63.674	68.190	80.000	39.500	11.698	-0.486	1.881
FEB09	126	58.148	58.300	79.500	38.000	13.377	0.050	1.515
MAR09	125	48.984	43.350	75.500	31.700	11.409	0.682	2.266
APR09	125	41.650	39.900	61.500	29.750	7.484	0.752	2.704
MAY09	121	34.857	34.000	49.500	26.000	4.730	1.187	4.927
JUN09	120	33.572	34.000	39.000	25.500	2.732	-0.782	3.658
JUL09	122	32.038	32.550	37.000	24.500	2.627	-1.018	3.655
AUG09	124	34.722	35.300	38.900	27.500	2.495	-0.919	3.399
SEP09	125	35.997	36.000	40.910	28.630	2.260	-0.376	2.959
OCT09	125	35.910	36.600	41.300	28.450	3.147	-0.797	2.769
NOV09	128	37.019	37.415	42.500	30.500	2.977	-0.330	2.051
DEC09	130	37.505	37.550	43.700	31.630	3.036	0.223	2.307
JAN10	127	38.336	38.380	44.650	32.750	2.752	0.076	2.256
FEB10	126	39.864	38.525	62.000	33.500	5.267	1.832	6.406
MAR10	125	41.852	36.500	83.950	31.000	12.141	1.894	6.329
APR10	126	43.132	41.800	73.700	30.000	10.319	0.996	3.539
MAY10	124	40.555	42.440	52.950	30.600	5.645	-0.177	2.180
JUN10	124	43.050	43.890	49.500	32.930	3.784	-1.004	3.445
JUL10	153	39.552	38.900	50.600	30.610	6.155	0.185	1.466
AUG10	128	45.510	45.525	50.650	39.500	2.603	-0.162	2.413
SEP10	130	47.238	46.600	52.780	41.100	2.852	0.104	2.277
OCT10	128	48.913	49.130	53.000	43.650	2.479	-0.174	1.829
NOV10	130	49.890	50.400	53.830	44.240	2.308	-0.531	2.269
DEC10	131	51.013	50.150	68.330	44.650	4.331	1.845	6.806
JAN11	130	56.185	51.375	90.770	47.600	10.387	1.699	4.751

Table 1 continued.								
FEB11	129	58.468	52.880	85.100	48.250	9.351	0.906	2.571
MAR11	127	58.132	59.300	78.050	46.980	8.536	0.186	1.677
APR11	128	58.583	60.275	74.600	46.000	7.492	-0.276	2.104
MAY11	125	51.618	52.500	60.950	41.850	3.879	-0.579	3.470
JUN11	124	52.137	52.000	58.500	45.500	2.774	0.046	2.264
JUL11	153	47.178	47.890	58.100	37.900	5.843	0.076	1.594
AUG11	123	50.829	51.500	58.630	40.700	4.466	-0.548	2.243
SEP11	126	52.224	53.540	60.200	43.400	5.058	-0.149	1.547
OCT11	125	50.953	49.800	60.600	32.000	6.343	-0.546	3.020
NOV11	128	50.799	49.840	62.500	41.850	5.086	0.602	2.642
DEC11	129	49.254	49.700	58.380	38.900	3.658	-0.324	3.976
SPOT $_{\text{Phase I}}$	664	36.995	33.512	80.415	10.240	13.141	0.673	2.942
LOAD $_{\text{Phase I}}$	664	656.240	668.964	1074.392	294.305	191.976	-0.217	2.277
SPOT $_{\text{Phase II}}$	1012	46.354	44.760	134.804	8.095	13.699	1.038	5.774
LOAD $_{\text{Phase II}}$	1012	982.916	942.122	1542.310	588.302	217.817	0.543	2.621

Note: The period covered is from 03/05/2005 to 31/12/2011. Phase I of the EU ETS ended in December 2007. Both the trading and delivery of the NOV05 to DEC07 (JUL08 to DEC11) electricity futures was during Phase I (Phase II) of the EU ETS. SPOT refers to Nord Pool's system price. Electricity prices are quoted in €/MWh, while load in GWh.

Table 2. Descriptive statistics of electricity prices and load in the French power market

Contract	# Obs.	Mean	Median	Maximum	Minimum	Std. Dev.	Skewness	Kurtosis
NOV05	64	51.188	42.937	51.100	53.480	49.580	0.847	0.372
DEC05	64	52.238	49.972	50.860	67.530	49.100	3.954	2.115
JAN06	64	59.910	57.742	57.250	81.650	50.400	9.881	0.969
FEB06	65	65.524	57.465	63.350	85.840	50.950	9.739	0.117
MAR06	63	65.248	51.274	66.930	76.250	51.710	6.313	-0.769
APR06	64	55.553	43.045	55.385	60.150	49.630	2.160	-0.698
MAY06	62	49.391	40.707	50.100	52.900	38.000	3.148	-1.797
JUN06	62	49.342	39.799	52.990	57.200	37.130	7.382	-0.575
JUL06	60	46.595	40.339	44.910	54.730	39.480	4.902	0.635
AUG06	62	46.762	41.089	45.300	61.500	38.630	6.032	0.965
SEP06	65	52.577	41.051	51.720	58.750	48.890	2.367	0.691
OCT06	66	55.298	48.108	56.185	61.000	46.650	3.391	-0.976
NOV06	65	69.768	58.580	70.750	76.850	59.610	5.607	-0.155
DEC06	64	66.374	63.761	67.295	72.120	50.360	4.656	-1.634
JAN07	127	73.060	65.735	75.250	78.500	57.670	5.168	-1.068
FEB07	129	68.890	60.507	72.500	78.500	44.130	9.901	-1.146
MAR07	126	55.471	50.831	57.965	69.000	28.450	11.306	-0.856
APR07	127	38.844	38.720	42.560	47.500	27.060	6.968	-0.498
MAY07	124	33.497	33.774	32.275	42.750	25.480	5.992	0.138
JUN07	122	38.019	32.184	37.080	46.170	31.720	4.134	0.343
JUL07	124	41.854	32.220	41.530	51.510	31.870	4.826	0.165
AUG07	124	34.884	30.817	34.400	42.720	26.650	3.490	0.052
SEP07	127	36.313	28.207	36.000	43.000	31.740	3.099	0.133
OCT07	125	39.592	31.072	39.000	46.250	34.670	3.620	0.399
NOV07	129	52.904	36.857	52.300	76.130	47.130	4.917	2.218
DEC07	131	55.225	39.539	51.440	83.530	44.870	10.747	1.318
JUL08	125	68.494	51.982	67.580	91.890	58.490	6.834	0.824
AUG08	127	59.847	55.112	57.250	75.250	51.460	6.197	0.861
SEP08	127	73.474	58.772	74.750	90.670	58.500	8.858	-0.024
OCT08	130	84.405	67.942	86.845	99.870	61.870	10.702	-0.683
NOV08	131	103.243	75.745	103.540	123.330	88.150	8.904	0.233
DEC08	130	98.466	75.715	99.000	121.000	70.380	11.466	-0.345
JAN09	129	103.200	77.131	108.940	129.350	65.510	18.877	-0.684
FEB09	127	94.274	76.322	100.000	123.670	57.830	22.820	-0.195
MAR09	126	73.182	73.284	67.315	105.450	37.850	19.758	0.286
APR09	126	51.891	61.321	52.745	72.820	33.600	11.451	0.000
MAY09	123	38.396	59.231	35.950	54.490	27.800	8.246	0.317
JUN09	123	39.630	57.105	36.000	53.690	31.040	7.088	0.758
JUL09	124	40.652	53.030	38.500	57.440	35.130	5.069	1.458
AUG09	127	31.717	48.734	31.630	39.290	27.330	2.616	0.906
SEP09	128	39.155	39.296	38.710	43.440	33.300	2.047	-0.155
OCT09	67	45.760	48.238	45.350	50.570	43.250	2.021	1.004
NOV09	65	59.425	46.569	57.540	78.800	53.250	6.044	1.615
DEC09	75	60.157	44.798	57.930	77.750	51.250	6.324	1.190
JAN10	64	63.390	44.894	62.625	81.500	50.230	9.441	0.417
FEB10	62	55.303	43.578	53.440	72.000	45.660	6.971	0.766
MAR10	59	43.993	42.113	42.630	49.450	39.500	2.775	0.214
APR10	62	38.197	39.025	38.015	40.500	37.000	0.835	0.977
MAY10	64	35.154	38.317	34.100	42.750	32.820	2.563	1.339
JUN10	64	42.873	38.126	42.500	51.000	37.590	4.379	0.187
JUL10	64	46.189	38.465	47.085	51.000	39.280	2.649	-0.995
AUG10	66	42.734	38.374	42.845	46.120	39.250	1.599	-0.064
SEP10	67	50.783	38.525	50.030	56.800	46.100	2.945	0.425
OCT10	67	55.590	43.501	55.750	61.500	50.950	2.035	0.440
NOV10	65	59.746	43.924	59.000	64.500	53.250	3.068	-0.109
DEC10	66	56.331	44.118	56.290	61.610	52.250	2.525	0.207
JAN11	65	59.747	45.796	59.550	63.780	55.880	2.344	-0.001

Table 2 continued.								
FEB11	64	55.461	46.085	55.425	60.360	51.000	2.514	0.171
MAR11	63	52.894	46.261	53.010	58.000	49.210	1.974	0.190
APR11	84	50.769	45.200	50.000	62.970	47.380	3.421	1.833
MAY11	103	49.194	46.156	46.620	61.950	42.980	5.086	0.722
JUN11	125	50.202	46.877	48.520	59.290	44.930	3.899	0.357
JUL11	64	55.643	47.599	56.625	61.290	45.710	3.685	-0.848
AUG11	76	48.967	47.757	50.095	55.410	35.500	4.402	-0.843
SEP11	107	57.206	48.280	58.310	64.220	48.650	4.664	-0.279
OCT11	84	63.285	52.452	63.250	68.350	57.780	2.601	0.132
NOV11	77	66.219	53.666	67.250	70.910	57.500	3.535	-0.980
DEC11	66	63.585	54.082	64.325	69.170	53.350	4.229	-0.579
SPOT $_{\text{Phase I}}$	685	48.311	42.052	314.269	9.513	24.907	3.506	27.829
LOAD $_{\text{Phase I}}$	685	55.532	51.182	78.867	36.417	9.349	0.628	2.225
SPOT $_{\text{Phase II}}$	1033	54.079	51.504	118.162	14.015	16.568	0.878	3.833
LOAD $_{\text{Phase II}}$	1033	57.958	54.341	87.284	38.070	10.545	0.673	2.432

Note: The period covered is from 03/05/2005 to 31/12/2011. Phase I of the EU ETS ended in December 2007. Both the trading and delivery of the NOV05 to DEC07 (JUL08 to DEC11) electricity futures was during Phase I (Phase II) of the EU ETS. SPOT refers to EPEX's Phelix Base index. Electricity prices are quoted in €/MWh, while load in GWh.

Table 3. Descriptive statistics of electricity prices and load in the British power market

Contract	# Obs.	Mean	Median	Maximum	Minimum	Std. Dev.	Skewness	Kurtosis
NOV05	206	42.937	43.640	57.070	30.560	6.406	-0.194	1.993
DEC05	227	49.972	51.200	85.670	32.560	8.884	0.339	3.989
JAN06	250	57.742	58.865	87.020	38.750	10.606	0.168	2.580
FEB06	250	57.465	58.105	84.520	38.250	9.693	0.112	2.825
MAR06	250	51.274	51.435	75.020	34.350	7.899	0.252	3.133
APR06	250	43.045	44.100	51.000	31.260	5.291	-0.801	2.525
MAY06	250	40.707	41.700	47.980	32.200	3.305	-0.880	3.163
JUN06	250	39.799	40.405	45.250	30.520	2.987	-0.691	2.885
JUL06	250	40.339	40.530	45.430	33.830	2.676	-0.277	2.183
AUG06	250	41.089	41.695	47.230	35.980	2.617	0.034	1.980
SEP06	250	41.051	40.720	48.100	35.920	3.059	0.185	1.774
OCT06	250	48.108	47.885	59.400	36.030	5.212	0.075	2.320
NOV06	250	58.580	58.800	71.650	43.230	6.772	-0.263	2.482
DEC06	250	63.761	64.605	76.180	46.350	6.628	-0.525	2.795
JAN07	253	65.735	69.300	78.300	39.180	10.005	-1.081	3.362
FEB07	254	60.507	64.940	75.900	27.950	12.589	-1.088	3.199
MAR07	253	50.831	55.970	69.560	20.100	13.676	-0.750	2.375
APR07	253	38.720	41.900	53.500	19.500	10.563	-0.639	1.904
MAY07	253	33.774	37.400	44.500	19.000	8.905	-0.475	1.595
JUN07	252	32.184	34.530	44.500	20.750	7.798	-0.034	1.377
JUL07	253	32.220	30.400	43.380	23.750	6.237	0.389	1.698
AUG07	254	30.817	27.500	44.380	22.500	6.453	0.735	2.092
SEP07	251	28.207	25.700	43.250	20.250	5.956	0.834	2.412
OCT07	253	31.072	29.190	49.500	25.500	5.147	1.505	5.314
NOV07	252	36.857	36.000	49.040	30.500	3.785	0.892	3.181
DEC07	252	39.539	38.000	60.520	30.500	5.018	1.876	6.870
JUL08	255	51.982	49.700	87.440	36.300	13.282	0.840	2.898
AUG08	255	55.112	51.480	86.220	36.480	14.464	0.737	2.484
SEP08	255	58.772	54.000	86.800	36.410	15.543	0.464	1.842
OCT08	254	67.942	63.765	115.960	41.600	16.941	0.252	1.946
NOV08	253	75.745	73.260	150.500	42.150	23.800	0.566	2.670
DEC08	254	75.715	76.555	122.250	42.150	19.158	0.086	2.143
JAN09	252	77.131	76.565	109.000	46.600	15.563	0.066	1.780
FEB09	253	76.322	76.130	98.730	50.530	13.985	0.017	1.532
MAR09	253	73.284	71.400	98.730	38.080	15.435	-0.081	1.853
APR09	255	61.321	61.600	85.500	33.950	14.871	-0.220	1.803
MAY09	253	59.231	61.100	85.500	33.910	16.687	-0.121	1.518
JUN09	253	57.105	52.720	85.500	34.910	17.348	0.121	1.416
JUL09	253	53.030	47.950	87.130	32.610	16.486	0.544	1.767
AUG09	253	48.734	44.410	78.890	30.990	15.323	0.701	2.021
SEP09	189	39.296	37.630	51.690	32.340	5.353	0.847	2.514
OCT09	254	48.238	45.085	82.320	33.580	10.925	0.980	3.441
NOV09	254	46.569	44.720	65.570	37.100	7.300	0.891	2.807
DEC09	254	44.798	44.050	59.040	33.710	5.873	0.723	2.744
JAN10	259	44.894	45.360	58.460	34.010	5.496	-0.030	2.437
FEB10	260	43.578	43.330	54.150	34.650	5.043	-0.039	1.829
MAR10	260	42.113	41.575	52.410	34.080	5.241	0.080	1.618
APR10	259	39.025	38.750	45.820	33.360	3.583	0.217	1.818
MAY10	261	38.317	37.700	45.800	33.390	3.465	0.399	2.031
JUN10	262	38.126	37.760	45.370	33.620	3.033	0.362	2.155
JUL10	262	38.465	38.190	44.790	33.840	2.836	0.189	1.864
AUG10	262	38.374	38.080	44.860	33.700	2.990	0.301	2.031
SEP10	242	38.525	38.020	45.880	33.810	3.202	0.450	2.147
OCT10	262	43.501	43.050	51.030	38.100	3.020	0.376	2.603
NOV10	262	43.924	44.160	50.530	38.100	2.900	0.018	2.739
DEC10	259	44.118	44.460	51.540	38.100	3.033	0.005	2.746
JAN11	258	45.796	46.080	54.170	38.550	3.674	-0.158	2.618

Table 3 continued.								
FEB11	259	46.085	46.150	54.380	38.550	3.805	-0.257	2.466
MAR11	259	46.261	46.360	58.450	38.550	3.388	-0.456	3.459
APR11	260	45.200	44.415	56.160	36.100	3.380	0.372	4.103
MAY11	258	46.156	45.595	56.690	41.650	3.372	1.136	3.617
JUN11	259	46.877	46.270	56.660	41.960	3.637	0.802	2.683
JUL11	259	47.599	46.970	56.310	41.980	3.973	0.544	2.141
AUG11	259	47.757	47.330	55.960	42.080	3.656	0.431	2.145
SEP11	269	48.280	47.550	56.770	42.080	3.965	0.437	2.036
OCT11	294	52.452	51.770	61.250	46.610	3.627	0.584	2.245
NOV11	314	53.666	54.020	61.870	46.610	4.105	0.024	1.582
DEC11	334	54.082	54.290	62.510	46.610	4.457	-0.024	1.431
SPOT $_{\text{Phase I}}$	683	36.539	31.890	183.320	16.840	16.837	2.776	15.906
LOAD $_{\text{Phase I}}$	683	41.126	39.693	51.332	31.670	4.416	0.534	2.121
SPOT $_{\text{Phase II}}$	1010	50.678	46.875	151.330	24.060	18.072	1.857	7.604
LOAD $_{\text{Phase II}}$	1010	39.317	38.192	50.702	28.163	4.677	0.454	2.141

Note: The period covered is from 03/05/2005 to 31/12/2011. Phase I of the EU ETS ended in December 2007. Both the trading and delivery of the NOV05 to DEC07 (JUL08 to DEC11) electricity futures was during Phase I (Phase II) of the EU ETS. SPOT refers to APX's UK Base index. Electricity prices are quoted in £/MWh, while load in GWh.

Table 4. Unit root test results for baseload electricity spot and logarithmic spot prices

Panel A: Spot prices		**Nordic power market** (Nord Pool System Price)		**French power market** (EPEX Phelix Base)		**British power market** (APX UK Base)	
Test	Null Hypothesis	C	TC	C	TC	C	TC
ADF	Unit Root	-3.332**	-3.398*	-4.629***	-4.616***	-4.762***	-4.811***
PP	Unit Root	-6.217***	-6.640***	-41.366***	-41.384***	-17.891***	-18.303***
KPSS	Stationarity	0.728*	0.141**	0.215***	0.201***	0.532**	0.297**
Panel B: Log spot prices							
Test	Null Hypothesis	C	TC	C	TC	C	TC
ADF	Unit Root	-3.627***	-3.709**	-4.735***	-4.709***	-4.018***	-4.081***
PP	Unit Root	-7.094***	-7.536***	-28.719***	-28.856***	-12.937***	-13.730***
KPSS	Stationarity	0.708*	0.155**	0.276***	0.178***	0.497**	0.169**

Note: The results are presented both with a constant (C) and a trend and constant (TC) in the test equation. *, **, *** denote statistical significance at the 10%, 5% and 1% level, respectively. ADF refers to the Augmented Dickey-Fuller test (Dickey and Fuller, 1979), PP to the Philips-Peron test (Phillips and Peron, 1988) and KPSS to the Kwiatkowski-Phillips-Schmidt-Shin test (Kwiatkowski et al., 1992). The lag structure in the ADF test is selected automatically on the basis of the Bayesian Information Criterion (BIC). For both PP and KPSS the bandwidth parameter is selected according to the approach suggested by Newey and West (1994).

Table 5. Descriptive statistics of carbon futures prices and returns

Contract	# Obs.	Mean	Median	Maximum	Minimum	Std. Dev.	Skewness	Kurtosis
EUA $_{\text{Phase I}}$	664	12.50	15.00	30.45	0.01	10.19	0.00	1.47
EUA $_{\text{Phase II}}$	1012	15.91	14.73	29.33	6.45	4.51	0.97	3.34
R $_{\text{EUA Phase I}}$	663	-0.01	0.00	1.10	-1.39	0.11	-3.11	73.44
R $_{\text{EUA Phase II}}$	1011	0.00	0.00	0.11	-0.10	0.02	-0.12	5.37

Note: The period covered is from 03/05/2005 to 31/12/2011. EUA refers to prices and R_{EUA} to logarithmic returns of a rolled-over EUA futures series constructed using contracts traded in NYSE ICE with December 2006 and December 2007 (2008 and 2011) expiries for Phase I (Phase II) of the EU ETS. Carbon futures prices are quoted in €/EUA.

Table 6. Descriptive statistics of realized risk premia for the Nordic electricity futures

Contract	# Obs.	Mean	Median	Maximum	Minimum	Std. Dev.	Skewness	Kurtosis
RP_{NOV05}	126	6.572***	6.877	13.781	2.475	2.256	0.498	3.214
RP_{DEC05}	130	4.833***	4.733	11.590	-0.287	2.153	0.520	3.584
RP_{JAN06}	130	0.005	-0.148	5.377	-4.373	1.867	0.509	4.121
RP_{FEB06}	131	-2.408***	-2.597	5.053	-6.267	1.723	1.006	5.983
RP_{MAR06}	128	-13.752***	-15.018	-3.843	-18.443	3.224	1.145	3.452
RP_{APR06}	129	-13.041***	-15.739	4.611	-19.639	6.063	1.151	3.285
RP_{MAY06}	125	2.384*	1.289	16.169	-6.431	6.539	0.482	1.884
RP_{JUN06}	123	-3.133**	-4.588	8.982	-12.418	6.192	0.360	2.073
RP_{JUL06}	123	-6.696***	-7.363	2.587	-14.913	5.000	0.177	1.864
RP_{AUG06}	122	-18.204***	-18.003	-8.378	-27.418	4.646	0.009	2.010
RP_{SEP06}	125	-10.364***	-12.304	17.446	-23.754	8.599	1.359	4.775
RP_{OCT06}	123	1.883	-0.114	26.736	-14.114	9.210	0.582	2.736
RP_{NOV06}	128	12.806***	12.773	37.548	-4.952	9.191	0.299	2.554
RP_{DEC06}	130	28.579***	28.255	50.355	3.755	9.848	-0.106	2.728
RP_{JAN07}	128	34.714***	37.376	58.186	8.786	12.955	-0.575	2.431
RP_{FEB07}	129	27.942***	35.233	58.433	-1.517	17.486	-0.343	1.719
RP_{MAR07}	126	21.772***	18.667	45.592	1.442	15.283	0.149	1.444
RP_{APR07}	127	13.324***	8.109	38.309	-0.141	12.059	0.680	2.104
RP_{MAY07}	123	28.977***	26.850	43.750	21.900	6.173	0.831	2.386
RP_{JUN07}	121	1.185	0.157	11.587	-4.943	3.869	1.027	3.360
RP_{JUL07}	123	5.265***	5.178	9.148	0.948	1.885	-0.158	2.270
RP_{AUG07}	123	8.074***	7.835	13.835	1.385	2.562	-0.360	3.122
RP_{SEP07}	126	1.374***	1.829	7.774	-5.126	2.677	-0.297	3.082
RP_{OCT07}	124	-6.331***	-6.453	-0.343	-10.793	2.177	0.594	3.285
RP_{NOV07}	129	-7.359***	-8.559	6.011	-12.089	3.604	1.643	5.302
RP_{DEC07}	131	-2.512***	-3.978	7.672	-7.778	3.815	0.762	2.373
RP_{JUL08}	124	-7.540***	-6.791	3.959	-18.941	6.209	0.143	1.893
RP_{AUG08}	125	-10.155***	-11.670	5.080	-22.920	7.194	0.245	1.746
RP_{SEP08}	125	-14.529***	-12.385	0.485	-29.165	8.050	-0.180	1.977
RP_{OCT08}	129	3.003***	3.489	15.989	-11.911	7.213	-0.265	2.190
RP_{NOV08}	130	13.108***	13.376	25.076	-0.674	6.095	-0.276	2.378
RP_{DEC08}	130	18.905***	20.944	31.529	-1.621	8.135	-0.707	2.613
RP_{JAN09}	128	21.396***	25.912	37.722	-2.778	11.698	-0.486	1.881
RP_{FEB09}	126	19.415***	19.567	40.767	-0.733	13.377	0.050	1.515
RP_{MAR09}	125	13.279***	7.645	39.795	-4.005	11.409	0.682	2.266
RP_{APR09}	125	6.414***	4.664	26.264	-5.486	7.484	0.752	2.704
RP_{MAY09}	121	0.307	-0.550	14.950	-8.550	4.730	1.187	4.927
RP_{JUN09}	120	-3.022***	-2.594	2.406	-11.094	2.732	-0.782	3.658
RP_{JUL09}	122	-1.378***	-0.866	3.584	-8.916	2.627	-1.018	3.655
RP_{AUG09}	124	1.381***	1.959	5.559	-5.841	2.495	-0.919	3.399
RP_{SEP09}	123	-7.617***	-6.791	3.959	-18.941	6.174	0.154	1.913
RP_{OCT09}	125	-10.155***	-11.670	5.080	-22.920	7.194	0.245	1.746
RP_{NOV09}	125	-14.529***	-12.385	0.485	-29.165	8.050	-0.180	1.977
RP_{DEC09}	129	3.003**	3.489	15.989	-11.911	7.213	-0.265	2.190
RP_{JAN10}	130	13.108***	13.376	25.076	-0.674	6.095	-0.276	2.378
RP_{FEB10}	130	18.905***	20.944	31.529	-1.621	8.135	-0.707	2.613
RP_{MAR10}	128	21.392***	25.912	37.722	-2.778	11.695	-0.486	1.881
RP_{APR10}	126	19.416***	19.567	40.767	-0.733	13.377	0.050	1.515
RP_{MAY10}	125	13.280***	7.645	39.795	-4.005	11.409	0.682	2.266
RP_{JUN10}	125	6.415***	4.664	26.264	-5.486	7.484	0.752	2.704
RP_{JUL10}	121	0.307	-0.550	14.950	-8.550	4.730	1.187	4.927
RP_{AUG10}	120	-3.022***	-2.594	2.406	-11.094	2.732	-0.782	3.658
RP_{SEP10}	122	-1.378***	-0.866	3.584	-8.916	2.627	-1.018	3.655

$\mathbf{RP_{OCT10}}$	124	1.381***	1.959	5.559	-5.841	2.495	-0.919	3.399
$\mathbf{RP_{NOV10}}$	125	6.239***	6.242	11.152	-1.128	2.260	-0.376	2.959
$\mathbf{RP_{DEC10}}$	125	1.113*	1.804	6.504	-6.346	3.147	-0.797	2.769
$\mathbf{RP_{JAN11}}$	128	-0.095	0.301	5.386	-6.614	2.977	-0.330	2.051
Table 6 continued.								
$\mathbf{RP_{FEB11}}$	130	-3.127***	-3.082	3.068	-9.002	3.036	0.223	2.307
$\mathbf{RP_{MAR11}}$	126	-18.942***	-18.896	-12.586	-24.486	2.722	0.066	2.263
$\mathbf{RP_{APR11}}$	125	-31.392***	-32.741	-9.241	-37.741	5.286	1.835	6.386
$\mathbf{RP_{MAY11}}$	124	-16.121***	-21.486	25.964	-26.986	12.190	1.884	6.272
$\mathbf{RP_{JUN11}}$	125	-4.520**	-4.677	26.023	-17.677	10.356	0.986	3.507
$\mathbf{RP_{JUL11}}$	123	-5.331***	-3.458	7.042	-15.308	5.663	-0.188	2.173
$\mathbf{RP_{AUG11}}$	123	-3.924***	-3.059	2.491	-14.079	3.780	-1.031	3.511
$\mathbf{RP_{SEP11}}$	252	-6.948***	-7.588	4.097	-15.893	6.167	0.184	1.460
$\mathbf{RP_{OCT11}}$	128	1.253***	1.269	6.394	-4.756	2.603	-0.162	2.413
$\mathbf{RP_{NOV11}}$	130	-2.608***	-3.246	2.934	-8.746	2.852	0.104	2.277
$\mathbf{RP_{DEC11}}$	128	-1.508***	-1.292	2.578	-6.772	2.479	-0.174	1.829

Note: The period covered is from 03/05/2005 to 31/12/2011. Phase I of the EU ETS ended in December 2007. RP_{NOV05} to RP_{DEC07} (RP_{JUL08} to RP_{DEC11}) correspond to realized risk premia of the Nordic electricity futures that were both traded and delivered during Phase I (Phase II) of the EU ETS. *, **, *** denote statistical significance at the 10%, 5% and 1% level, respectively. Risk premia are expressed in €/MWh.

Table 7. Descriptive statistics of realized risk premia for the French electricity futures

Contract	# Obs.	Mean	Median	Maximum	Minimum	Std. Dev.	Skewness	Kurtosis
$\mathbf{RP}_{\mathbf{NOV05}}$	64	4.781***	4.693	7.073	3.173	0.847	0.372	2.659
$\mathbf{RP}_{\mathbf{DEC05}}$	64	-91.073***	-92.451	-75.781	-94.211	3.954	2.115	6.796
$\mathbf{RP}_{\mathbf{JAN06}}$	63	-29.991***	-32.483	-7.933	-39.183	9.623	1.018	2.787
$\mathbf{RP}_{\mathbf{FEB06}}$	64	-17.589***	-20.036	2.879	-32.011	9.738	0.150	1.652
$\mathbf{RP}_{\mathbf{MAR06}}$	62	-14.817***	-13.102	-3.767	-28.307	6.352	-0.746	2.792
$\mathbf{RP}_{\mathbf{APR06}}$	64	10.229***	10.061	14.826	4.306	2.160	-0.698	4.353
$\mathbf{RP}_{\mathbf{MAY06}}$	61	10.690***	11.358	14.158	-0.742	3.157	-1.843	6.338
$\mathbf{RP}_{\mathbf{JUN06}}$	60	6.126***	9.666	13.871	-6.199	7.365	-0.598	1.578
$\mathbf{RP}_{\mathbf{JUL06}}$	58	-3.244***	-4.872	4.948	-10.302	4.859	0.658	1.942
$\mathbf{RP}_{\mathbf{AUG06}}$	61	-90.384***	-91.874	-75.724	-98.594	6.051	0.942	2.730
$\mathbf{RP}_{\mathbf{SEP06}}$	65	8.573***	7.716	14.746	4.886	2.367	0.691	2.908
$\mathbf{RP}_{\mathbf{OCT06}}$	66	18.255***	19.142	23.957	9.607	3.391	-0.976	3.353
$\mathbf{RP}_{\mathbf{NOV06}}$	65	21.988***	22.970	29.070	11.830	5.607	-0.155	1.415
$\mathbf{RP}_{\mathbf{DEC06}}$	64	23.291***	24.212	29.037	7.277	4.656	-1.634	6.002
$\mathbf{RP}_{\mathbf{JAN07}}$	127	28.077***	30.267	33.517	12.687	5.168	-1.068	3.009
$\mathbf{RP}_{\mathbf{FEB07}}$	129	26.747***	30.357	36.357	1.987	9.901	-1.146	3.148
$\mathbf{RP}_{\mathbf{MAR07}}$	126	29.679***	32.173	43.208	2.658	11.306	-0.856	2.678
$\mathbf{RP}_{\mathbf{APR07}}$	127	10.034***	13.750	18.690	-1.750	6.968	-0.498	1.616
$\mathbf{RP}_{\mathbf{MAY07}}$	123	5.635***	4.495	14.845	-2.425	5.997	0.123	1.324
$\mathbf{RP}_{\mathbf{JUN07}}$	121	-0.355	-1.308	7.762	-6.688	4.135	0.329	1.789
$\mathbf{RP}_{\mathbf{JUL07}}$	123	12.830**	12.659	22.459	2.819	4.837	0.151	2.090
$\mathbf{RP}_{\mathbf{AUG07}}$	123	10.384***	9.903	18.203	2.133	3.499	0.039	2.693
$\mathbf{RP}_{\mathbf{SEP07}}$	126	2.417**	2.103	9.108	-2.152	3.111	0.135	1.759
$\mathbf{RP}_{\mathbf{OCT07}}$	124	-5.148***	-5.700	1.550	-10.030	3.607	0.419	1.693
$\mathbf{RP}_{\mathbf{NOV07}}$	129	-75.780***	-76.384	-52.554	-81.554	4.917	2.218	9.979
$\mathbf{RP}_{\mathbf{DEC07}}$	131	-19.347***	-23.132	8.958	-29.702	10.747	1.318	3.460
$\mathbf{RP}_{\mathbf{JUL08}}$	122	-17.820***	-18.797	5.503	-27.897	6.856	0.821	3.598
$\mathbf{RP}_{\mathbf{AUG08}}$	125	-15.749***	-18.415	-0.415	-24.205	6.220	0.839	2.556
$\mathbf{RP}_{\mathbf{SEP08}}$	125	-11.540***	-10.278	5.512	-26.658	8.829	-0.038	1.845
$\mathbf{RP}_{\mathbf{OCT08}}$	129	1.889	4.359	17.289	-20.711	10.718	-0.700	2.349
$\mathbf{RP}_{\mathbf{NOV08}}$	130	5.979***	6.231	25.976	-9.204	8.877	0.225	2.163
$\mathbf{RP}_{\mathbf{DEC08}}$	130	17.745***	18.279	40.279	-10.341	11.466	-0.345	3.130
$\mathbf{RP}_{\mathbf{JAN09}}$	128	80.967***	86.582	106.862	43.022	18.728	-0.705	2.237
$\mathbf{RP}_{\mathbf{FEB09}}$	126	21.124***	27.704	50.319	-15.521	22.798	-0.213	1.400
$\mathbf{RP}_{\mathbf{MAR09}}$	125	33.476***	28.857	65.677	-1.923	19.823	0.276	1.828
$\mathbf{RP}_{\mathbf{APR09}}$	125	18.828***	19.705	39.785	0.565	11.493	0.007	1.877
$\mathbf{RP}_{\mathbf{MAY09}}$	121	-6.250***	-8.673	9.867	-16.823	8.250	0.323	1.545
$\mathbf{RP}_{\mathbf{JUN09}}$	119	7.796***	4.630	21.860	-0.790	7.086	0.745	2.084
$\mathbf{RP}_{\mathbf{JUL09}}$	120	12.254***	10.019	28.959	6.649	5.132	1.407	4.200
$\mathbf{RP}_{\mathbf{AUG09}}$	123	0.921*	0.833	8.493	-3.467	2.642	0.911	3.913
$\mathbf{RP}_{\mathbf{SEP09}}$	124	-4.493***	-4.973	-0.193	-10.333	2.063	-0.148	3.069
$\mathbf{RP}_{\mathbf{OCT09}}$	67	-4.601***	-5.011	0.209	-7.111	2.021	1.004	3.113
$\mathbf{RP}_{\mathbf{NOV09}}$	65	-3.972***	-5.857	15.403	-10.147	6.044	1.615	4.940
$\mathbf{RP}_{\mathbf{DEC09}}$	75	16.895***	14.668	34.488	7.988	6.324	1.190	3.478
$\mathbf{RP}_{\mathbf{JAN10}}$	63	30.746***	29.954	48.704	17.434	9.437	0.393	2.038
$\mathbf{RP}_{\mathbf{FEB10}}$	60	1.001	-0.950	17.610	-8.730	7.067	0.726	2.686
$\mathbf{RP}_{\mathbf{MAR10}}$	56	4.526***	3.144	10.024	0.074	2.792	0.250	1.700
$\mathbf{RP}_{\mathbf{APR10}}$	53	5.640***	5.462	7.932	4.432	0.832	0.881	3.369
$\mathbf{RP}_{\mathbf{MAY10}}$	54	-6.531***	-7.461	0.854	-8.986	2.636	1.257	3.561
$\mathbf{RP}_{\mathbf{JUN10}}$	56	-0.067	0.039	7.474	-5.776	4.336	-0.022	1.388
$\mathbf{RP}_{\mathbf{JUL10}}$	62	-2.897***	-2.084	1.771	-9.949	2.565	-1.129	3.582
$\mathbf{RP}_{\mathbf{AUG10}}$	66	0.475	0.586	3.861	-3.009	1.599	-0.064	2.398
$\mathbf{RP}_{\mathbf{SEP10}}$	66	8.828***	8.207	14.802	4.102	2.946	0.401	1.770
$\mathbf{RP}_{\mathbf{OCT10}}$	65	0.691	0.821	6.571	-3.979	2.032	0.454	3.576

$\mathbf{RP_{NOV10}}$	63	-14.127***	-14.823	-9.323	-20.573	3.054	-0.120	2.019
$\mathbf{RP_{DEC10}}$	64	-0.823	-0.882	4.438	-4.922	2.547	0.196	1.933
$\mathbf{RP_{JAN11}}$	64	4.108***	3.916	8.106	0.206	2.345	-0.032	1.811

Table 7 continued.

$\mathbf{RP_{FEB11}}$	60	-2.249***	-2.498	2.702	-6.658	2.576	0.215	1.942
$\mathbf{RP_{MAR11}}$	60	-3.398***	-3.322	1.743	-7.047	2.017	0.236	2.496
$\mathbf{RP_{APR11}}$	81	-4.282***	-5.077	7.903	-7.687	3.483	1.789	5.902
$\mathbf{RP_{MAY11}}$	99	-5.272***	-7.888	7.482	-11.488	5.102	0.712	2.072
$\mathbf{RP_{JUN11}}$	121	2.341***	0.647	11.417	-2.943	3.932	0.344	1.599
$\mathbf{RP_{JUL11}}$	61	8.658***	9.688	14.358	-1.222	3.761	-0.800	3.028
$\mathbf{RP_{AUG11}}$	76	7.564***	8.692	14.007	-5.903	4.402	-0.843	3.299
$\mathbf{RP_{SEP11}}$	106	2.945***	4.031	10.006	-5.564	4.660	-0.264	1.687
$\mathbf{RP_{OCT11}}$	83	8.326***	8.309	13.409	2.839	2.611	0.151	2.357
$\mathbf{RP_{NOV11}}$	76	8.911***	9.937	13.652	0.242	3.531	-0.971	3.013
$\mathbf{RP_{DEC11}}$	64	7.392***	8.178	13.023	-2.797	4.237	-0.589	2.464

Note: The period covered is from 03/05/2005 to 31/12/2011. Phase I of the EU ETS ended in December 2007. RP_{NOV05} to RP_{DEC07} (RP_{JUL08} to RP_{DEC11}) correspond to realized risk premia of the French electricity futures that were both traded and delivered during Phase I (Phase II) of the EU ETS. *, **, *** denote statistical significance at the 10%, 5% and 1% level, respectively. Risk premia are expressed in €/MWh.

Table 8. Descriptive statistics of realized risk premia for the British electricity futures

Contract	# Obs.	Mean	Median	Maximum	Minimum	Std. Dev.	Skewness	Kurtosis
RP$_{\mathbf{NOV05}}$	119	12.709***	12.710	22.280	6.560	3.342	0.373	2.638
RP$_{\mathbf{DEC05}}$	140	-23.325***	-25.000	7.040	-31.550	6.038	2.109	9.198
RP$_{\mathbf{JAN06}}$	162	-5.234***	-7.040	17.870	-15.650	7.107	1.025	3.605
RP$_{\mathbf{FEB06}}$	182	7.898***	6.510	30.460	-3.210	6.799	1.047	3.837
RP$_{\mathbf{MAR06}}$	202	-5.230***	-6.555	15.790	-16.330	6.147	0.955	4.060
RP$_{\mathbf{APR06}}$	225	6.594***	7.110	13.370	-4.980	4.209	-0.978	3.502
RP$_{\mathbf{MAY06}}$	242	2.830***	3.655	9.920	-5.410	3.117	-0.871	3.325
RP$_{\mathbf{JUN06}}$	247	6.873***	7.530	12.380	-2.350	3.040	-0.685	2.820
RP$_{\mathbf{JUL06}}$	247	-3.427***	-3.170	1.740	-9.860	2.755	-0.335	2.246
RP$_{\mathbf{AUG06}}$	249	3.017***	3.630	9.110	-2.140	2.606	-0.031	1.970
RP$_{\mathbf{SEP06}}$	247	10.583***	10.120	17.720	5.540	3.082	0.197	1.769
RP$_{\mathbf{OCT06}}$	248	16.330***	15.945	28.000	1.350	5.536	-0.065	2.583
RP$_{\mathbf{NOV06}}$	249	29.444***	29.850	43.110	11.530	7.114	-0.327	2.574
RP$_{\mathbf{DEC06}}$	246	23.884***	24.825	36.730	3.700	6.937	-0.621	3.055
RP$_{\mathbf{JAN07}}$	246	41.111***	44.580	53.780	14.660	9.908	-1.054	3.323
RP$_{\mathbf{FEB07}}$	247	37.156***	41.410	52.750	4.800	12.566	-1.081	3.196
RP$_{\mathbf{MAR07}}$	246	32.092***	37.350	51.090	1.630	13.668	-0.732	2.357
RP$_{\mathbf{APR07}}$	246	18.522***	21.635	33.510	-0.490	10.584	-0.615	1.869
RP$_{\mathbf{MAY07}}$	247	14.551***	18.140	25.340	-0.160	8.910	-0.464	1.585
RP$_{\mathbf{JUN07}}$	247	9.793***	12.340	22.040	-1.710	7.796	-0.054	1.380
RP$_{\mathbf{JUL07}}$	248	10.613***	8.830	21.710	2.080	6.278	0.365	1.666
RP$_{\mathbf{AUG07}}$	249	10.895***	7.520	24.400	2.520	6.499	0.711	2.046
RP$_{\mathbf{SEP07}}$	246	-16.927***	-19.480	-1.930	-24.930	5.991	0.818	2.371
RP$_{\mathbf{OCT07}}$	248	3.487***	1.585	21.890	-2.110	5.172	1.499	5.281
RP$_{\mathbf{NOV07}}$	247	-15.175***	-16.010	-2.970	-21.510	3.809	0.901	3.172
RP$_{\mathbf{DEC07}}$	247	0.702	-0.820	21.700	-8.320	5.058	1.876	6.814
RP$_{\mathbf{JUL08}}$	120	-12.509***	-16.255	12.260	-25.480	10.959	0.667	2.222
RP$_{\mathbf{AUG08}}$	140	-11.614***	-15.105	9.930	-27.090	12.348	0.456	1.726
RP$_{\mathbf{SEP08}}$	160	-18.241***	-19.095	1.360	-36.940	13.215	0.071	1.363
RP$_{\mathbf{OCT08}}$	184	-9.154***	-6.125	31.610	-32.350	13.860	0.114	2.171
RP$_{\mathbf{NOV08}}$	204	12.760***	11.905	80.830	-21.670	21.484	0.577	2.871
RP$_{\mathbf{DEC08}}$	224	30.604***	31.760	73.400	-0.850	16.995	0.173	2.205
RP$_{\mathbf{JAN09}}$	247	33.232***	32.780	64.780	3.780	15.449	0.070	1.739
RP$_{\mathbf{FEB09}}$	248	22.070***	21.945	44.290	-3.910	14.031	-0.010	1.528
RP$_{\mathbf{MAR09}}$	248	34.110***	32.360	59.420	-1.230	15.529	-0.102	1.844
RP$_{\mathbf{APR09}}$	251	27.998***	28.220	52.120	0.570	14.953	-0.228	1.793
RP$_{\mathbf{MAY09}}$	248	27.434***	29.370	53.570	1.980	16.749	-0.132	1.511
RP$_{\mathbf{JUN09}}$	247	19.106***	15.900	47.090	-3.500	17.323	0.085	1.408
RP$_{\mathbf{JUL09}}$	246	15.172***	9.955	48.920	-5.600	16.558	0.506	1.723
RP$_{\mathbf{AUG09}}$	246	18.042***	13.525	47.950	0.050	15.435	0.668	1.965
RP$_{\mathbf{SEP09}}$	182	3.725***	2.110	16.190	-3.160	5.345	0.850	2.530
RP$_{\mathbf{OCT09}}$	247	17.811***	14.660	51.870	3.130	11.035	0.970	3.389
RP$_{\mathbf{NOV09}}$	247	6.446***	4.600	25.480	-2.990	7.341	0.896	2.813
RP$_{\mathbf{DEC09}}$	247	14.715***	14.050	29.040	3.710	5.860	0.727	2.760
RP$_{\mathbf{JAN10}}$	251	10.564***	10.120	24.260	-0.190	5.425	-0.036	2.420
RP$_{\mathbf{FEB10}}$	253	7.925***	7.680	18.540	-0.960	5.030	-0.016	1.849
RP$_{\mathbf{MAR10}}$	251	5.508***	4.960	15.830	-2.500	5.195	0.091	1.645
RP$_{\mathbf{APR10}}$	244	0.474	0.270	7.200	-5.260	3.516	0.203	1.867
RP$_{\mathbf{MAY10}}$	244	0.150	-0.440	7.520	-4.890	3.396	0.371	2.074
RP$_{\mathbf{JUN10}}$	248	-4.064***	-4.420	3.030	-8.720	2.983	0.302	2.158
RP$_{\mathbf{JUL10}}$	249	-1.530***	-1.760	4.630	-6.320	2.807	0.116	1.884
RP$_{\mathbf{AUG10}}$	249	-4.229***	-4.570	2.080	-9.080	2.956	0.243	2.036
RP$_{\mathbf{SEP10}}$	228	-8.042***	-8.500	-0.870	-12.910	3.185	0.392	2.119
RP$_{\mathbf{OCT10}}$	247	-0.285	-0.700	7.080	-5.850	2.994	0.345	2.622

RP$_{NOV10}$	247	-0.617	-0.450	5.820	-6.610	2.840	-0.003	2.879
RP$_{DEC10}$	243	-0.954**	-0.700	6.290	-7.150	2.972	-0.021	2.894
RP$_{JAN11}$	243	-2.173***	-2.080	5.950	-9.670	3.561	-0.186	2.801

Table 8 continued.

RP$_{FEB11}$	242	-2.074***	-2.130	6.010	-9.820	3.656	-0.303	2.663
RP$_{MAR11}$	244	0.985**	0.930	12.980	-6.920	3.209	-0.457	3.904
RP$_{APR11}$	251	-3.658***	-4.450	7.230	-12.830	3.289	0.526	4.187
RP$_{MAY11}$	251	-1.545***	-2.090	9.010	-6.030	3.371	1.156	3.676
RP$_{JUN11}$	252	-2.409***	-3.020	7.380	-7.320	3.637	0.805	2.690
RP$_{JUL11}$	252	0.724	0.085	9.430	-4.900	3.971	0.533	2.120
RP$_{AUG11}$	252	0.800	0.340	8.990	-4.890	3.652	0.422	2.134
RP$_{SEP11}$	263	0.988*	0.220	9.470	-5.220	3.961	0.432	2.023
RP$_{OCT11}$	287	-0.552	-1.230	8.240	-6.400	3.624	0.572	2.218
RP$_{NOV11}$	300	5.515***	6.245	13.650	-1.610	4.132	-0.020	1.563
RP$_{DEC11}$	300	10.414***	12.370	18.620	2.720	4.553	-0.127	1.397

Note: The period covered is from 03/05/2005 to 31/12/2011. Phase I of the EU ETS ended in December 2007. RP$_{NOV05}$ to RP$_{DEC07}$ (RP$_{JUL08}$ to RP$_{DEC11}$) correspond to realized risk premia of the British electricity futures that were both traded and delivered during Phase I (Phase II) of the EU ETS. *, **, *** denote statistical significance at the 10%, 5% and 1% level, respectively. Risk premia are expressed in £/MWh.

Table 9. Regression results of realized risk premia on economic risk factors for the Nordic electricity futures

	α_i	β_i	γ_i	δ_i	$\bar{R}^2(\%)$	$\Delta\bar{R}^2(\%)$
RP_{NOV05}	0.77^{***}	-0.17	-0.32	0.11	31.9	0.3
RP_{DEC05}	0.70^{*}	-0.11	-0.60^{*}	0.05	18.3	-0.4
RP_{JAN06}	0.70^{**}	-0.08	-0.64^{**}	-0.05	24.8	-0.4
RP_{FEB06}	0.36^{**}	-0.14	0.00	0.06	11.2	-0.5
RP_{MAR06}	1.01^{***}	0.19	-0.55^{**}	-0.34^{**}	48.3	9.1
RP_{APR06}	0.62^{***}	-0.05	-0.39^{**}	-0.60^{***}	28.7	15.6
RP_{MAY06}	-0.16	0.03	-0.10	-0.14	3.6	1.0
RP_{JUN06}	-0.26	-0.14	0.11	0.04	-0.1	-0.8
RP_{JUL06}	-0.78^{*}	-0.47^{***}	0.29	0.24	25.2	2.2
RP_{AUG06}	-0.62	-0.09	0.15	0.00	24.4	-0.6
RP_{SEP06}	-0.32	-0.27^{**}	0.02	-0.18	29.0	0.5
RP_{OCT06}	-0.33	-0.44^{***}	0.10	-0.31	51.6	2.9
RP_{NOV06}	-0.42^{**}	-0.39^{***}	0.11	-0.16	53.1	0.4
RP_{DEC06}	0.02	-0.02	-0.16	-0.46^{**}	27.3	8.8
RP_{JAN07}	0.02	0.30	-0.63^{**}	-0.34^{***}	40.8	9.8
RP_{FEB07}	0.14	0.34^{***}	-0.71^{***}	-0.59^{***}	65.5	14.5
RP_{MAR07}	0.24	0.14	-0.56^{***}	-0.64^{***}	59.5	12.5
RP_{APR07}	-0.31	-0.11	0.19	-0.47^{**}	44.9	6.1
RP_{MAY07}	-0.08	-0.13	0.23	-0.59^{***}	36.8	18.1
RP_{JUN07}	-0.10	-0.57^{**}	0.51^{**}	-0.51^{***}	48.8	16.7
RP_{JUL07}	0.47^{**}	-0.01	-0.20	-0.32^{**}	15.8	7.6
RP_{AUG07}	0.08	0.20	-0.47	0.08	18.7	-0.1
RP_{SEP07}	-0.54^{**}	0.06	-0.31	-0.12	64.7	0.7
RP_{OCT07}	-0.48^{**}	0.11	-0.27	-0.20^{**}	50.1	2.9
RP_{NOV07}	-0.89^{***}	-0.47^{**}	0.13	-0.05	31.6	-0.3
RP_{DEC07}	-1.09^{***}	-0.21	0.30^{**}	0.00	50.7	-0.4
RP_{JUL08}	0.70^{**}	0.22	-0.58^{**}	0.12	8.9	0.3
RP_{AUG08}	1.54^{***}	-0.25^{***}	-0.81^{***}	0.50^{***}	70.5	18.1
RP_{SEP08}	1.08^{***}	-0.04	-0.82^{***}	0.28^{**}	30.7	5.9
RP_{OCT08}	0.24	-0.14	-0.55^{**}	-0.16	15.7	1.3
RP_{NOV08}	0.21	-0.19^{**}	-0.70^{***}	-0.64^{***}	47.4	22.8
RP_{DEC08}	0.39^{*}	-0.29^{***}	-0.42^{***}	-0.71^{***}	56.7	32.0
RP_{JAN09}	0.32^{***}	-0.15	-0.15	-0.65^{***}	59.8	27.6
RP_{FEB09}	-0.05	-0.33^{*}	-0.18	-0.65^{***}	63.0	32.4
RP_{MAR09}	-0.37^{***}	-0.08	-0.14	-0.68^{***}	68.2	40.3
RP_{APR09}	-0.54^{***}	-0.33^{**}	0.24^{*}	-0.82^{***}	65.0	58.9
RP_{MAY09}	-0.43^{***}	-0.42^{**}	0.36^{**}	-0.77^{***}	44.3	44.7
RP_{JUN09}	-0.06	-0.21	0.19	-0.80^{***}	56.6	34.5
RP_{JUL09}	-0.01	0.19	-0.06	-0.76^{***}	68.8	25.6
RP_{AUG09}	0.32	0.56^{***}	-0.58^{***}	-0.55^{***}	62.8	20.1
RP_{SEP09}	-0.24	0.48^{***}	0.07	-0.51^{***}	38.5	16.0
RP_{OCT09}	0.35	0.10	-0.14	-0.44^{***}	16.4	14.3
RP_{NOV09}	0.39	0.30	-0.35	0.41^{***}	17.5	14.9
RP_{DEC09}	0.40^{*}	0.24	-0.36	0.25^{*}	8.8	5.3
RP_{JAN10}	0.47^{**}	0.03	-0.28	0.09	8.3	-0.1
RP_{FEB10}	1.07^{***}	0.15^{**}	-0.42^{***}	0.06	66.8	0.0
RP_{MAR10}	0.71^{***}	-0.17	0.01	-0.22^{*}	46.3	3.7
RP_{APR10}	0.81^{***}	-0.05	-0.09	-0.25^{***}	49.6	3.1
RP_{MAY10}	0.77^{***}	0.02	-0.11	-0.31^{***}	38.9	5.8
RP_{JUN10}	0.24	-0.23	0.13	-0.13	10.4	0.6
RP_{JUL10}	0.57^{***}	-0.14^{*}	-0.03	-0.03	32.7	-0.2
RP_{AUG10}	0.21	0.03	0.26	0.37^{**}	34.8	9.0
RP_{SEP10}	0.54^{**}	0.06	-0.03	0.38^{*}	38.0	10.3
RP_{OCT10}	0.19	-0.19	0.26	-0.06	14.8	-0.3

RP_{NOV10}	0.01	0.04	0.38	-0.23	12.1	3.8
RP_{DEC10}	-0.04	0.03	0.30	-0.22^{*}	6.9	2.8
RP_{JAN11}	0.15	0.10	0.35^{*}	-0.25^{**}	40.1	3.5

Table 9 continued.

RP_{FEB11}	0.50^{**}	0.35^{***}	-0.08	-0.24^{**}	56.7	3.8
RP_{MAR11}	0.80^{***}	0.35^{***}	-0.22	-0.03	68.5	-0.2
RP_{APR11}	0.94^{***}	0.25^{***}	-0.34^{***}	0.29^{**}	55.0	7.3
RP_{MAY11}	0.96^{***}	0.25^{*}	-0.81^{***}	0.44^{***}	28.6	15.6
RP_{JUN11}	0.69^{***}	0.32^{**}	-0.67^{**}	0.58^{***}	33.7	28.2
RP_{JUL11}	-0.07	0.57^{***}	-0.01	-0.10	31.2	0.6
RP_{AUG11}	-0.16	0.30^{**}	-0.18	-0.45^{***}	51.7	14.5
RP_{SEP11}	-0.50^{***}	0.28^{**}	0.17	-0.41^{***}	69.0	12.2
RP_{OCT11}	-0.51^{**}	0.38^{***}	-0.02	-0.31^{***}	73.4	8.6
RP_{NOV11}	-0.75^{***}	0.35^{***}	0.23^{*}	-0.38^{***}	78.0	14.2
RP_{DEC11}	-0.75^{***}	0.34^{***}	0.47^{***}	-0.36^{***}	47.7	12.5

Note: The test equation is: $RP_{it} = c_i + \alpha_i \cdot \sigma_{S,t} + \beta_i \cdot \sigma_{L,t} + \gamma_i \cdot \sigma_{R,t} + \delta_i \cdot \sigma_{C,t} + \varepsilon_{it}$ where RP_{it} is the realized risk premium of contract i on day t; $\sigma_{S,t}$, $\sigma_{L,t}$, $\sigma_{R,t}$ and $\sigma_{C,t}$ is the conditional volatility of the electricity spot price, load, revenues and carbon futures returns on day t, respectively. The estimations refer to one-by-one regressions of the risk premium for each electricity futures contract on the four risk factors. The last column ($\Delta\bar{R}^2$) presents the change in the adjusted R-squared coefficient ($\bar{R}^2$) as compared to the case when the regressions are estimated without including the carbon risk factor. For comparison purposes, all variables are standardized prior to estimation by subtracting the mean and dividing with the standard deviation. Newey and West (1987) corrected standard errors are employed for the estimations. *, **, *** denote statistical significance at the 10%, 5% and 1% level, respectively.

Table 10. Regression results of realized risk premia on economic risk factors for the French electricity futures

	α_i	β_i	γ_i	δ_i	$\bar{R}^2(\%)$	$\Delta\bar{R}^2(\%)$
RP_{NOV05}	0.33	-0.14	-0.09	-0.55***	18.0	19.4
RP_{DEC05}	0.20	-0.14	0.47	0.24	52.1	1.3
RP_{JAN06}	1.06***	0.27***	-0.77***	-0.55**	69.9	9.7
RP_{FEB06}	1.05***	0.38***	-0.64***	-0.05	64.7	-0.4
RP_{MAR06}	0.27	0.09	-0.29	-0.55**	15.5	19.6
RP_{APR06}	-0.57	0.05	0.45	0.26	10.5	4.8
RP_{MAY06}	-0.01	-0.28***	0.28	-0.69***	24.8	18.8
RP_{JUN06}	0.31	-0.04	-0.04	-0.67***	59.8	20.5
RP_{JUL06}	0.68***	0.20	-0.28***	-0.30**	70.2	4.6
RP_{AUG06}	1.06***	-0.05	-0.41	-0.27**	67.0	4.8
RP_{SEP06}	-0.44*	-0.01	0.64***	-0.71***	24.3	21.0
RP_{OCT06}	0.74***	0.04	-0.40*	-0.52***	22.1	26.4
RP_{NOV06}	1.04***	0.13***	-0.68***	-0.27***	71.5	7.3
RP_{DEC06}	-0.45	0.19	0.17	-0.26*	11.5	4.7
RP_{JAN07}	0.38***	-0.31**	-0.23*	-1.25**	19.3	15.7
RP_{FEB07}	0.22***	-0.21***	-0.08	-0.68***	17.4	23.3
RP_{MAR07}	0.17	-0.15	-0.11	-0.86***	8.4	20.3
RP_{APR07}	0.38**	0.09	-0.47**	-0.71***	8.5	28.4
RP_{MAY07}	0.11	0.02	-0.08	-0.66***	6.0	38.9
RP_{JUN07}	0.13	0.10	-0.18	-0.49***	4.9	21.0
RP_{JUL07}	-0.47	0.24**	0.03	-0.10	24.5	0.2
RP_{AUG07}	-0.87***	0.12*	0.46***	0.06	43.7	-0.1
RP_{SEP07}	-0.60***	0.16	0.27*	0.41***	31.9	15.8
RP_{OCT07}	-0.65***	0.19	0.37**	0.35***	34.3	11.1
RP_{NOV07}	0.16	0.13	0.19	0.05	10.5	-0.5
RP_{DEC07}	0.83***	0.10	-0.31	0.06	38.2	-0.2
RP_{JUL08}	-0.18	-0.26**	0.41	-0.56***	19.0	26.1
RP_{AUG08}	0.86***	-0.02	-0.24	-0.08	47.0	0.2
RP_{SEP08}	1.23***	0.18**	-0.58***	-0.07	71.0	0.2
RP_{OCT08}	1.09***	0.19*	-0.56***	-0.04	56.4	-0.2
RP_{NOV08}	0.44*	0.05	-0.26	0.03	7.8	-0.7
RP_{DEC08}	0.43*	0.01	-0.22	-0.28**	9.9	6.8
RP_{JAN09}	0.63***	0.07	-0.34***	-0.55***	25.3	28.9
RP_{FEB09}	0.14	-0.16	-0.27	-0.63***	1.1	36.6
RP_{MAR09}	-0.04	-0.29***	0.07	-0.69***	13.5	35.7
RP_{APR09}	0.41	-0.02	-0.26	-0.58***	39.3	15.9
RP_{MAY09}	0.21	0.05	-0.09	-0.56***	20.9	20.7
RP_{JUN09}	0.31	0.00	-0.05	-0.39***	22.4	8.8
RP_{JUL09}	0.83***	0.15	-0.28	-0.11*	48.5	0.5
RP_{AUG09}	0.82***	0.04	-0.66**	-0.10	31.0	0.2
RP_{SEP09}	0.37**	0.08	-0.15	-0.56***	11.9	30.4
RP_{OCT09}	0.46*	0.18	-0.03	-0.31	43.6	5.2
RP_{NOV09}	-0.17	0.03	0.59	0.49***	-0.4	14.1
RP_{DEC09}	-0.01	0.06	0.01	0.12	-3.9	-0.4
RP_{JAN10}	0.99***	0.13	-0.45**	-0.14	4.3	1.3
RP_{FEB10}	-0.19	0.08	-0.11	-0.52***	15.4	19.8
RP_{MAR10}	-1.06***	-0.05	0.45*	0.06	57.9	-0.6
RP_{APR10}	-0.36	0.13	0.28	0.50*	25.7	8.8
RP_{MAY10}	-0.92***	-0.12	0.12	0.36	37.9	6.9
RP_{JUN10}	-0.60***	-0.22***	0.23***	0.61***	62.5	28.7
RP_{JUL10}	-0.46**	-0.40**	0.45*	0.44***	29.4	13.7
RP_{AUG10}	-0.72***	-0.25	0.68**	-0.62***	4.6	33.6
RP_{SEP10}	-0.12	-0.54	0.76	-0.25	3.5	3.3
RP_{OCT10}	0.83**	0.54	-0.98	-0.37	4.3	4.3
RP_{NOV10}	0.98***	0.24***	-0.21***	0.13**	89.0	0.8

RP$_{DEC10}$	1.21***	0.12	-0.60***	0.11	80.1	0.9
RP$_{JAN11}$	0.87*	-0.24	-0.66	-0.32*	24.9	5.2

Table 10 continued.

RP$_{FEB11}$	1.01***	0.17**	-0.19	0.11	68.4	0.1
RP$_{MAR11}$	0.52**	0.33***	0.06	-0.08	46.5	-0.3
RP$_{APR11}$	-0.13	0.00	0.03	-0.78***	5.7	58.9
RP$_{MAY11}$	-0.60***	0.05	0.28**	0.69***	30.7	44.6
RP$_{JUN11}$	-0.61***	-0.03	0.29**	0.46***	22.4	20.6
RP$_{JUL11}$	0.22	-0.01	-0.32**	-0.75***	7.5	55.5
RP$_{AUG11}$	-0.11	0.18	-0.06	-0.71***	18.0	25.6
RP$_{SEP11}$	-0.34	-0.04	0.43*	-0.65***	8.4	36.3
RP$_{OCT11}$	-0.78***	-0.13	0.75***	-0.35*	17.6	11.0
RP$_{NOV11}$	-0.90***	-0.09	0.44	0.28	34.0	5.7
RP$_{DEC11}$	-0.66***	-0.20	0.81***	-0.58***	29.2	30.9

Note: The test equation is: $RP_{it} = c_i + \alpha_i \cdot \sigma_{S,t} + \beta_i \cdot \sigma_{L,t} + \gamma_i \cdot \sigma_{R,t} + \delta_i \cdot \sigma_{C,t} + \varepsilon_{it}$ where RP_{it} is the realized risk premium of contract i on day t; $\sigma_{S,t}$, $\sigma_{L,t}$, $\sigma_{R,t}$ and $\sigma_{C,t}$ is the conditional volatility of the electricity spot price, load, revenues and carbon futures returns on day t, respectively. The estimations refer to one-by-one regressions of the risk premium for each electricity futures contract on the four risk factors. The last column ($\Delta\bar{R}^2$) presents the change in the adjusted R-squared coefficient ($\bar{R}^2$) as compared to the case when the regressions are estimated without including the carbon risk factor. For comparison purposes, all variables are standardized prior to estimation by subtracting the mean and dividing with the standard deviation. Newey and West (1987) corrected standard errors are employed for the estimations. *, **, *** denote statistical significance at the 10%, 5% and 1% level, respectively.

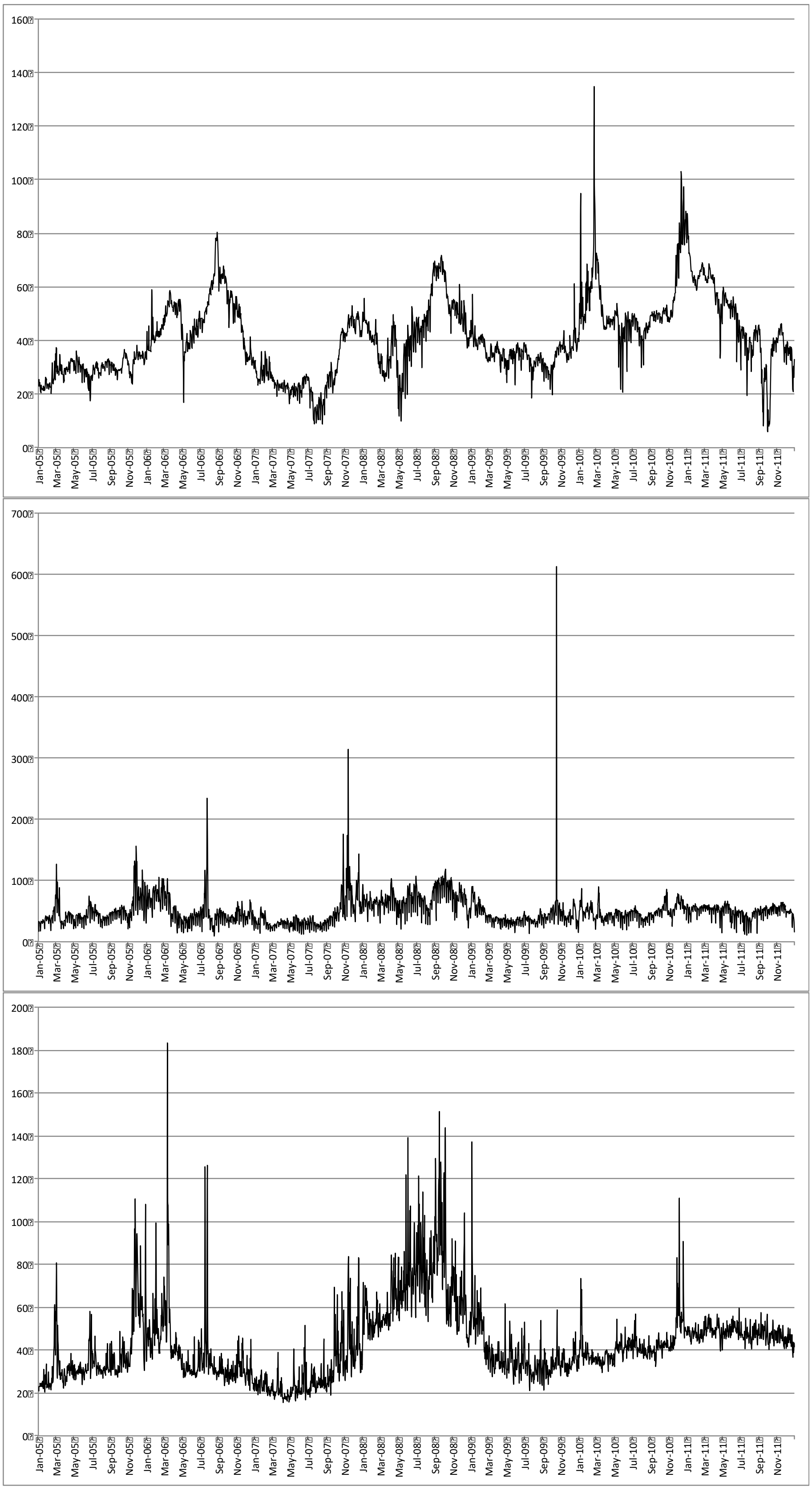
Table 11. Regression results of realized risk premia on economic risk factors for the British electricity futures

	α_i	β_i	γ_i	δ_i	$\bar{R}^2(\%)$	$\Delta\bar{R}^2(\%)$
RP_{NOV05}	-0.11	-0.02	0.31	0.64^{***}	8.3	15.0
RP_{DEC05}	0.12	-0.16	0.42	0.34^{**}	28.2	6.6
RP_{JAN06}	0.53^{**}	-0.11	0.12	0.16	41.6	1.5
RP_{FEB06}	-0.09	-0.19^{*}	0.59^{***}	0.34^{**}	15.3	10.0
RP_{MAR06}	-0.03	-0.15	0.43^{**}	0.35^{**}	9.4	10.8
RP_{APR06}	0.52^{***}	-0.03	0.07	0.17^{**}	29.7	2.3
RP_{MAY06}	0.63^{***}	-0.03	-0.13	0.09	26.0	0.5
RP_{JUN06}	0.68^{***}	0.01	-0.26^{**}	-0.38^{***}	33.7	13.8
RP_{JUL06}	0.63^{***}	0.07	-0.33^{**}	-0.30^{**}	24.5	7.9
RP_{AUG06}	0.91^{***}	0.17^{**}	-0.55^{***}	-0.18	36.6	2.6
RP_{SEP06}	0.28	0.20^{**}	-0.19	-0.25^{**}	7.2	5.2
RP_{OCT06}	0.52^{**}	0.21^{**}	-0.17	0.21^{***}	14.6	3.3
RP_{NOV06}	0.65^{***}	0.24^{***}	-0.26	0.46^{***}	14.4	17.4
RP_{DEC06}	0.60^{**}	0.25^{***}	-0.27	0.35^{***}	11.7	9.3
RP_{JAN07}	0.59^{***}	0.23^{***}	-0.27^{*}	0.25^{***}	13.0	4.5
RP_{FEB07}	0.36^{**}	-0.09	-0.13	0.09	5.1	0.3
RP_{MAR07}	0.40^{***}	0.02	-0.23^{*}	-0.12	8.9	0.8
RP_{APR07}	0.38^{***}	0.06	-0.30^{**}	-0.23	10.5	4.0
RP_{MAY07}	0.21	-0.03	-0.13	-0.33	6.1	8.6
RP_{JUN07}	0.17	-0.10	-0.02	-0.70^{***}	16.8	23.1
RP_{JUL07}	0.42^{***}	-0.06	-0.27^{**}	-0.67^{***}	24.2	20.4
RP_{AUG07}	0.28^{*}	-0.01	-0.30^{**}	-0.71^{***}	17.4	35.7
RP_{SEP07}	-0.21^{*}	-0.08	0.03	-0.72^{***}	6.2	31.9
RP_{OCT07}	-0.35^{***}	-0.14	0.08	-0.53^{***}	9.0	27.6
RP_{NOV07}	0.05	-0.06	0.09	-0.21	-0.5	3.7
RP_{DEC07}	0.69^{***}	0.17^{**}	-0.27	-0.03	22.6	-0.3
RP_{JUL08}	-0.01	-0.27^{**}	0.40	-0.47^{***}	24.9	18.2
RP_{AUG08}	0.10	-0.34^{***}	0.43	-0.11	24.8	0.7
RP_{SEP08}	0.21	-0.35^{***}	0.37	-0.07	29.9	0.0
RP_{OCT08}	0.11	-0.32^{**}	0.42^{*}	-0.09	25.4	0.4
RP_{NOV08}	0.26	-0.25^{*}	0.30	0.08	30.0	0.3
RP_{DEC08}	0.29	-0.24	0.24	0.02	27.5	-0.3
RP_{JAN09}	0.31	-0.24	0.18	-0.21^{*}	22.8	4.0
RP_{FEB09}	0.75^{***}	-0.06	-0.31^{*}	-0.51^{***}	20.1	23.4
RP_{MAR09}	0.48^{***}	-0.09	-0.18	-0.66^{***}	7.7	41.3
RP_{APR09}	0.26^{**}	-0.11	-0.12	-0.75^{***}	11.4	52.3
RP_{MAY09}	0.20^{*}	0.13^{**}	-0.07	-0.73^{***}	22.3	43.5
RP_{JUN09}	0.21	-0.15^{*}	-0.12	-0.68^{***}	29.5	30.9
RP_{JUL09}	0.38^{**}	-0.10	-0.20	-0.47^{***}	25.9	16.0
RP_{AUG09}	0.66^{***}	0.04	-0.31^{**}	-0.23^{*}	31.9	4.0
RP_{SEP09}	0.82^{***}	0.26^{*}	-0.35^{**}	0.20^{**}	33.1	3.5
RP_{OCT09}	0.91^{***}	0.08	-0.43^{***}	0.30^{***}	31.8	8.3
RP_{NOV09}	0.72^{***}	0.17^{*}	-0.37^{**}	0.34^{***}	19.7	11.1
RP_{DEC09}	0.69^{***}	0.16	-0.26^{**}	0.43^{***}	22.3	18.3
RP_{JAN10}	0.78^{***}	0.19^{*}	-0.27^{**}	0.43^{***}	34.6	18.0
RP_{FEB10}	0.48^{**}	0.03	-0.34^{*}	0.49^{***}	7.7	23.5
RP_{MAR10}	0.22	-0.07	-0.02	0.51^{***}	2.0	26.1
RP_{APR10}	0.30	-0.12	-0.03	0.50^{***}	7.7	24.6
RP_{MAY10}	0.33	-0.17^{*}	0.02	0.31^{***}	19.0	8.4
RP_{JUN10}	0.05	-0.27^{***}	0.22	0.24^{*}	11.1	5.1
RP_{JUL10}	-0.45^{***}	-0.34^{***}	0.46^{***}	0.00	10.5	-0.4
RP_{AUG10}	-0.47^{***}	-0.12	0.46^{***}	-0.10	7.2	0.6
RP_{SEP10}	-0.69^{***}	-0.17	0.55^{***}	-0.04	18.1	-0.3
RP_{OCT10}	-0.06	-0.14	0.21	0.27^{**}	5.6	5.5
RP_{NOV10}	-0.42^{**}	-0.18	0.44^{**}	0.08	5.5	0.0
RP_{DEC10}	-0.68^{***}	-0.19	0.55^{***}	0.10	13.4	0.3

RP$_{JAN11}$	-0.33	-0.11	0.67***	-0.24*	13.1	5.1
Table 11 continued.						
RP$_{FEB11}$	-0.04	-0.09	0.49***	-0.15	19.8	1.8
RP$_{MAR11}$	0.38***	-0.10	0.11	0.10*	18.7	0.6
RP$_{APR11}$	0.46***	-0.08	-0.12	0.00	12.6	-0.4
RP$_{MAY11}$	0.36***	-0.04	-0.14	-0.01	5.9	-0.4
RP$_{JUN11}$	0.18	-0.07	0.01	0.04	2.0	-0.2
RP$_{JUL11}$	0.10	-0.06	0.00	0.09	-0.4	0.3
RP$_{AUG11}$	0.09	0.07	0.02	0.12	0.1	1.0
RP$_{SEP11}$	0.03	0.08	0.04	0.11	-0.4	0.6
RP$_{OCT11}$	-0.07	0.12	0.10	0.10	0.5	0.7
RP$_{NOV11}$	-0.07	0.08	0.05	0.38***	0.3	12.8
RP$_{DEC11}$	-0.07	0.05	0.05	0.47***	1.0	20.4

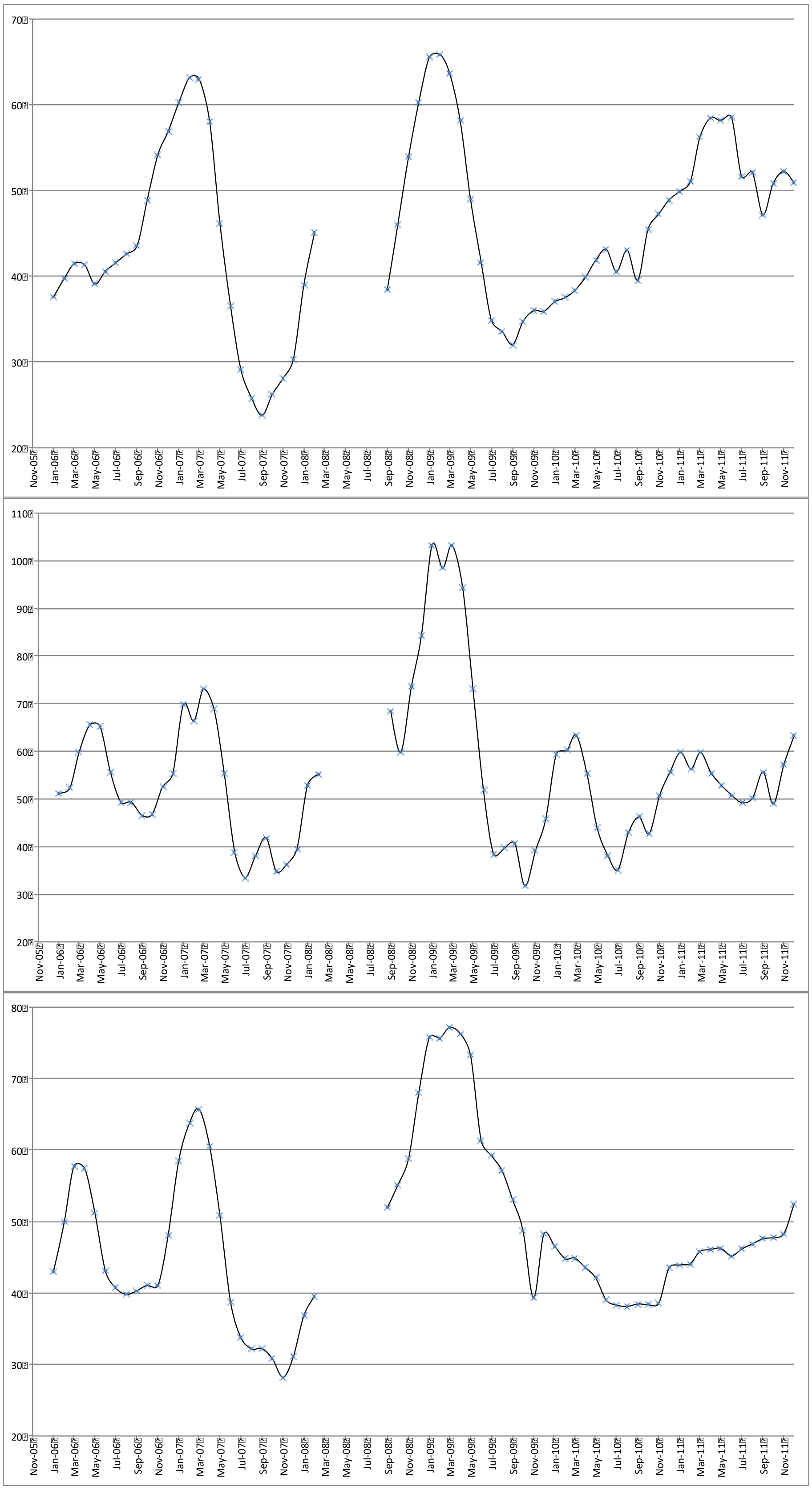
Note: The test equation is: $RP_{it} = c_i + \alpha_i \cdot \sigma_{S,t} + \beta_i \cdot \sigma_{L,t} + \gamma_i \cdot \sigma_{R,t} + \delta_i \cdot \sigma_{C,t} + \varepsilon_{it}$ where RP_{it} is the realized risk premium of contract i on day t; $\sigma_{S,t}$, $\sigma_{L,t}$, $\sigma_{R,t}$ and $\sigma_{C,t}$ is the conditional volatility of the electricity spot price, load, revenues and carbon futures returns on day t, respectively. The estimations refer to one-by-one regressions of the risk premium for each electricity futures contract on the four risk factors. The last column ($\Delta\bar{R}^2$) presents the change in the adjusted R-squared coefficient ($\bar{R}^2$) as compared to the case when the regressions are estimated without including the carbon risk factor. For comparison purposes, all variables are standardized prior to estimation by subtracting the mean and dividing with the standard deviation. Newey and West (1987) corrected standard errors are employed for the estimations. *, **, *** denote statistical significance at the 10%, 5% and 1% level, respectively.

Figure 1. Electricity spot prices in the Nordic (top), French (middle) and British power market (bottom)



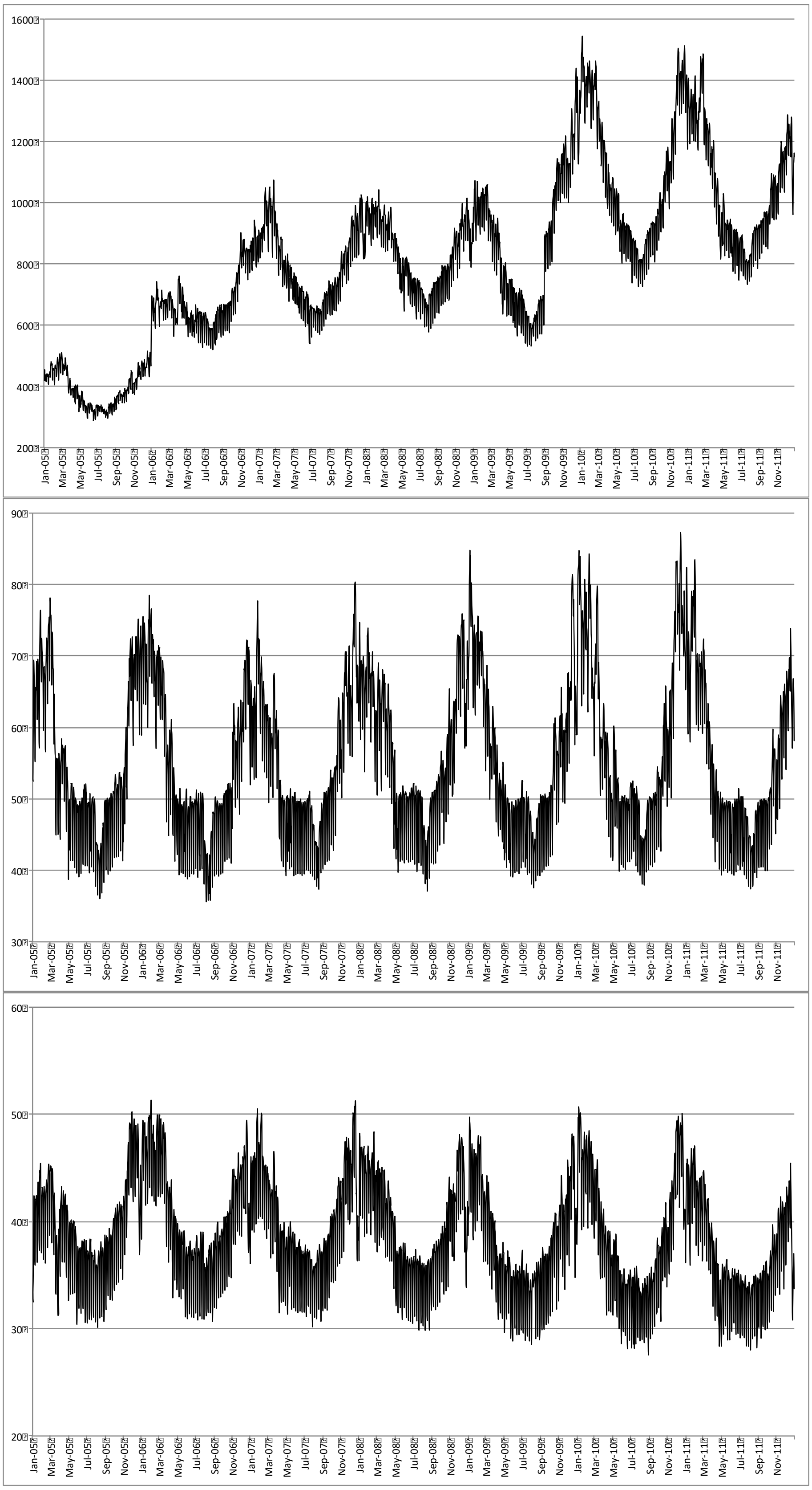
Note: The period covered is from 03/05/2005 to 31/12/2011. Electricity prices in both the Nordic and French market are quoted in €/MWh, while in the British in £/MWh.

Figure 2. Electricity futures curve for the Nordic (top), French (middle) and British contracts (bottom)



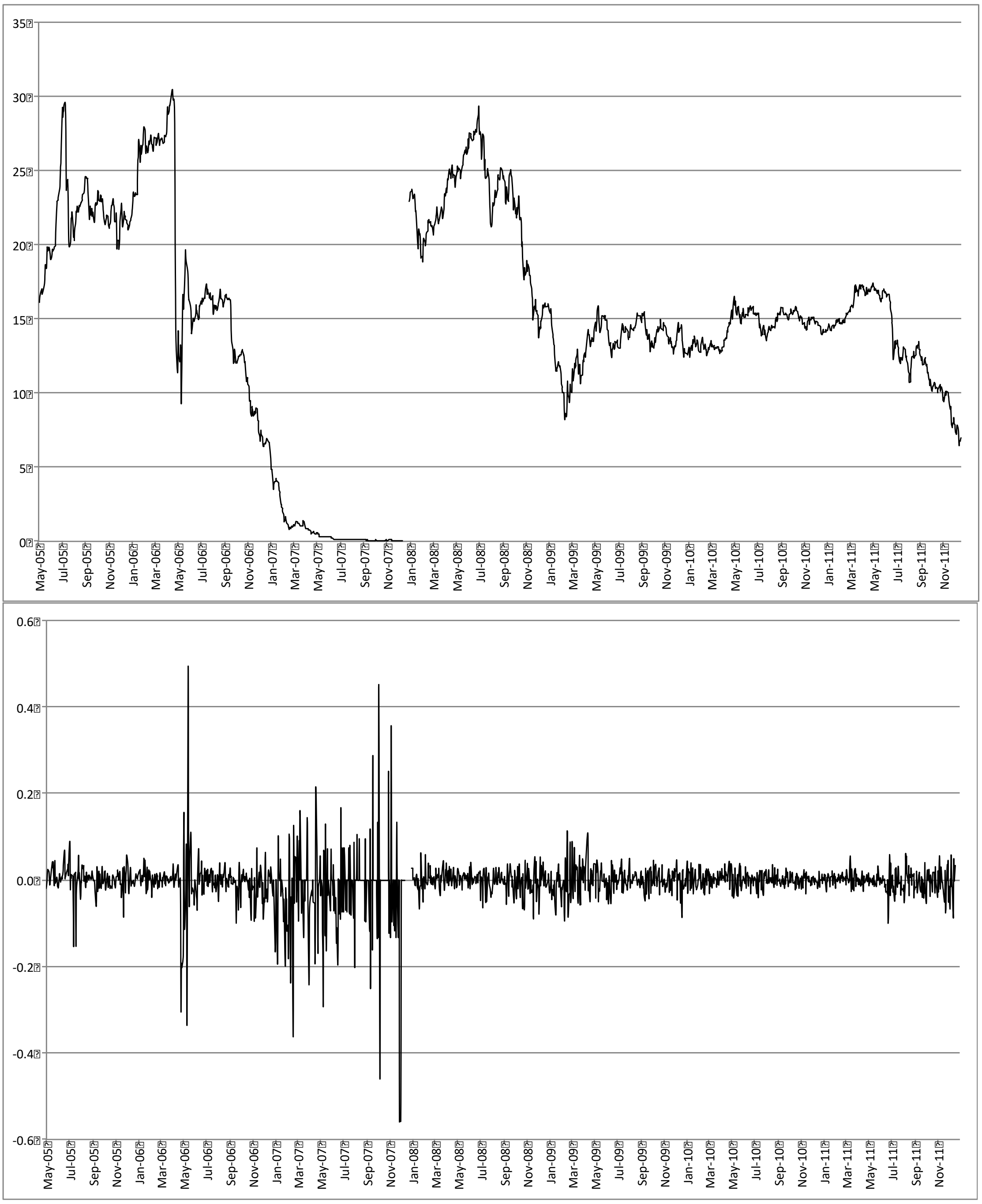
Note: The figure displays the average price of the monthly electricity futures traded from 03/05/2005 to 31/12/2011 for the delivery months November 2005 to December 2007 (Phase I of the EU ETS) and July 2008 to December 2011 (Phase II). The contracts with delivery in the months January to June 2008 are excluded from the analysis because their trading (or part of it) and maturity took place in different EU ETS phases. Electricity prices for both the Nordic and French futures are quoted in €/MWh, while for the British contracts in £/MWh.

Figure 3. Electricity load in the Nordic (top), French (middle) and British power market (bottom)



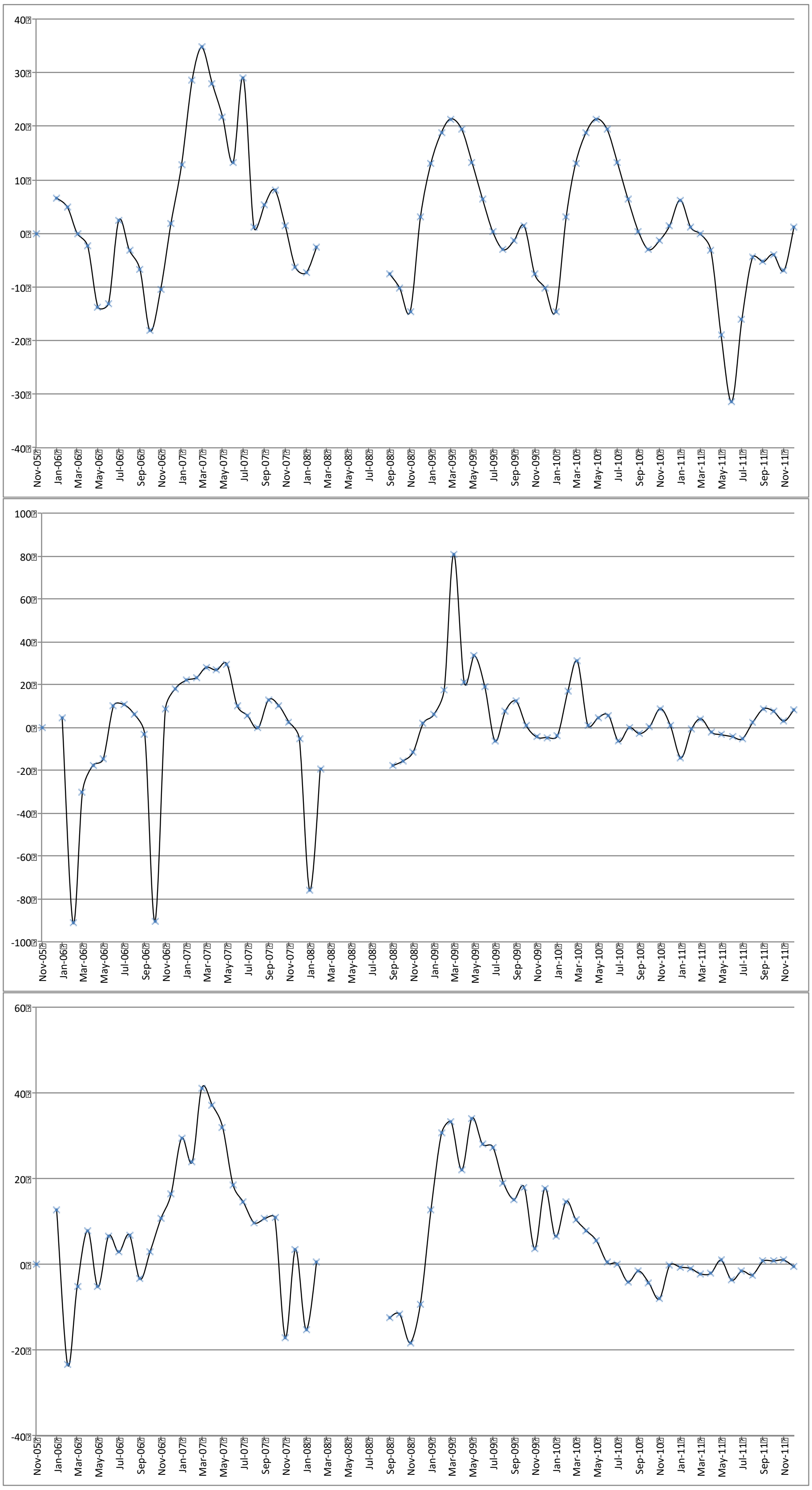
Note: The period covered is from 03/05/2005 to 31/12/2011. Electricity load is quoted in GWh.

Figure 4. Carbon futures prices (top) and logarithmic returns (bottom)



Note: The period covered is from 03/05/2005 to 31/12/2011. Phase I of the EU ETS ended in December 2007. The figure depicts the prices (top) and logarithmic returns (bottom) of a rolled-over EUA futures series constructed using the contracts traded in NYSE ICE with December 2006 and December 2007 (2008 and 2011) expiries for Phase I (Phase II) of the EU ETS. Carbon futures prices are quoted in €/EUA.

Figure 5. Realized risk premia for the Nordic (top), French (middle) and British electricity futures (bottom)



Note: The figure displays the mean of the realized risk premia of the electricity futures traded between 03/05/2005 to 31/12/2011 for the delivery months November 2005 to December 2007 (Phase I of the EU ETS) and July 2008 to December 2011 (Phase II). The risk premia for the electricity contracts with delivery in the months January to June 2008 are excluded from the analysis because the trading of these futures (or part of it) and maturity took place in different EU ETS phases. Risk premia for both the Nordic and French futures are expressed in €/MWh, while for the British contacts in £/MWh.