Energy Economics 44 (2014) 178–190

Contents lists available at ScienceDirect

Energy Economics

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

Revisiting the relationship between spot and futures prices in the Nord Pool electricity market

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ARTICLE INFO

Article history:
Received 1 October 2013
Received in revised form 4 March 2014
Accepted 8 March 2014
Available online 25 April 2014

JEL classification:
C20
C52
G13
G14
G41
G47

Keywords:
Electricity market
Spot and futures prices
Risk premium
Convenience yield

ABSTRACT

This work discusses potential pitfalls of applying linear regression models for explaining the relationship between spot and futures prices in electricity markets, in particular, the bias coming from the simultaneity problem, the effect of correlated measurement errors and the impact of seasonality on the regression results. Studying a 13-year long (1998–2010) price series of spot and futures prices at Nord Pool and employing regression models with GARCH residuals, we show that the impact of the water reservoir level on the risk premium is positive, which is to be expected, but contradicts the results of Botterud et al. (2010). We also show that after taking into account the seasonality of the water level, the storage cost theory proposed by Botterud et al. (2010) to explain the behavior of convenience yield has only limited support in the data.

1. Introduction

The Nordic commodity market for electricity, known as Nord Pool, was established in 1992 as a consequence of the Norwegian energy act of 1991 that formally paved the way for deregulation. In the years to follow Sweden (1996), Finland (1998) and Denmark (2000) joined what became the world's first international power exchange. In 2002 the physical electricity market *Elspot* was separated from the derivatives market and renamed Nord Pool Spot. The last few years saw the Baltic states join the Nord Pool Spot. As of 2012 over 70% of the total power consumption in the Nordic–Baltic region is traded in the spot market, a fraction that has steadily been growing since the inception of the exchange in the 1990s (Nord Pool Spot, 2013). In 2010 the financial derivatives market Nord Pool, also known as *Eltermin*, changed its name to NASDAQ OMX Commodities Europe after an acquisition by NASDAQ OMX. In this market a range of Nordic power derivatives are being traded: monthly, quarterly and annual forwards, daily and weekly futures, options and contracts for difference. Note that contrary to the commonly used definition of a forward contract as an over-the-counter (bilateral) agreement, Nord Pool (NASDAQ OMX) defines these contracts as standardized and exchange traded but not marked-to-market agreements for delivery of electricity during a certain period (a month, a quarter, a year) in the future. They can be treated as longer term futures contracts and, hence, we use the terms interchangeably in this paper. The product range traded at NASDAQ OMX is much wider nowadays and includes Dutch, German and UK power futures and forwards, UK Natural Gas futures and carbon products (EUA, CER). The Nordic *Eltermin* market has been highly successful, with churn ratios – the number of times a product is traded above its physical consumption – between 4 and 7 in the last decade (NASDAQ OMX, 2012; Ofgem, 2009).

Yet regardless of this commercial success it is not clear that the forward market (understood as the market for exchange traded electricity futures and forward contracts) is operating efficiently. Christensen et al. (2007) report that significant forward premia existed at Nord Pool in the period 2003–2006 and that they were related to both spot market volatility and abuse of market power and manipulation in the spot and forward markets by one of the dominant producers in Western Denmark. In a study focusing on the Nord Pool *Eltermin* market,

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http://dx.doi.org/10.1016/j.eneco.2014.03.007
0140-9883/

Kristiansen (2007) finds inefficiencies in the pricing of synthetic seasonal contracts constructed by monthly contracts. Also Gjolberg and Brattested (2011) find evidence of market inefficiency. Studying Nord Pool data in the period 1995–2008 they reach a conclusion that the differences between futures prices and subsequent spot prices are very significant and their high magnitude can hardly be explained by the level of risk. Furthermore, Redl and Bunn (2013) argue that while forward markets in general promote market completeness, facilitate risk management and induce greater competitive behavior in the spot markets, the transaction costs (including premia) that prevail in the markets may well eliminate some of these benefits in practice. Finally, Maciejowska (2014) finds that speculative activity may play an important role in the electricity price formation process and thus influence the efficiency of forward markets.

It is therefore important to be able to identify and estimate the components of the premia implied by forward electricity prices. However, in spite of an increasing amount of literature (see also Benth et al., 2008b; Bessembinder and Lemmon, 2002; Bunn and Chen, 2013; Diko et al., 2006; Douglas and Popova, 2008; Handika and Trueck, 2013; Haugom and Ullrich, 2012; Huisman and Kilic, 2012; Janczura, 2014; Longstaff and Wang, 2004; Karakatsani and Bunn, 2005; Kolos and Ronn, 2008; Redl et al., 2009; Ronn and Wimschulte, 2009; Weron, 2008), this topic remains a challenging and relatively unresolved area of research. Much of this has to do with the confusion around the terminology in published research (more details in the next section). The terms *risk premium*, *forward premium*, *forward risk premium* and *market price of risk* are not uniquely defined and in some cases used interchangeably. Furthermore, some authors analyze *ex-post* (or *realized*) premia, while others construct expectations of the spot price to compute *ex-ante* premia. While being conceptually attractive, the latter are highly dependent on the subjective choice of a model for the spot price, and therefore tend to be less comparable between different studies. Finally, different authors use different datasets, not only in terms of the generation stack and the power market where the data originates from, but – more importantly – also in terms of the time scale considered: short-term (days) vs. mid-term (weeks, months) forward prices.

In this paper we focus on ex-post (realized) risk premia in the Nord Pool market. We recover them from the prices of weekly futures contracts of maturities ranging from 1 to 6 weeks. Hence, as in Botterud et al. (2010), Gjolberg and Brattested (2011) or Lucia and Torro (2011), the time scale used is weekly. Overall, the sample comprises 679 weekly data points in the 13-year long period: January 1998–December 2010. When analyzing Nord Pool data we should bear in mind two things. First, this is a hydro-dominated market with roughly 50% of the total generation capacity coming from this renewable source. In Norway alone the share of hydropower exceeds 95%. The precipitation in the mountains and the filling of the water reservoirs during the Spring flood are therefore a crucial factor for the functioning of the Nord Pool market and for explaining the relationship between futures and spot prices (Torro, 2009; Weron, 2008). Second, the Nord Pool market is characterized by significant seasonal variations in weather conditions (including water inflow) and in consumption. We pay special attention to the analysis of these seasonal effects and their influence on risk premia.

The contribution of our paper is twofold. First, we point out some problems with the risk premium model proposed by Botterud et al. (2010) and show that after they are taken care of, the observed relation of the water level and the risk premium is actually of opposite sign. We emphasize potential pitfalls of making no distinction between ex-ante and ex-post risk premia. We also analyze the convenience yield model proposed by these authors and show that existing evidence gives less unambiguous support to the storage cost theory than initially claimed by the authors. Second, we revisit the Nord Pool market with a longer, more recent 13-year dataset (1998–2010), extending the former study by four years, and employ GARCH components in the regression models for the risk premium and the convenience yield. We show that the latter approach leads to a better description of the studied phenomenon.

The remainder of the article is organized as follows. In Section 2 we discuss the spot-forward price relationship and the concepts of the risk premium and the convenience yield. We also review the literature and emphasize the similarities and differences between the studies and the terminology used. In Section 3 we comment on the pitfalls of regression analysis and discuss possible ways to avoid them. In Section 4 we describe the conducted empirical study, compare our results with those of Botterud et al. (2010) and provide evidence in favor of the regression models with GARCH residuals for the risk premium. Finally, in Section 5 we wrap up the results and conclude.

2. Risk premia in electricity markets

2.1. Definitions of the risk premium

For commodities, the relationship between spot and forward prices (and between prices of futures or forward contracts with different maturities) is often explained in terms of the *convenience yield*, an approach dating back to Kaldor (1939). The convenience yield is defined as the premium to a holder of a physical commodity as opposed to a futures or forward contract written on it (see e.g. Geman, 2005; Weron, 2006). However, electricity is a ‘flow’ rather than a ‘stock’ commodity. It is produced and consumed continuously and is essentially non-storable, at least not economically. So does the notion of the convenience yield make sense in the context of electricity? Can we quantify the benefit from ‘holding’ electricity, not to mention the storage cost? As there is no consensus on this issue in the literature (we will return to this discussion in Section 2.3) let us now focus on the second economic theory, which considers equilibrium relationships between futures prices and expected spot prices. Within this approach, which can be traced back to Keynes (1930), the forward price is viewed as being determined as the expected spot price plus an *ex-ante risk premium*. In other words, the ex-ante risk premium is the difference between the spot price forecast, which is the best estimate of the going rate of commodity (e.g. electricity) at some specific time in the future, and the forward price, i.e. the actual price a trader is prepared to pay today for delivery of this commodity in the future (Botterud et al., 2010; Diko et al., 2006; Hirshleifer, 1989; Janczura, 2014; Pindyck, 2001; Weron, 2006, 2008):

$$\mathrm{RP}^{*}_{t,T} = \ln\{\mathbb{E}_t(S_{t+T})\} - \ln\left(F_{t,T}\right) = \ln\left\{\frac{\mathbb{E}_t(S_{t+T})}{F_{t,T}}\right\}, \tag{1}$$

where $\mathbb{E}_t(S_{t+T})$ is a forecast made today (time t) regarding the spot price at a future date $(t + T)$ and $F_{t,T}$ is the price of a futures (or forward) contract quoted today with delivery period starting at this future date. Note that the above definition of the risk premium as a log difference and the notation for the forward price is used here for consistency with the paper of Botterud et al. (2010). However, it is more common in the literature to consider a simple difference and the second subscript in $F_{t,T}$ to define the delivery date, not the time to delivery. Note also that the expectation $\mathbb{E}_t(S_{t+T})$ in Eq. (1) is taken at time t with respect to the ‘real-world’ or ‘risky’ probability measure, say $\mathcal{P}$, and concerns the spot price S_{t+T} at a future date $(t + T)$. On the other hand, the futures price $F_{t,T}$ is the expectation made also at time t of the spot price S_{t+T} but with respect to the ‘risk-neutral’ or ‘risk-adjusted’ measure, say $\mathcal{P}^{\lambda}$ (see Weron, 2008); more formally: $F_{t,T} = \mathbb{E}^{\lambda}_t(S_{t+T})$.

This consideration leads us to the so-called *market price of risk*, a notion popular in the financial mathematics literature (Benth et al., 2008a, 2008b; Geman, 2005; Janczura, 2014; Kolos and Ronn, 2008; Ronn and Wimschulte, 2009; Weron, 2006, 2008). The market price of risk can be seen as a drift adjustment (a constant $-\lambda$, a deterministic function of time $-\lambda_t$) in the stochastic differential equation (SDE) governing the