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Intra-day and regime-switching dynamics in electricity price formation ☆

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ABSTRACT

This paper analyses the complex, non-linear effects of spot price drivers in wholesale electricity markets: their intra-day dynamics and transient irregularities. The context is the UK market, after the reforms introduced in March 2001, analysed with an original set of price drivers reflecting economic, technical, strategic, risk, behavioural and market design effects. Models are estimated separately as daily time-series of the 48 half-hourly trading periods. All coefficients exhibit substantial intra-day variation, relating to the heterogeneity of operating plants and market design aspects. This reveals a market responding to economic fundamentals and plant operating properties, with learning and emergent financial characteristics, as well as some strategic manipulation of capacity, most effectively exercised by the more flexible plants. Using regime-switching parameters, the effects of capacity margin and inter-day capacity adjustment are elucidated, suggesting rent-seeking behaviour, despite the relatively low prices at the time. Overall, high-frequency, aggregate fundamental price models can usefully uncover critical aspects of market performance, evolution and agent behaviour.

1. Introduction

Price formation in spot electricity markets is a complex process posing substantial modelling challenges. This is due to a convolution of factors, including: i) the instantaneous nature of the commodity, ii) the shape of the supply function, which, in the presence of diverse plant technologies, is intrinsically steeply increasing, discontinuous and convex, iii) the exercise of market power, which results from

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oligopolistic structures, agents' asymmetries and the negligible demand elasticity to price in the short-term, iv) complex market designs due to real-time balancing, and v) substantial agents learning through daily-repeated auctions, but subject to frequent regulatory interventions and market structure changes. Various stochastic models have been proposed for the idiosyncratic price dynamics that arise (e.g. Escribano et al., 2002; de Jong and Huisman, 2003; Knittel and Roberts, 2005; Geman and Roncoroni, 2006). To serve the needs of derivatives pricing, one focus has been upon autoregressive, stylised specifications, which replicate essential price properties, such as mean-reversion, seasonality, jump occurrence, and volatility clustering, but provide limited explanatory insights on price formation.

In contrast, clarifying the degree to which prices reflect economic, technical, strategic, risk, or behavioural factors across intra-day trading periods and over time may reveal the degree of market efficiency, the subtleties of agent behaviour and the market attractors in particular situations. Such insights are important for regulators, in their market monitoring as well as to market agents, in order to understand their risk exposures. In addition, price models based on market fundamentals are appealing for short-term forecasting and scenario construction, as they allow agents to incorporate specific expectations about future market conditions and hence convert private information to possible strategic advantage. A purely statistical model cannot create such agent-specific, conditional expectations.

Nevertheless, existing fundamental models for electricity prices exhibit a number of limitations. Firstly, they are primarily constrained to autoregressive effects and the price responses to demand, fuel prices or weather conditions, such as temperature, precipitation and wind (e.g. Nogales et al., 2002; Kanamura and Ohashi, 2004; Vehvilainen and Pyykkonen, 2004; Kosater, 2006; Rambharat et al., 2005; Huisman, 2007). In competitive electricity markets, such effects need to be complemented with: i) aspects of plant dynamics, as suggested by technical and economic arguments, ii) measures of risk, as implied by Longstaff and Wang (2004), iii) market design and market structure effects (e.g. Wolak, 2000; Bower and Bunn, 2001), iv) agent learning and iv) strategic behaviour. Although market power has been documented extensively in market assessments as well as in competition models (e.g. Wolfram, 1999; Borenstein et al., 1999; Green and Newbery, 1992; Day et al., 2002), relevant indicators do not appear in econometric price models. Secondly, many specifications tend to refer to daily average prices, whilst intra-day patterns of trading display distinct price profiles, reflecting the daily variation of demand and operational constraints. In this context, profitability may be selectively achieved by agent strategies across the day. Nevertheless, only a few high-frequency studies[1] have appeared in the literature (e.g. Huisman et al., 2007). Finally, existing formulations generally assume constant effects, over time, but this disregards the evolution of agents' behaviour to changing market conditions.

Motivated by the above issues, this paper proposes fundamental price models – linear and regime-switching regressions – to clarify the determinants of prices and in particular, the size, intra-day variation and transient irregularities of various effects. Our context is the British[2] electricity market, over the first year after the 2001 reforms, which transformed the compulsory day-ahead power pool, operating since 1990, into a fully liberalised, continuous, voluntary trading process. Among our principal objectives is to identify the extent to which prices in the new market were cost-reflective, in terms of economic fundamentals, or manifested, despite their low levels during this period, some forms of strategic pricing. As various countries restructure their electricity markets and introduce further liberalising reforms, the inferences derived from the British market can have significant implications.

To elucidate the fine aspects of electricity price formation, econometric modelling is undertaken on an original, high-frequency data set. After defining a variety of potential price drivers, models are estimated across the 48 trading periods of the day. These specifications reveal a substantial, systematic component in prices as well as considerable diurnal heterogeneity in price formation. Subsequently, as spot electricity prices exhibit recurrent, fast-reverting spikes, of unpredictable magnitude and timing, which induce severe financial risks, and auction theory predicts the existence of multiple equilibria (Green and Newbery, 1992; von der Fehr and Harbord, 1993), an appealing hypothesis to be tested is whether the price formation

[1] Guthrie and Videbeck (2007) define five clusters of trading periods with similar demand and supply characteristics. Longstaff and Wang (2004) investigate the responses of the day-ahead forward premium to risks, relating to unexpected demand, price and revenues, and obtain varying coefficients across the day. Their significance is however limited to a few trading periods.

[2] For simplicity, the wholesale electricity market for England and Wales is referred to as British, although it does not include the Scottish region at this period.