Computers & Operations Research 66 (2016) 415–433

Contents lists available at ScienceDirect

Computers & Operations Research

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

Modeling spot price dependence in Australian electricity markets with applications to risk management

Katja Ignatieva [a,*], Stefan Trück [b]

[a] School of Risk and Actuarial Studies, Business School, University of New South Wales, Sydney, Australia
[b] Department of Applied Finance and Actuarial Studies, Macquarie University, Sydney, Australia

ARTICLE INFO

Available online 3 September 2015

Keywords:
Electricity markets
Regional markets
Dependence modeling
Copulas
Tail dependence
Risk management

ABSTRACT

We examine the dependence structure of electricity spot prices across regional markets in Australia. One of the major objectives in establishing a national electricity market was to provide a nationally integrated and efficient electricity market, limiting market power of generators in the separate regional markets. Our analysis is based on a GARCH approach to model the marginal price series in the considered regions in combination with copulae to capture the dependence structure between the marginals. We apply different copula models including Archimedean, elliptical and copula mixture models. We find a positive dependence structure between the prices for all considered markets, while the strongest dependence is exhibited between markets that are connected via interconnector transmission lines. Regarding the nature of dependence, the Student-*t* copula provides a good fit to the data, while the overall best results are obtained using copula mixture models due to their ability to also capture asymmetric dependence in the tails of the distribution. Interestingly, our results also suggest that for the four major markets, NSW, QLD, SA and VIC, the degree of dependence has decreased starting from the year 2008 towards the end of the sample period in 2010. Examining the Value-at-Risk of stylized portfolios constructed from electricity spot contracts in different markets, we find that the Student-*t* and mixture copula models outperform the Gaussian copula in a backtesting study. Our results are important for risk management and hedging decisions of market participants, in particular for those operating in several regional markets simultaneously.

1. Introduction

This paper examines the dependence structure between spot electricity prices across regional markets in the Australian National Electricity Market (NEM). The market operates as an interconnected grid comprising several regional networks providing supply of electricity to retailers and end-users. The NEM includes the states of New South Wales (NSW), Queensland (QLD), South Australia (SA), Victoria (VIC) and the Australian Capital Territory (ACT), while Tasmania (TAS) is connected to the network via a submarine power cable to Victoria. Within the national power grid, electricity can be transmitted between different regions via the so-called interconnectors. These may be of particular importance when the price of electricity in adjoining regions is low enough to displace local supply, but also when the energy demand in a particular region is higher than the amount of electricity that can be provided by local generators. One of the major objectives in establishing a national electricity market was, and still is, to achieve efficient delivery of network services and electricity infrastructure to meet the long term interests of consumers [5]. To achieve this aim, the NEM was established to provide a nationally integrated and efficient electricity market, limiting market power of generators in the separate regional markets [77]. However, as pointed out by Higgs [34], the networks for each state are still usually characterized by a small number of market participants while sizeable differences in electricity prices can be observed. On the other hand, there have been various occasions when extreme price observations or price spikes happened jointly in several markets. Therefore, there is a strong interest for market participants to analyze and model dependencies between wholesale electricity prices in regional Australian wholesale electricity markets.

This study is aimed to give a better understanding of the price dynamics in, and across, regional electricity spot markets. Hereby, we focus in particular on dependence between regional prices and conduct a pioneer study on the use of copulae for capturing this complex dependence structure. Our study yields important insights with respect to joint price movements, spillover effects, extreme price outcomes and the impact of interconnection within the

* Corresponding author.
E-mail address: k.ignatieva@unsw.edu.au (K. Ignatieva).

http://dx.doi.org/10.1016/j.cor.2015.07.019
0305-0548/

Australian electricity market. We complement and extend existing work by Higgs and Worthington [35], Worthington et al. [77] and Higgs [34] on Australian electricity markets by providing a deeper analysis of the actual dependence structure between observed spot prices. Our results are of great interest to electricity traders but also for the development of risk management and hedging strategies for market participants such as large producers and retailers who operate in several of the considered regional markets simultaneously. Also the so-called merchant interconnectors who may earn revenue by purchasing electricity in a lower priced region and selling it to a higher priced region have a strong interest in the dependence structure between different markets.

A key objective when establishing the NEM was to provide an efficient and nationally integrated electricity market. In the long run, such a market should provide similar prices for electricity across the states and, thus, limit the market power of generators in the regional markets. The issue of market power, reflecting systemic economic withholding of capacity by generators in various regional markets, recently has also been investigated by the Australian Energy Market Commission [2]. Despite existing interconnectors, limitations of physical transfer capacity as well as congestions still lead to sometimes significantly different price behavior in the considered regional markets. As pointed out by the Australian Government Productivity Commission [5], stakeholders have also raised concerns about potential underinvestment in interconnectors in the NEM. Garnaut [31] suggests that without having enough interconnector capacity to cope with the potentially large shifts in interstate flows of electricity, much of the generation capacity must remain within a regional market, even if there are more economic sources elsewhere. Thus, interconnector constraints could be reflected in regionally differentiated, volatile and unnecessarily high electricity prices. According to the Australian Government Productivity Commission [5] also the expectation that merchant interconnectors would play an important role in the NEM has not been realized up to date. Therefore, our study on the dependence structure between regional markets may also shed light into Australian electricity markets with respect to developing guidelines for market mechanisms, trading strategies for merchant interconnectors or the construction of new interconnectors between state grids.

So far only a limited number of studies have concentrated on the dependence or a multivariate analysis of different regional electricity markets. De Vany and Walls [19] were the first to study the joint behavior of electricity spot prices in different US markets. They find cointegration and some evidence for a pattern of nearly uniform prices despite a rather inefficient transmission network between the considered regional markets. Worthington et al. [77] employ a multivariate GARCH model to investigate price and volatility spillovers in Australian electricity markets. This analysis is further extended by Higgs [34] who applies a family of constant and dynamic conditional correlation MGARCH models to examine the effects of cross-correlation volatility spillovers between regional Australian electricity markets. The author finds that the highest conditional correlations are evident between the well-connected markets, indicating the presence of strong interdependence between these markets with weaker interdependence between the least interconnected markets. Park et al. [63] investigate the connection between various US spot markets using vector autoregression and the so-called directed acyclic graph methods. They suggest that the relationship among markets is not only dependent on transmission lines but is also affected by similar and dissimilar institutional arrangements. Haldrup and Nielsen [33] use Markov regime switching models in combination with long memory processes to model the dependence between pairs of regional electricity prices in the NordPool market. Micola and Bunn [59] characterize the relationship between two network based oligopoly markets when local players share the interconnection's ownership on a natural gas pipeline. They suggest that the relationship between local price differentials and capacity utilization is increasing and convex. Bollino and Polinori [11], focusing on different electricity markets in Italy, apply a model for contagion and identify significant contagion effects separately from interdependence of the markets. Applying Granger causality tests and cointegration analysis to Californian electricity markets, Dempster et al. [20] find only a moderate degree of integration among these markets. Zachmann [79] examines to which extent European electricity wholesale day-ahead prices converge towards arbitrage freeness. Using a Kalman filter to analyze Dutch-German and Danish-German cross-border capacity auction prices the author shows the absence of arbitrage opportunities between these markets when congestion costs are taken into account. Le Pen and Sévi [50] estimate a VAR-BEKK model and find evidence of return and volatility spillovers between the German, the Dutch and the British forward electricity market. Furthermore, investigating the impact of shocks on expected conditional volatility, author suggests that a shock has a high positive impact only if its size is large compared to the current level of volatility. Smith et al. [70] apply skewed Student t-copulae in combination with a Bayesian approach to model non-linear dependence between regional spot prices. Finally, Füss et al. [30] develop a fundamental multi-market model for the pricing of electricity spot and derivatives contracts in order to analyze how key stylized facts of electricity prices such as volatility and price spikes are impacted by interconnectivity between electricity wholesale markets.

While a number of authors have examined the connection between different regional electricity markets, so far only very few studies have applied copulae to model the possibly non-linear dependence structure between different regional electricity markets. In our analysis, we aim to find a model which appropriately describes the price behavior of each of the regional electricity markets, followed by modeling the dependence structure among the markets using a multivariate copulae approach. Copulae allow us to separate the study of univariate marginals, the regional electricity markets, from the study of a dependence structure. Using copulae is motivated by their ability to measure non-linear dependence between price series which arise for example when we deal with models which do not support the normality assumption. On the other hand, copulae have been extensively used in other financial markets when modeling the dependence between various assets in a portfolio, FX rates, or studying the dependencies between international stock markets, see e.g. Breymann et al. [12], Cherubini et al. [15], McNeil et al. [58], Ignatieva and Platen [41], just to mention a few.

Our study concentrates on Australian electricity markets that differ from other countries and continents in a sense that the market operates as a nationally interconnected grid, providing strong linkage between the regional markets. Using daily spot electricity prices from January 1, 2006 to January 1, 2010 we examine the price behavior and dependence structure between wholesale electricity prices in five Australian regions: NSW, QLD, SA, TAS and VIC. Four of these regions (except TAS) are major regional markets in Australia that have also been considered in the previous literature, see e.g. Higgs and Worthington [35], Worthington et al. [77], and Higgs [34]. After capturing the marginal distributions for each regional market, we study the dependence structure between the markets using multivariate copulae. The usage of combining a model with time-varying volatility with a copula approach is also motivated by the fact that the dependence between regional electricity markets is not constant but may vary over time. Such an analysis will also provide important information on the possibly changing dependence structure between the