Energy Strategy Reviews 21 (2018) 121–129

Contents lists available at ScienceDirect

Energy Strategy Reviews

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

# Modeling the price dynamics of three different gas markets-records theory

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ARTICLE INFO

*Keywords:*
Yang model
Random walk model
Natural gas markets
Extremes
Price records

ABSTRACT

Previous research on extreme values has been used in commodity pricing, more specifically in trying to capture the dynamic behavior of the random occurrences of extreme events, such as price spikes/drops. This research uses the records theory to study the effect of extreme gas prices and the probability of future records.

To our knowledge, records theory was not previously applied to gas markets. The aim of this study is to test the stability of three different regional gas markets, each having its own supply and demand characteristics.

Records theory, studies observations that are higher than all previous ones, which is equivalent to say the maximum/minimum observation up to present time, and those records, are concentrated in the tail of a given distribution.

In this study, several models are developed to test and analyze the stability of three main regional gas markets (U.S, Europe and Asia). The *classical* model is used for the case where gas prices are independent and identically distributed (*i. i. d case*). Alternative models, such as Yang model and the discrete-time random walk, are used, where the number of records grows faster than in the *i. i. d* case and where records are not only concentrated among the first observations.

In spite of the non-independent and non-identically distributed properties of the models, the results are distribution free. Consequently, the applicant will not be concerned by identifying the distribution type and the complexity of the models is reduced.

## 1. Introduction

The global natural gas market is comprised of regional markets that are often grouped based on the regions of natural gas trade (i.e., North America, Europe, and Asia). In recent years, roughly 70% of global natural gas trade has been transported to market destinations within the country of production, while the remaining have crossed international borders, either through long-distance pipelines or through liquefied natural gas [1]. The evolution of the global natural gas market is dependent on a number of factors: natural gas reserves, the production in conjunction with demand, and the ability to meet demand with supplies from other regions.

Three regional gas markets exist around the world, and each one is clustered by a regional spot market:

The US market – cleared by Henry Hub spot prices.
The European market – cleared by spot prices at European hubs.
The Asian market – cleared by spot LNG prices.

In Europe and the US's regional market, natural gas is mostly purchased through pipelines due to large domestic resources and strong grids. The lack of such infrastructures in North East Asia prevents the import of natural gas through pipelines. Therefore, natural gas could be only imported in the form of Liquefied Natural Gas (LNG), which is shipped on maritime tankers. The highest demand for natural gas in 2017 was in North America, a value that is closely followed by Europe, then Asia.[2]

Two basic pricing systems are commonly used for international trade of natural gas. The split in price formation varies deeply between regional markets, depending on several structural factors such as regulation, liberalization process, contracting practices, existence of a spot market, liquidity, and share of imports.

- Gas-on-gas pricing, where the price of natural gas is competitively determined based on gas market spot prices. As such, prices vary as a response to natural gas supply and demand.
- Oil-indexation pricing, where the price of natural gas is determined

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[2] LNG represents approximately 30% of international natural gas trade, and is used to meet both primary and peak natural gas demand. Japan and Korea, the two largest LNG importers jointly comprised around 50% of the global LNG market in 2015–2016.

https://doi.org/10.1016/j.esr.2018.05.003
Received 23 November 2017; Received in revised form 4 May 2018; Accepted 31 May 2018

based on oil market spot prices. As such, prices vary as a response to oil supply and demand.

North America has the most liberalized system, where gas pricing is highly competitive and is based on supply/demand balances (gas-on-gas pricing). On the other side, Asian and European gas prices are highly influenced by oil-indexation. In Northeast Asia, for example, almost all LNG contract volumes are indexed to crude benchmarks (e.g. JCC, Brent), because of their dependence on external imports [2]. However, as long-term contracts expire, the oil-indexation system is eroding.

It is almost challenging to get an accurate assessment of gas indexation levels and growth. Most of the supply contracts are structural long term portfolio contracts which are considered to be highly sensitive confidential information. Typically contract terms and conditions have evolved over time through the processes of renegotiation and price re-openers [3].

Facts have shown that natural gas, which is traded on the wholesale market, exhibits particularly large increases in price volatility. The rise of competition and deregulation leads to relatively free energy markets, which are characterized by high price shifts. Therefore, the market is, "vulnerable" to price spikes/drops. In response to an unpredictable, volatile and risky environment, protection against market risk has become a necessity.

Accordingly, it is important to model the gas price fluctuations and implement an effective tool for energy price risk management. Value at Risk ($VaR$) has become a popular risk measure in the financial industry. Since $VaR$ estimations are only related to the tails of a probability distribution, techniques from Extreme Value Theory (EVT) may prove particularly effective.

The study of extremes focuses on outliers, a characteristic which enables a better prediction of unexpected extreme changes [4]. The inherent stylized facts exhibited by commodity markets make the direct use of EVT impossible. For this reason, most of the applications in commodity markets involve a conditional approach two steps introduced [5], and is known as the GARCHEVT approach.

The first step captures the stochastic volatility of the time series. The second step consists of applying EVT to the pseudo-independent and identically distributed ($i.\,i.\,d$) innovations obtained in the first step [6–9].

Another line of research includes other stylized facts, such as long-term memory, change of regimen in volatility and asymmetric effects [10]. For instance [11], analyze the regimen changes on volatilities for crude oil markets (Brent and WTI) and stock markets of UK, France and Japan and find two possible volatility regimens [12]. also consider volatility models including long-range memory for estimating risk measures for some major crude oil and gas commodities. The research showed that, models with long-range memory and asymmetry perform best in one-day-ahead forecasting [13]. explores the relevance of asymmetry and long-term memory to model. A forecast of the conditional volatility was applied in four widely traded commodities (crude oil, natural gas, gold, and silver). The findings show that nonlinear GARCH models, capturing these stylized facts perform better in terms of volatility forecasting.

Finally, the study of extremes can also find the pair wise dependence (co-movement) between different markets that can vary from almost independent to strongly dependent in contrast to previous literature [14,15].

The application of records theory to study extreme events instead of the classical EVT generates many advantages. First, almost all the results of the EVT are asymptotic, non-exact, and depend on the choice of the underlying distribution. While in many of the record theory findings, results are exact and non-asymptotic [16,17].

In addition, several properties of record models are distribution free, i.e. (independent of the choice of the underlying distribution. This helps practitioners to overcome the theoretical complexity, which is hidden behind the choice of the right distribution.

Second, the EVT approach is generally applied in a context where the observations are independent and identically distributed ($i.\,i.\,d$), which is not always a good hypothesis to be considered. Moreover, going beyond the $i.\,i.\,d$ case in EVT makes the work even more complicated. However, record models beyond $i.\,i.\,d$ context are easily manipulated. Worthy to note, several properties retain their distribution-free nature, which is a big advantage in practical problems.

Finally, in EVT all the results concentrate on the value of the extreme events. This is done by studying the standardized maxima of the observations, without taking into consideration the time these extreme events took place. However, records theory focuses on the values and times of extreme events, a feature making the analysis of the potential results richer. The study of time in record models is accounted for through particular random variables called Record Indicators [18].

Classical econometric models, usually focusing on the whole distribution, have been widely used in literature. Models such as univariate and multivariate GARCH are the most popular methods used for analyzing high-frequency time series data. Authors such as [19–21] have used this classical approach to model natural gas/oil volatility.

As widely agreed in the literature, inferences that do not take into consideration the regime switching phenomenon may lead to unreliable results for much high-frequency time series. In the case of oil and gas markets, sudden short period shocks will not be accounted for.[3] Authors such as [22] and [23], have shown that evidence of regime-switching shall not be ignored in the behavior of natural gas prices, and that the regime switching model performs noticeably better than non-switching models in these cases.

To find evidence of causality between supply and demand variables that affects the natural gas prices, stochastic models such as, multivariate vector autoregressive (VAR) and vector error correction (VECM) models were used by Refs. [25] and [26]. Others, such as [27], study the relationship between international gas market prices and their relation to the oil price through principal components analysis and Johansen likelihood-based co-integration procedure.

In contrast to VAR and VECM models, that assume a stable relationship, the relationship between the variables could be different in the separate regimes. Therefore, authors such as [24] have used the Markov-switching vector autoregressive (MS-VAR) models.

However, all the classical models cited above contain a large number of parameters, a fact that poses estimation challenges, and over-parameterization concerns [28,29]. Such difficulties do not concern the records theory, which does not impose constraints on the quality and distribution of residuals. This certainly alleviates the use of multiple statistical tests that make the classical econometric approaches defined on hypothesis quasi-impossible to be entirely verified.

Non-parametric and non-linear models are also used in literature. The machine learning is essential and can be used to model the complex non-linear relationship between different variables because they are "constraint-free". Therefore, there is no need for additional tests (i.e. normality test for residuals, autocorrelation, etc.). [30], uses machine learning techniques to forecast the movement of the day ahead natural gas spot prices. A second category, such as [31], use the neural network to predict the daily natural gas consumption needed by gas utilities. A third category, like [32], use Gamma test, a mathematically proven smooth test with a wide variety of applications that helps machine learning modelers choose the best input combination before calibrating and testing models, a characteristic that reduces the inputs selection uncertainty.

However, the records theory deals with extreme value of extreme values. As a consequence, the number of available observations is generally small [16]. Thus, the use machine learning models is not

[3] For example, a major event-causing shock will lead to an immediate increase in volatility in natural gas returns.