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# Modeling and forecasting extreme commodity prices: A Markov-Switching based extreme value model

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ABSTRACT

We propose a Markov-Switching Multifractal Peaks-Over-Threshold (MSM-POT) model to capture the dynamic behavior of the random occurrences of extreme events exceeding a high threshold in time series of returns. This approach allows introducing changes of regimes in the conditional mean function of the inter-exceedance times (i.e., the time between two consecutive extreme events) in order to admit the presence of short- and long-term memory patterns. Further, through its multifractal structure, the MSM-POT approach is able to capture the typical stylized facts of extreme events observed in financial time series, such as temporal clustering of the size of exceedances and temporal behavior of tail thickness.

We compare the performance of the MSM-POT model with competing self-exciting models and a GARCH-EVT approach in an in- and out-of-sample VaR forecasting exercise based on the extreme returns of six daily commodity futures prices (i.e. Brent and WTI crude oil, cocoa, cotton, copper, and gold). Empirical results suggest that the VaR estimates generated by the MSM-POT model for the returns analyzed produce the most accurate forecasts.



## 1. Introduction

In recent years, futures of commodity markets have experienced rapid growth with a diversified number of commodity-based businesses, which generally fall into three categories; soft (cocoa, coffee, wheat, etc.), metals (gold, copper, silver, etc.), and energy (oil, gas, electricity, coal, among others). At present, the extreme prices of various commodities whose forces are outside the control of the organization have presented a challenge in risk assessment to businesses. In order to mitigate these extreme events, companies have to develop an effective risk management of commodities through various strategies, and optimize profits by using the most appropriate methods to reduce such risks. The most common risk metric to quantify the risk exposure of a financial entity is the Value at Risk (VaR). Roughly speaking, VaR is defined as the maximum probable loss that a given portfolio can experience with a determined probability within a certain time horizon.

Most existing studies utilize conditional volatility models with a wide range of sophistication to compute this risk measure (Agnolucci, 2009, Aloui and Jammazi, 2009, Fan et al., 2008, Hung et al., 2008, Wei et al., 2010). Extreme value theory (EVT) has been used recently in commodity markets due to the growing need and interest in managing commodity price risk. However, the inherent stylized facts exhibited by commodity markets make the direct use of EVT with the data impossible. For this reason, most of the applications in commodity markets involve a conditional approach of two steps introduced by McNeil and Frey (2000), the so-called GARCH-EVT approach. The first step captures the stochastic volatility of the time series, while the second step consists of applying EVT to the pseudo-independent and identically distributed (iid) innovations obtained in the first step (Byström, 2004, Chen and Giles, 2014, Chiu et al., 2010, Fong Chan and Gray, 2006, Krehbiel and Adkins, 2005, Marimoutou et al., 2009).

Over the last years, a new approach in EVT based on point process theory has emerged for modeling extreme events in financial markets

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directly. This methodology allows accounting for the full range of stylized facts present at extreme levels directly (Chavez-Demoulin et al., 2005, Chavez-Demoulin and McGill, 2012, Herrera, 2013, Herrera and González, 2014). The main advantage of this line of research, in comparison with the conditional two-step EVT approach, is that unlike the latter approach, no stochastic volatility model need to be imposed onto the returns, hence direct estimation of the model is feasible. This methodology provides a new perspective on the behavior of extreme events since it considers only the intensity of the extreme events and the size of those occurring over a high threshold, conditional on the history of the process. This positive herding behavior captures the cluster behavior that is so common in financial markets. Hence these stochastic processes are called self-exciting marked point processes (SEMPP).

The article distinguishes itself from the literature in several ways. Our study extends the previous literature in EVT and commodity markets by presenting a self-exciting marked point process (SEMPP) model that is able to capture a wide range of stylized facts present in extreme returns, specifically clustering, temporal behavior of tail thickness, sudden changes of regimen, and short- and long-term memory behavior.

In this framework, the conditional mean function of the inter-exceedance times (i.e., the time between two consecutive extreme events) is the multiplicative product of a large but finite number of random components. We call this model the Markov-Switching Multifractal - Peaks Over Threshold model, the MSM-POT model for short. This model is inspired by the Markov-Switching Multifractal Duration (MSMD) model by Chen et al. (2013), although with some important differences. In particular, Chen et al. (2013) introduce the MSMD model as a mixture of exponentials to describe the conditional intensity of a point process, whereas our motivation lies in modeling the expected inter-exceedance times of extreme events as a Markov-switching process.

We compare the performance of the MSM-POT model with a GARCH-EVT approach and two competing SEMPP models, the Hawkes-POT and the Autoregressive Conditional Duration - POT (ACD-POT) models introduced by Chavez-Demoulin et al. (2005) and Herrera and Schipp (2013), respectively. We show the usefulness of the MSM-POT approach in six major futures markets representing the three main categories of commodities: Brent and WTI crude oil, cocoa and cotton, copper and gold. The sample period is January 2, 1990 to December 31, 2014. To the best of our knowledge, this new EVT approach is the first to capture different degrees of short- and long-term dependence and changes in regimen in inter-exceedance times for a set of commodity price returns during periods of stress.

From an empirical perspective the main results during the in-sample and out-of-sample periods are the following: (1) in terms of goodness of fit the MSM-POT is the best suited model in all cases, followed by the ACD-POT model; (2) the MSM-POT provides the best VaR estimates for all commodities at almost all confidence levels; (3) The MSM-POT, ACD-POT and GARCH-EVT models exhibit perfect unconditional coverage (i.e., number of times that actual returns exceed VaR estimates) in-sample in all the commodity markets; (4) in terms of independently distributed VaR exceptions, the metal markets show a slight preference for the MSM-POT model over the ACD-POT approach; in the oil markets none of the models outperforms any of the others; while in the soft market the MSM-POT exhibits the best results; (5) in the out-of-sample VaR forecast, all models are sufficiently accurate for one-year forecasting, however, the MSM-POT approach is the only one that does not violate any backtesting statistic for the daily horizon.

This article is organized as follows. In Section 2 previous literature on VaR estimation in commodity markets is discussed. In Section 3 the methodology used is detailed. In Section 4 the data description and its preliminary analysis are presented. Estimation results are then reported for the MSM-POT models, the GARCH-EVT approach and the other two SEMPP alternatives for comparison. In Section 6 the results for the VaR forecasting both in- and out-of-sample are described. And finally, concluding remarks are presented.

## 2. Literature review

Currently, there are three major areas of research related to VaR estimation in commodity markets. The first area concerns capturing the dynamic behavior of the volatility through the time during crisis periods, which is normally done by means of a stochastic volatility model (Cheng and Hung, 2011, Fan et al., 2008, Giot and Laurent, 2003, Hammoudeh et al., 2011, Hung et al., 2008). For instance, Giot and Laurent (2003) is one of the early studies on VaR estimation for long- and short-term trading positions. They utilize an APARCH model with Skew-t Student distribution for the innovations in a set of commodity markets; aluminum, copper, nickel, Brent crude oil and WTI. Their findings show that this class of model delivers excellent results since the rate of violations of the VaR is statistically equal to its expected values in most of the returns analyzed. In a more recent study, Hammoudeh et al. (2011) utilize different approaches to estimate the VaR in the price returns of gold, silver, platinum and palladium. Their findings indicate that, for the forecasting period, the GARCH with Student t- distribution for the innovations produces the most accurate VaR estimates for all four precious metals.

A second stream of research is modeling these crisis periods utilizing only the information provided by extreme observations in combination, in some cases, with stochastic volatility models (Byström, 2004, Chen and Giles, 2014, Chiu et al., 2010, Fong Chan and Gray, 2006, Hammoudeh et al., 2013, Krehbiel and Adkins, 2005, Marimoutou et al., 2009). Starting with energy markets, specifically oil markets, Krehbiel and Adkins (2005) estimate the VaR for the daily logarithmic returns of the NYMEX energy complex and conclude that this method is significantly more accurate for measuring risk exposure. Marimoutou et al. (2009) also calculate the VaR for long- and short-term trading positions in the oil market by utilizing both unconditional and conditional EVT models for the forecasting. They found out that the GARCH-EVT model and the Filtered Historical Simulation approach are the most powerful approaches. In electricity markets Byström (2004) employs this framework in NordPool hourly electricity returns. His main finding is that this approach produces a more accurate characterization of the tail distribution than a pure GARCH model. Similar conclusions are reported by Fong Chan and Gray (2006) for the electricity markets of Victoria, NordPool, Alberta, Hayward and PJM using an AR-EGARCH-EVT model. Surprisingly, to our knowledge, there are only two empirical studies addressing the estimation of risk measures in metal markets using this conditional EVT approach, Chen and Giles (2014) and Hammoudeh et al. (2013). The latter authors compare different approaches for estimating the VaR for four precious metals, oil, and the S&P 500 index, and calculate their daily capital requirements. In terms of statistical properties, one of the best performances is obtained by the conditional EVT.

The most recent literature in EVT includes modeling the dynamic behavior of these extreme events by means of a SEMPP model. The first study using this methodology is Chavez-Demoulin et al. (2005). These authors introduce the Hawkes-POT approach, in which the Poisson intensity that commonly characterizes the frequency of extreme events over a high threshold in the iid case, is replaced by a self-excited point process, the so-called Hawkes process (Hawkes, 1971). Herrera and Schipp (2013) subsequently introduce the ACD-POT model, in which the inter-exceedance times (times between extreme events) are used instead, as resource of self-enforcing for the estimation of the conditional intensity that