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Adaptive signal processing of asset price dynamics with predictability analysis

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Abstract

In this paper we illustrate the optimal filtering of log returns of commodity prices in which both the mean and volatility are modulated by a hidden Markov chain with finite state space. The optimal estimate of the Markov chain and the parameters of the price model are given in terms of discrete-time recursive filters. We provide an application on a set of high frequency gold price data for the period 1973–2006 and analyse the *h*-step ahead price predictions against the Diebold–Kilian metric. Within the modelling framework where the mean and volatility are switching regimes, our findings suggest that a two-state hidden Markov model is sufficient to describe the dynamics of the data and the gold price is predictable up to a certain extent in the short term but almost impossible to predict in the long term. The proposed model is also benchmarked with ARCH and GARCH models with respect to price predictability and forecasting errors.

Keywords: Hidden Markov model; Optimal parameter estimation; Regime-switching model; Gold price

1. Introduction

The prices of commodities are important determinants of economic fundamentals as well as significant indicators of economic growth and activity. Hence, the modelling and analysis of commodity price dynamics are a central concern to investors and in general to the financial and economic research community.

There are several approaches that were put forward to model prices in the commodity markets especially on precious metals such as gold. Recent developments in this area make use of (i) economic framework of supply and demand, (ii) neural networks, (iii) factor models and (iv) stochastic processes. Our aim is to widen this set of currently available commodity price models and parameter estimation techniques in the literature. In particular, we shall enrich models based on stochastic processes by introducing more flexibility in a simple way.

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This work will address the problem of estimating the optimal parameters of a commodity price model using a hidden Markov chain in discrete time that modulates the regime-switching dynamics of the price model parameters. Hidden Markov model (HMM) filtering methods are quite popular in electronics and electrical engineering, physics and statistics but are rather new in probing the finer structures of the commodity markets.

Four general categories of modelling approaches are mentioned above. An economic-oriented modelling of commodity price dynamics deals with the estimation of a model of price formation in which supply and demand shocks are speculative storage. See Deaton and Laroque [11], for example. Mirmirani [25] employs neural networks to investigate commodity price behaviour. A further related application of neural networks can be found in Armano et al. [2]. Other modelling approaches of gold prices include, amongst others, the factor models with parameter estimation via Kalman filtering of Schwartz [27] and Schwartz and Smith [28]. The use of stochastic processes to model spot prices of commodities can be found further in Brennan [7], and Amin et al. [1]. However, as noted in Dai and Singleton [10] these types of diffusion-based stochastic processes do not have the perfect ability to capture the 'quiet' and 'turbulent' moments of a market. Hamilton [20] addresses this deficiency by incorporating the switching of regimes.

Indeed, empirical evidence provides considerable support for regime-switching models. For instance, the study of Bansal and Zhou [3] reveals that standard models including affine specifications with up to three factors are rejected by the data using the efficient method of moments, and regime shifts are intimately related to business cycles. The investigation of Chu et al. [9] is another example, amongst others, that advocates the use of regime-switching models to describe returns and volatility dynamics in the stock market. More recently, there is also a noticeable acceptance of the regime-switching framework in other related fields such as option pricing (e.g., [6]), electricity pricing (e.g., [19]) and even initiation of tax reforms (e.g., [8]). These studies serve as motivation for imposing parameters in our model to shift amongst a number of states. In many implementations such as the approach of Bollen et al. [4], algorithms are designed to compute the likelihood function successively on the basis of a conditional distribution of observations. The HMM technique directly provides immediate recursive filters for estimates of model parameters without stipulating a priori the dynamics of the observation series other than to say that the observed process is governed by a Markov chain. In addition, in the context of commodity price modelling, recursive filtering, which gives rise to a self-calibrating model, is an innovation over models in the past that are heavily dependent on the static model fitting approach of maximum likelihood estimation.

In Elliott et al. [16] the HMM estimation procedures were applied to analyse the US bond market in which the interest rate process is assumed simply as a Markov chain in discrete time. Our application augments methodologies in financial modelling through our specification that both the mean and volatility of the log returns of the asset price process are governed by a finite state discrete-time Markov chain. In this paper, we shall demonstrate the change of probability measure techniques in estimating optimally the parameters of a commodity price model. This is carried out via the adaptive processing of signals received in the financial market. Whilst the approach used in this study is an adaptation of the HMM results from Elliott [13], we tailor the application to commodity pricing. The proposed algorithms developed here for filtering and parameter estimation may require more calculations than those obtained in Hamilton [21]. Nevertheless, with the availability of sophisticated computing technologies nowadays implementing the algorithms should be easy and straightforward.

In this paper, we contribute further to the approaches in commodity price modelling and we perform empirical investigations. Specifically, we first provide an introduction on how to apply the HMM filtering techniques in conjunction with a Markov-regime switching model capable of describing the dynamics of a large class of asset price processes in the market. Second, we examine the use of HMM in capturing the dynamics of high frequency gold data spanning the period of 1973–2006. Third, our exposition discusses an application of the results due to Diebold and Kilian [12] in an attempt to characterise the level of gold market predictability. This is in contrast to many studies which simply make a comparison between the series of predicted values and series of actual observations in the assessment of a model. Fourth, in terms of evaluating predictability of gold price data in our investigation, we benchmark our regime-switching model with ARCH/GARCH models to see the benefit derived from this proposed model; we also include forecasting errors to complete the comparison. Finally, the results of our empirical work involving gold price data validates certain similarities to those obtained by previous researchers who analysed other types of market.