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Ensemble forecasting of Value at Risk via Multi Resolution Analysis based methodology in metals markets

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ABSTRACT

Subject to shocks worldwide, the metals markets in the era of structural changes and globalization have seen a very competitive and volatile market environment. Proper risk measurement and management in the metals markets are of critical value to the investors belonging to different parts of the economy due to their unique role as important industry inputs to the manufacturing process. Although traditional risk management methodologies have worked in the past, we are now facing the challenge of rapidly changing market conditions. Markets now demand the methodologies that estimate more reliable and accurate VaRs. This paper proposes a Multi Resolution Analysis (MRA) based nonlinear ensemble methodology for Value at Risk Estimates (MRNEVaR). The MRA using wavelet analysis is introduced to analyze the dynamic risk evolution at a finer time scale domain and provide insights into different aspects of the underlying risk evolution. The nonlinear ensemble approach using the artificial neural network technique is introduced to determine the optimal ensemble weights and stabilize the forecasts. Performances of the proposed MRNEVaR and more traditional ARMA–GARCH VaR are evaluated and compared during empirical studies in three major metals markets using Kupiec backtesting and Diebold–Mariano test procedures. Experiment results confirm that VaR estimates produced by MRNEVaR provide superior forecasts that are significantly more reliable and accurate than traditional methods.

1. Introduction

As important production inputs, metals' prices and fluctuations therein have been of critical concern to both industries and academics worldwide. Measurement and management of risks arising from metals' price fluctuations are an integrated part of the decision making process – from mineral valuation to ore development process (Dooley & Lenihan, 2005). Recently, accelerating structural changes in metals industries have posed challenges to traditional risk management tools in terms of the need for higher accuracy and reliability (Figuerola-Ferretti & Gilbert, 2001).

Meanwhile, risk measurement is also particularly valuable for metals industries due to its unique features. On the one hand, the metals markets are relatively well developed so that both spot and future data at different frequencies are available. On the other hand, due to high inventory costs, metals are not frequently traded and are subject to influences from various business factors, including the relative rate of growth (changes) of supply and demand, competitions (competitors' pricing decisions), commodities substitutions, technology trends, international market conditions, etc. (McMillan & Speight, 2001). Thus, it is a more volatile environment that requires the protection of risk management techniques at higher reliability and accuracy.

This paper uses Value at Risk (VaR) theories to measure downside risks in metals markets. VaR is a statistical number describing the potential downside risk over a given holding period at a certain confidence level. Over the years, attempts have been made from different directions to estimate appropriate VaR numbers. They could be mainly classified into three categories, namely, parametric, semi parametric and non-parametric approaches (Dowd, 2005; Jorion, 2001). Unfortunately, current approaches offer insufficient explanatory power facing the transient risk prevalent and the heavy-tailed leptokurtic asset returns in the market while leaving little room for further performance improvement (Makridakis, 1989; Palm & Zellner, 1992).

Facing the demand for measuring and managing risk evolution of such high level of complexity at a more accurate and reliable scale, this paper moves away from traditional approaches by replacing the questionable homogeneous single time horizon assumptions with the Heterogeneous Market Hypothesis (HMH) (Dacorogna, Gençay, Muller, & Pictet, 2001; Levy & Levy, 1996). Following the HMH, this paper assumes that markets are

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heterogeneous in structure and attempts to introduce innovative tools to model them (Dacorogna et al., 2001). The heterogeneous market structure has been established as the stylized facts in recent years by numerous empirical researches investigating the fractal, extreme and heterogeneous market characteristics. E.g. the extreme value theory has been proposed to model the transient event risks and the leptokurtic market returns, showing positive performance in the energy market. Interestingly in the conditional forecasting case, the proposed GARCH–EVT algorithm is essentially a multi stage forecasting process combining the estimation of normal market risk level with the extreme risk level estimated from the residual assuming the extreme value distribution (Fan, Zhang, Tsai, & Wei, 2008; Marimoutou, Raggad, & Trabelsi, 2009). This could be viewed as a restrictive case where the heterogeneous market structure is recognized as the combination of normal and extreme Data Generating Processes (DGPs). Meanwhile, researchers also have begun to use Gaussian Mixture Models to analyze the heterogeneous market structure with the assumptions that markets consist of the underlying DGP conforming to the same Gaussian distributions with different parameters (Shahbaba, 2009). The investigation is usually carried out in the restrictive case of two distribution mixture models since the modeling and computational complexity increases significantly in the more general cases.

However, this paper takes a different modeling approach from previous approaches, to model the heterogeneous market structure with more flexibility and less assumption restriction. Recent researches investigating the fractal market characteristics also provide inspirations to the importance of investment time horizon as an important scale along which different underlying DGPs interact and evolve to form the joint heterogeneous market structure (Rachev, Weron, & Weron, 1999; Weron & Weron, 2000). This gives rise to the proposition of HMH. Two emerging techniques – the Multi Resolution Analysis (MRA) and the ensemble (i.e. forecast combination) algorithm are introduced to track the multi-scale time varying data characteristics. More specifically MRA using the wavelet analysis with different wavelet families to decompose the original metals markets price series at different scales. Advanced econometric and time series models are used to fit these decomposed data and make forecasts. The aggregated forecasts are reconstructed from sub forecasts at different scales based on the wavelet synthesis technique. Since these estimates are biased as influenced by different wavelet families employed, the final forecast is produced using ensemble approaches. I.e. intelligent techniques such as neural network are used to find the optimal weight to combine them.

The major contribution of this paper is the introduction of the MRA based methodology to analyze and model the multi scale market structure. This helps reveal the unobserved latent factors dominated by a simpler underlying DGP from the original data of mixture distribution, which could be better modeled with greater conformity with the particular models' assumptions. This approach is also consistent with the proposed Heterogeneous Market Hypothesis (HMH) of the metals markets. Meanwhile, we also make exploratory attempts to stabilize and optimize the forecasts by using nonlinear ensemble (NE) algorithm to determine the optimal weights to ensemble the individual forecasts based on different wavelet families (Van Der Voort, Dougherty, & Watson, 1996; Yu, Wang, & Lai, 2005).

Experiments based on weekly metals markets price series are conducted to compare the performance of the proposed Multi Resolution Nonlinear Ensemble approach and the more traditional ARMA–GARCH approaches to VaR estimates. The weekly data are obtained by a transformation of the original data at a daily frequency. The transformation is made necessary since the computation of daily VaR would require the intradaily data to compute the volatility measures including historical volatility and realized volatility, where intradaily data are usually contaminated with noises and are not publicly available at the time being. Performance evaluation is conducted by statistical test procedures including Kupiec backtesting procedures and Diebold–Mariano test of equal predictive accuracy. Experiment results show significant performance improvement over traditional ARMA–GARCH models with improved model reliability and prediction accuracy.

The outline of this paper develops as follows: the relevant theories for VaR estimations, wavelet analysis, MRA and ensemble algorithm are briefly reviewed in the second section. The third section proposes the theoretical framework and implementation procedures for MRNEVaR. Empirical studies in three metals markets are conducted in the fourth section. Performance of both MRNEVaR and ARMA–GARCH VaR are evaluated and compared. The fifth section concludes.

2. Relevant theories

2.1. Value at Risk (VaR)

Value at Risk (VaR) has now become the well accepted industry standard for risk measurement. Compared to the traditional risk measurement technique, it focuses on the measurement of downside risks that are more of concern to investors. VaR is a single summarizing statistical number that measures the magnitude of the maximum possible downside risk over a certain investment horizon with the given confidence level as in (1)

$$p(r_t \leqslant -r_{VaR}) = a_{cl} \quad (1)$$

where r_t denotes the return of the portfolio over the time period t. cl is the associated investment confidence level.

The estimation of the appropriate VaR number is of critical concern to its applicability since no explicit analytical form of risk evolution is given in the original definition. Over the years the development of VaR estimation methodology follows three different routes. These can be categorized as parametric, non-parametric and semi parametric approaches.

Non-parametric approach extends historical patterns directly into the future without any specific assumptions about data patterns. These include traditional techniques such as historical simulation, Monte Carlo simulation and artificial neural networks, as part of more recent developments. Both historical simulation and Monte Carlo simulation methods serve as the benchmark, as evidenced in many empirical works (Agnolucci, 2009; Cabedo & Moya, 2003; Cheong, 2009; Chiu, Chuang, & Lai, 2010; Costello, Asem, & Gardner, 2008; Fan et al., 2008; Giot & Laurent, 2003; He, Xie, Chen, & Lai, 2009; Hung, Lee, & Liu, 2008; Marimoutou et al., 2009; Sadeghi & Shavvalpour, 2006). There are also other non parametric models available including models based on neural network, genetic algorithm, etc. The 'let data speak for itself' principle accommodates unknown data characteristics and faithfully reincarnates them during the estimation process. However, the applicability of this approach is constrained by several limitations. Firstly the accuracy and reliability of non parametric approach rely heavily on the exact match between the price behavior in the future and in the past. Secondly, the performance of this approach is also sensitive to the data window and the sample size chosen, i.e., to make effective estimates, a large number of samples are required while a sufficient length of the data window is needed to cover relevant data patterns. Thirdly, the non-parametric approach also offers little insights into the underlying risk evolution, which makes effective risk control and management difficult (Dowd, 2005).

Parametric approaches fit analytical models into data and derive estimates with strong assumptions imposed. Typical