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Hidden Markov model analysis of extreme behaviors of foreign exchange rates

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HIGHLIGHTS

- We employ two econometric tools for the specific purposes: (1) to determine the bootstrap goodness of fit test for the Generalized Pareto distribution (GPD) of the tail behaviors proposed by Villaseñor-Alva and González-Estrada (2009); and (2) to identify, estimate, and test the hidden Markov model (HMM).
- The testing outcomes mostly reject the GPD assumption for this study. HMM estimation outcomes provide the detailed pictures.
- They evidence the multiple structural breaks in the returns and the gaps between the qualified extremes. The respective properties of the exchange markets are revealed in the comparisons of the estimation outcomes in terms of transition matrix, response parameter, and bivariate analysis.

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ABSTRACT

We examine the extreme behaviors at both the lower 5% and 1% quantile levels of the three exchange rates series (Japanese yen, Korean won, and New Taiwan dollar) against the US dollar between 2002 and 2017. We employ two econometric tools for specific purposes: (1) to determine the bootstrap goodness of fit test for the Generalized Pareto distribution (GPD) of the tail behaviors proposed by Villaseñor-Alva and González-Estrada (2009); and (2) to identify, estimate, and test the hidden Markov model (HMM). The testing outcomes mostly reject the GPD assumption for this study. HMM estimation outcomes provide the detailed pictures. They evidence the multiple structural breaks in the returns and the gaps between the qualified extremes. The respective properties of the exchange markets are revealed in the comparisons of the estimation outcomes in terms of transition matrix, response parameter, and bivariate analysis. In general, Japanese yen is evaluated as a resilient safe haven currency. Korean won exhibits longer distress duration. New Taiwan dollar occurs with heavier losses with longer gaps.

1. Introduction

Foreign exchange rate series are noticed for their excessive volatility and clusters of extremes [1], although these markets are subject to intervention or even possible manipulation. In addition to market pressures, national monetary and fiscal policies can also introduce abrupt changes. Exchange rate series are usually far from being stationary time series with stable parameters [2]. The extreme behavior of foreign exchange rate series has essential implications in theory, practice, and policy. For example, exchange rate risk management is an integral part in every firm's decisions about foreign currency exposure [3]. Their turbulent market behaviors make them one of the appropriate candidates to investigate the techniques

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of financial risk management. This issue is increasingly urgent, especially after a series of critical market moments at the local and global scales. This issue has imperative significance regarding international portfolio management, financial risk management, and the health condition of the foreign exchange rate system.

Previous studies mostly employ extreme value theory (EVT) or time series models. Most time series models deal with stationary data and capture the general trend, and accordingly limit their application to market turbulent behaviors. In spite of the volumes of application literature mostly based on GARCH family models, Andersen and Bollerslev [4] point out that volatility is not directly observable. A simple observation of a random variable with a known mean value is not an accurate estimate of its variance. It motivates us to consider the hidden states behind the observations in this study. Several articles attempt to discuss the issue of hidden states. For example, Hall and Yao [5] argue that ARCH and GARCH models can be modified to model the time series with heavy-tailed error. However, it takes a special designed bootstrap to approximate the error distribution, and their study has not received much academic attention. While some papers attempt to extend to nonstationary models [6,7], Feigin and Resnick [8] caution the pitfall of fitting the autoregressive models for heavy-tailed time series. While the ordinary time series models are designed to capture the general trend of the whole series, in comparison, the EVT remains as a more popular tool to capture exclusively the extreme behavior or tail behavior of the return distribution. The EVT is extensively applied in various fields [9], underpinning the study of the asymptotic distribution of extreme or rare events. However, while focusing on estimation and plot, those previous studies do not empirically test whether EVT is an appropriate assumption or not for tail fitting. Lin and Kao [10] and Zeileis, Shah and Patnaik [11] highlight that there are multiple structural changes in the tail behavior which violate the fundamental EVT assumption of identically and independently distributed extremes. We expect this issue to become more critical as we move to the more extreme quantile levels, which represent the major market critical moments.

Stoyanov, Rachev, Boryana and Frank [12] alert that we need to test families of fat-tailed distributions to confirm their modeling performance of the real data. Rocco [13] presents a critical survey and summarizes the limitation and shortcoming of EVT. EVT is based on the assumption that the distributions of extreme values of an independent and identically distributed sample from a common cumulative density function (CDF), as Fisher and Tippett [14] and Gnedenko [15] demonstrate. However, we are not certain about the exact shape of the CDF, even though EVT principally outperforms parametric assumption, nonparametric, or semiparametric methods. Furthermore, those techniques are based on the asymptotic theory of exceedance distribution over a threshold. Pickands [16] assumes that maximum likelihood or moment exists, but these assumptions are not necessarily supported by empirical data. The conditional versions of EVT, both univariate and multivariate, cannot avoid those fallacies and pitfalls of the original version [17]. Several studies confirm that significant structural breaks exist in the tail curve and invalidate EVT for tail fitting, because EVT assumes smooth decaying tail curves. Those empirical studies do not support EVT assumptions, such as those by Dierckx and Teugels [18], Zeileis, Shah and Patnaik [11], and Liu [19]. Additionally, those structural breaks represent regime shifts and impact the effectiveness of time series models, which mostly rely on the stationarity of series. We thus must consider the structural break for modeling extreme behaviors. While these critical findings are set aside, the estimation outcomes bias our decision validity or discredit policy recommendation. It is advisable to acknowledge the limitations of EVT and resort to a more appropriate alternative.

We concur with the assertion by Knight [20] that uncertainty in the extremes refers to the uncontrollable and unpredictable properties of the unknown and time-varying distribution. The author admits that those uncertainties often cannot be told, even with certainty from ideal observations. Among the possible alternatives, the regime switching model is a powerful tool to capture the stylized properties of foreign exchange series, such as fat tails and time-varying correlations [21–23]. However, regime-switching models, EVT, and GARCH models can depict the extreme behavior based on the aggregate terms such as variance–covariance or correlation. These models implicitly assume that all the information among the extremes are observable and arbitrarily ignore the possible latent information. The bottom line is that these aggregate measures cannot provide a detailed description of the extremes such as the regimes and transition among them. Those models are not developed to capture those properties which are accordingly hidden in the traditional model framework. Alternatively, the hidden Markov model (HMM) is a hidden regime-switching model and reasonably captures structural breaks. In essence, HMM is a doubly stochastic process — an underlying process that is not observable, but the results of which can be observed [24]. This model includes the hidden states and modulates the model parameters to incorporate regime-switching dynamics. Essentially, HMM is designed to recover a data sequence that is not immediately observable, but other data that depend on the sequence are. The process of the extremes matches these properties. Some articles employ HMM for the prediction oil price [25], studying term structure of interest rate [26], exploring bond credit risk [27], or analyzing the hidden information of credit quality [28]. However, those previous studies discuss the general direction of the series, not the extreme tail behavior. HMM has not been applied in studying the extreme behaviors of foreign exchange market whose hidden information are reflected in their significant structural change and correlation, to the best of our knowledge.

Furthermore, we also need to point out that this study aims to present a detailed description of the tail behavior of the return distribution. Meanwhile, Salhi, Deaconu, Lejay, Champagnat and Navet [29] employ HMM with EVT for Value-at-Risk estimation. Their study acknowledges the contribution of HMM but it focuses on a hybrid method to estimate the cut-off point at a specific quantile level of the lower tail, which targets on a different perspective from that of this study.

We adopt two measures to prevent the possible pitfalls or shortcomings of blunt applications of EVT and ordinary time series models in this study. We first test if EVT is an appropriate tool. Subsequently, we acknowledge and tackle the uncertainty existing in the tail. We employ HMM for empirical analysis with minimum assumption. With regard to the former, Villaseñor-Alva and González-Estrada [30] propose a goodness of fit test for the Generalized Pareto distribution