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A censored stochastic volatility approach to the estimation of price limit moves

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ABSTRACT

A censored stochastic volatility model is developed to reconstruct a return series censored by price limits, one popular form of market stabilization mechanisms. When price limits are reached, the observed prices are truncated and the equilibrium prices are unobservable, which makes further financial analyses difficult. The model offers theoretically sound estimates of censored returns and is demonstrated via simulations to outperform existing approaches with respect to the estimates of model parameters, unconditional means, and standard deviations. The algorithm is applied to model stock and futures returns and results are consistent with the simulation outcomes.

1. Introduction

One of the major challenges faced by all empirical price limit researchers is the appropriate handling of price limit moves. In essence, none of the empirical studies that examine financial data subject to price limits are immune from this challenging task. When price limits are hit, the observed prices are truncated and the equilibrium prices are unobservable, which makes it difficult to calculate true returns and volatilities for further financial analyses.[3] Existing studies do not provide a generally accepted solution. We contribute to the literature by developing a censored stochastic volatility (CSV) model to capture important features of a return series censored by price limits.

Price limits are imposed in many financial markets to prevent excessive price fluctuation.[4] Although price limit rules vary from country to country and market to market, broadly speaking, they may be defined as boundaries set by market regulators to restrict daily security price changes. Because prices are constrained, well-established financial analytical methods and models, such as a mean-variance analysis or GARCH (generalized autoregressive conditional heteroscedasticity) modeling, may create biased results. In their comprehensive literature review, Kim and Yang (2004) conclude that it is necessary for future studies to develop models that might overcome potential biases in the statistical inference that are due to the constrained return-generating process.

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[2] Both authors thank participants at the 2004 Joint Statistical Meetings for their valuable comments on an earlier version of the paper. The helpful suggestions from two anonymous referees and the editor Franz Palm are greatly acknowledged. The usual disclaimer applies.
[3] The term “equilibrium price” refers to a price that is cleared by the market. When price limits are reached, the observed prices are not equilibrium prices because the market is not cleared due to likely order imbalance.
[4] For example, the U.S. futures markets and many stock exchanges around the world—including China, Japan, Korea, Malaysia, Taiwan, and Thailand in Asia and Austria, Belgium, France, Greece, Italy, the Netherlands, Spain, and Switzerland in Europe—currently adopt price limits.

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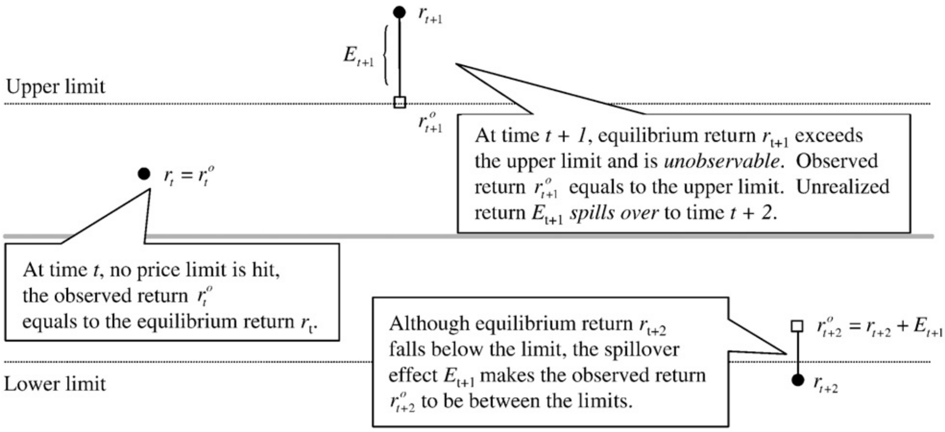

Fig. 1. Unobservability of price-limited data and the spillover effect.

Price-limited data share similar characteristics—such as heteroscedasticity and volatility clustering—with regular asset return data, but differ in two important ways. First, equilibrium prices are unobservable when price limits are hit, and observable prices are truncated at the limit. Second, when price limits are hit, the return beyond price limits must be reflected on the next trading day; thus, the unrealized return spills over to the following day, creating the spillover effect.[5] Fig. 1 provides a simple illustration of these two distinct features. At time t, the observed return r^o_t equals the equilibrium return r_t because it is within the price limit boundary.[6] At the next time period $t+1$, the equilibrium return r_{t+1} exceeds the upper price limit, but due to the price limit mechanism, we can only observe r^o_{t+1}. Because of the price limit constraint, the amount of the unrealized return E_{t+1} spills over to time $t+2$. Hence, though the equilibrium return r_{t+2} at time $t+2$ falls below the lower limit, the observed return r^o_{t+2} lies between the limits if the spillover portion E_{t+1} is included.

Our CSV model accounts for the unobservability and spillover effect associated with price limits.[7] Although several models have been developed to recognize the unobservable feature of price-limited data, to our knowledge, only Wei's (2002) censored-GARCH model has incorporated the spillover effect. However, as Wei (2002) acknowledges, the disadvantage of the censored-GARCH model is the long running time of its procedure, which makes it impractical to design a Monte Carlo simulation to verify its claimed performance. We are able to run simulations to show the superior performance of our CSV model because of the simple conditional likelihood function of its parameters and the resulting efficient algorithm for parameter estimation. We use a theoretically sound imputation method to generate fill-ins for censored observations and thereby create an imputed return series that is appropriate for subsequent financial analyses, such as option pricing or asset allocations. As suggested by Jacquier et al. (1994) and Andersen et al. (1999), we use the Markov chain Monte Carlo (MCMC) technique for efficient parameter estimation. Because our model addresses the spillover effect explicitly, a complete return series can be imputed even if price limits are reached on consecutive days, a situation that occurs in practice but cannot be handled appropriately by existing models.

The stochastic volatility (SV) models have recently gained popularity in modeling financial asset returns. Durham (2007) shows that SV models do a good job capturing the dynamic of volatility and the shape of the conditional distribution of financial asset returns. Nardari and Scruggs (2007) also utilize the SV process to capture the time-varying covariance matrix of returns in evaluating empirical implications of asset pricing theory. Our CSV model provides a realistic and flexible modeling of financial time series data in that it involves two noise processes and allows error terms to be correlated. Given the increasing adoption of SV models in empirical financial studies, our CSV model provides researchers an appropriate and efficient approach to handle price-limited data.

We compare our model with several existing approaches through a Monte Carlo simulation. The results suggest that our model outperforms other approaches with respect to the estimation of model parameters, the unconditional means, and the standard deviations. When the price limits are set at ±7%, our CSV model recovers censored returns and gives an estimate of standard deviation with less than 1% error. However, the standard deviation is underestimated by 5% when observed prices are used to calculate returns and by 14% when limited prices are deleted from the sample. The consequences of such underestimation can be substantial. First, an underestimation of volatility generally translates into the underpricing of an option, which can be costly to option traders. Second, the underestimation of risk affects asset allocation decisions by portfolio managers and capital budgeting decisions by corporate managers. In addition, results from empirical studies that use the underestimated standard deviation are likely to be biased.

We demonstrate the usefulness of our algorithm by modeling the returns of two actively traded stocks on the Taiwan Stock Exchange (TSE) and two U.S. futures contracts on the Chicago Board of Trade (CBOT) during volatile periods when price limit moves are more likely to occur. To examine the robustness of our results, we compare the performance of our CSV approach with that of

[5] Using an information-based argument, George and Hwang (1995) suggest that information is not fully reflected on the limit-hit day, and therefore, the remaining information must be reflected on the following day.

[6] The "equilibrium return" can be viewed as the true return when price limits were not present.

[7] Our model does not include the possible "magnet effect" proposed by Subrahmanyam (1994). Please see Berkman and Steenbeek (1998) and Cho et al. (2003) for models related to the magnet effect.