Interfaces with Other Disciplines

Time-varying quantile association regression model with applications to financial contagion and VaR

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This paper develops a quantile association regression model, which is able to capture the dynamic quantile dependence in the tails of conditional distributions. The association measure, the quantile-specific odds ratio (qor), captures the tendency of two random variables being simultaneously below specific quantiles. It is independent of marginal distributions and invariant to monotonic transformation, and enjoys methodological advantages over popular alternatives such as the copula. The ability of the qor measure to capture and forecast a range of different dependence structures is first shown via simulations. In the financial application, we implement the model and compute the qor on a daily basis to assess contagion for 10 stock markets during two recent crises. Our empirical results show that contagion exists during the US banking crisis between the US and all tested markets and between Greece and the tested European markets during the Euro crisis. Hence the model is able to capture the changes in quantile dependence between stock markets and offer a vivid description of market events. In addition, the model provides an accurate valuation of daily value-at-risk (VaR).

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1. Introduction

Financial contagion, the transmission of shocks to other markets and a significant increase in the cross-market dependence beyond fundamental level, has attracted great interest among academics, policy makers, and practitioners due to its profound implications for the real economy, risk management, and asset valuation.

In the literature, a large and growing number of models and different frameworks have been proposed and applied in the investigation of the dependence or the change in dependence between economic variables during crises. Earlier efforts measure historical correlation between stock return series (see, for example, Bertero and Mayer, 1990 and King & Wadhwani, 1990). However, they do not consider heteroscedasticity in the return dynamics (Forbes & Rigobon, 2002), nor do they take into account of the asymmetric effect between positive and negative returns. The dynamic nature of the stock return processes is later captured and modeled in the dynamic conditional correlation (DCC) model of Engle (2002), and widely applied in studying financial contagion or multivariate dependence (see, for example, Cho and Parhizgari, 2008; Syllinakis and Kouretas, 2011, and Celik, 2012).

Other methodological advances include the co-integration analysis (Bekaert, Harvey, and Ng, 2005 and Ostermark, 2001), the vector autoregression model (Yang & Bessler, 2008), the multivariate Extreme Value Theory (EVT) (Longin and Solnik, 2001 and Poon, Rockinger, & Tawn (2004)), the superquantile regression (Rockafellar, Roiyset, & Miranda, 2014), the co-exceedance method (Baur and Schulze, 2005; Christiansen and Randal, 2009, and Chevapatrakul & Tee, 2014), and the wavelet analysis (Capobianco, 2001 and Rua & Nunes, 2009).

In this paper, we make two contributions to the literature. The first contribution is that methodologically we develop a quantile association regression framework to evaluate bivariate quantile-specific association in a dynamic setting. We make use of the odds ratio, a versatile and robust statistic that provides useful information on the strength of relationship between variables (Ekholm, 2003 and McHugh, 2009). In specific, we extend a copula-based quantile-specific conditional association regression model proposed in Li, Cheng, and Fine (2014). The model centers around the quantile-specific odds ratio (qor) which computes the ratio that two random variables are simultaneously below their respective quantile. When applied to financial time series data, the qor can be used to measure the tendency that returns to two stock market indices are simultaneously below a threshold thus quantifying dependence between time series of stock returns in an accurate manner.

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A number of methodological advantages of this quantile association measure make it stand out. First and foremost, the quantile association measure, the qor, is shown to have a monotonic relationship with copula functions (Li et al., 2014). Put differently, it is similar to the conditional copula but more descriptive of the local associational strength and the underlying trend, because the qor at any specific quantile level is simply an odds ratio for quantifying the association between variables. Hence formulating the qor rather than copula functions renders a more convenient approach to modeling local association with more straightforward interpretations. In addition, this association measure is free from location and scale thus providing a clearer view of the local association structure when two variables have different locations or scales.

Second, compared with the global copula model assumptions and the two stage estimation procedure, the specified quantile association regression model imposes weaker restrictions on the association structure. For example, contrary to copula approach which needs to determine the structure of dependence, the quantile-based association method does not need to assume any type of structure. Instead, it estimates quantile association across all quantiles. Thus another advantage of the association measure is that dependence structures need not be determined ad hoc: they can be symmetric or asymmetric, linear or nonlinear. This allows a more flexible description of the underlying association at all quantile levels. We demonstrate the flexibility of this measure via an simulation exercise.

Third, there is a close relation between quantiles of a distribution and the value-at-risk (VaR) metric, as the VaR is nothing more than a certain quantile on the left tail of an asset or portfolio return distribution. In the empirical application, the day-to-day fluctuation of the VaR can be computed easily and precisely as part of the estimation procedure. We perform simulation exercises to illustrate the ability of the qor to capture and forecast different dependence structures. We generate 1000 observations by setting parameter values for four parametric copula functions with different underlying dynamics and estimate the time-varying qor from them. The mean square errors (MSE) and the mean absolute percentage errors (MAPE) indicate small differences between the exact and estimated qor values. Furthermore, we use the first 800 observations as the in-sample and make 1-day, 3-day, and 5-day forecasts in a rolling window manner. The low MAPE between the exact and forecast values suggest forecast precision.

Our second contribution comes from the financial applications of the model. Using daily data of major stock indices in the US, China, Japan, Korea, Hong Kong, the UK, France, Germany, Australia, and Greece over a long sample period from 2006 to mid-2014, our model application results show that the dependence between the US and tested markets changes during the recent financial and banking crisis, and that the dependence between Greece and the US, China, and three European neighbors UK, Germany and France also undergoes significant change during the European debt crisis. These are vividly reflected in the time-varying qor diagrams as we focus on the dependence at the 10 percent quantile on the left tail between the source country, the US for the banking crisis and Greece for the Eurozone crisis, respectively, and the rest of the tested markets. We observe a huge peak in the qor measure during the banking crisis and it is especially significant between the US and Japan, Korea, Hong Kong, and Australia, for whom the US is a major trading partner. We also observe a second and less dramatic peak in the qor due to the Eurozone crisis. These findings are consistent with market events unfolded during the crisis and robust when we examine dependence level at different quantiles.

The rest of the paper is organized as follows. Section 2 introduces the quantile association regression model and its estimation procedure, and discusses its relation with a number of popular alternative methods in the literature. In Section 3, we perform simulations to illustrate the ability of the qor measure in describing and forecasting different dependence structures. Section 4 outlines the data. In Section 5, we apply the model to data and analyze empirical results. Finally, Section 6 concludes.

2. Methodology

This section introduces the quantile association regression model and describes a polynomial-based estimation procedure for implementing the model. It also discusses the relation of the quantile association regression model with a few popular alternative methods in the literature.

2.1. The quantile association regression model

It is often important to study the association between two continuous variables. We adopt a quantile copula framework for modeling the quantile-specific conditional association proposed by Li et al. (2014), which allows us to consider the covariate effect at a continuum of quantiles. Let \((Y_1, Y_2)\) be a pair of real-valued continuous variables and \(Z = (1, Z_1, Z_2, \ldots, Z_p)^T\) be a \((p + 1)\)-dimensional covariate vector. We assume that \(\{Y_{1i}, Y_{2i}\}_{i=1}^{N}\) are \(N\) samples of \((Y_1, Y_2)\) and \(\{Z_{i}\}_{i=1}^{N}\) are \(N\) samples of the vector \(Z\).

Our objective is to evaluate the conditional association in the joint distribution of the two variables, \((Y_1, Y_2|Z)\), conditional upon the value of \(Z\). Some components of the vector \(Z\) influence both the marginal models and the underlying association, while others only affect the marginal model(s) or the association model. For simplicity, we let \(Z_1, Z_2\) and \(Z_3\) denote three subvectors of \(Z\) that may overlap and all include 1 as the first element, and assume that \(Z_1, Z_2,\) and \(Z_3\) influence the quantiles of \(Y_1\), the quantiles of \(Y_2\), and the underlying association between \(Y_1\) and \(Y_2\), respectively. Assume also that \(\{Z_{1i}\}_{i=1}^{N}, \{Z_{2i}\}_{i=1}^{N}\) and \(\{Z_{3i}\}_{i=1}^{N}\) are \(N\) samples of vectors \(Z_1, Z_2,\) and \(Z_3\), respectively.

The quantile association measure is defined as the following quantile-specific odds ratio (qor) at pre-specified quantiles \(\tau \equiv (\tau_1, \tau_2)^T\):
\[
qor(\tau | Z) = \frac{\text{odds}|Y_1 \leq Q_{\tau_1}(Z) | Y_2 \leq Q_{\tau_2}(Z) | Z |}{\text{odds}|Y_1 \leq Q_{\tau_1}(Z) | Y_2 > Q_{\tau_2}(Z) | Z |} = \frac{Pr(Y_1 \leq Q_{\tau_1}(Z), Y_2 \leq Q_{\tau_2}(Z) | Z)}{Pr(Y_1 \leq Q_{\tau_1}(Z), Y_2 > Q_{\tau_2}(Z) | Z)} = \frac{Pr(Y_1 > Q_{\tau_1}(Z), Y_2 \geq Q_{\tau_2}(Z) | Z)}{Pr(Y_1 > Q_{\tau_1}(Z), Y_2 > Q_{\tau_2}(Z) | Z)}
\]

(1)

where \(Q_{\tau_j}(u|Z) = \inf\{y : \Pr(Y_j \leq y|Z) \geq u\}, u \in (0, 1)\), is the marginal quantiles of \(Y_j\) conditionally upon \(Z\), \(j = 1, 2\). The qor compares the odds that the first outcome is below its quantile \(Q_{\tau_1}(Z)\) given that the second outcome is below its quantile \(Q_{\tau_2}(Z)\) to the odds given that the second outcome is on the opposite side of \(Q_{\tau_2}(Z)\). An interesting special case is when \(\tau_1 = \tau_2 = u\), thus the qor describes the tendency of \((Y_1, Y_2)\) to be concordantly below their respective ut quantile.1 As discussed previously, one major advantage of the quantile-specific odds ratio thus defined is that it completely removes the effect of location and scale of the bivariate outcomes.

For the marginal quantile function \(Q_j(u|Z) = \inf\{y : \Pr(Y_j \leq y|Z) \geq u\}, u \in (0, 1)\), we assume that:
\[
Q_j(u|Z) = m_j(Z)\beta_j(u), \quad u \in (0, 1),
\]

(2)

where \((p_j + 1) \times 1\) regression coefficients \(\beta_j(u)\) are functions of \(u\), and the link functions

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1 In this special case, the qor can be linked to the upper and lower tail dependence of copula functions. The proof is available upon request from the authors.
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