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Dependence structure and extreme comovements in international equity and bond markets

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ABSTRACT

Common negative extreme variations in returns are prevalent in international equity markets. This has been widely documented with statistical tools such as exceedance correlation, extreme value theory, and Gaussian bivariate GARCH or regime-switching models. We point to limits of these tools to characterize extreme dependence and propose an alternative regime-switching copula model that includes one normal regime in which dependence is symmetric and a second regime characterized by asymmetric dependence. We apply this model to international equity and bond markets, to allow for inter-market movements. Empirically, we find that dependence between international assets of the same type is strong in both regimes, especially in the asymmetric one, but weak between equities and bonds, even in the same country.

1. Introduction

There is ample evidence that negative returns are more dependent than positive returns in international equity markets. This phenomenon known as asymmetric dependence has been reported by many previous studies including Erb et al. (1994), Longin and Solnik (2001), Ang and Bekaert (2002), Ang and Chen (2002), Das and Uppal (2004), Patton (2004), and references therein. This asymmetric dependence has important implications for portfolio allocation, but to appreciate its full actual effects on portfolio diversification, stocks and bonds have to be considered together, both at the domestic and international levels to allow for inter-market movements.[1] Models of extreme dependence in international stock and bond markets are mainly missing in the literature. This is due mainly to the fact that measuring and modeling asymmetric dependence remains a challenge.

Previous studies relied on the concept of exceedance correlation, correlation computed for returns above or below a certain threshold, to investigate the dependence structure between financial returns.[2] Boyer et al. (1999) and Forbes and Rigobon (2002) remark that correlations estimated conditionally on high or low returns or volatility suffer from some conditioning bias. Correlation asymmetry may therefore appear spuriously if these biases are not accounted for. To avoid these problems, Longin and Solnik (2001) use extreme value theory (EVT) by focusing on the asymptotic value of exceedance correlation.[3] The benefit of EVT resides in the fact that the asymptotic result holds regardless of the distribution of returns. By the same token, as emphasized by Longin and Solnik (2001), EVT

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[1] Patton (2004) finds that the knowledge of asymmetric dependence leads to gains that are economically significant, while Ang and Bekaert (2002), in a regime switching setup, argue that the costs of ignoring the difference between regimes of high and low dependence are small, but increase with the possibility to invest in a risk-free asset.

[2] The exceedance correlation between two series of returns is defined as the correlation for a subsample in which the returns of both series are simultaneously lower (or greater) than the corresponding thresholds θ_1 and θ_2. Formally, exceedance correlation of variables X and Y at thresholds θ_1 and θ_2 is expressed by $Ex\_corr(Y,X;\ \theta_1,\theta_2) = \begin{cases} corr(X,Y|X \leqslant \theta_1,\ Y \leqslant \theta_2), \text{ for } \theta_1 \leqslant 0 \text{ and } \theta_2 \leqslant 0 \\ corr(X,Y|X \geqslant \theta_1,\ Y \geqslant \theta_2), \text{ for } \theta_1 \geqslant 0 \text{ and } \theta_2 \geqslant 0 \end{cases}$. Longin and Solnik (2001) use $\theta_1 = \theta_2 = \theta$, while Ang and Chen (2002) use $\theta_1 = (1+\theta)\overline{X}$ and $\theta_2 = (1+\theta)\overline{Y}$, where $\overline{X}$ and $\overline{Y}$ are the means of Y and X respectively.

[3] Extreme value theory (EVT) is used to characterize the distribution of a variable conditionally to the fact that its values are beyond a certain threshold, and the asymptotic distribution is obtained when this threshold tends to infinity. Hartmann et al. (2004) also use extreme-value analysis to capture the dependence structure between stock and bond returns for pairs of the G5 countries.

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cannot help to determine if a given return-generating process is able to reproduce the extreme asymmetric exceedance correlation observed in the data.

To overcome this shortcoming, we propose a model based on copulas that allows for tail dependence in lower returns and keeps tail independence for upper returns as suggested by the findings of Longin and Solnik (2001). Copulas are functions that build multivariate distribution functions from their unidimensional marginal distributions.[4] The tail dependence coefficient can be seen as the probability of the worst event occurring in one market given that the worst event occurs in another market. Contrary to exceedance correlation, the estimation of the tail dependence coefficient is not subject to the problem of choosing an appropriate threshold and the use of extreme value distributions such as the Pareto distribution. Another difference is that tail dependence is completely defined by the dependence structure and is not affected by variations in marginal distributions.

The disentangling between marginal distributions and dependence helps overcoming the curse of dimensionality associated with the estimation of models with several variables. For example, in multivariate GARCH models, the estimation becomes intractable when the number of series being modeled is high. The CCC of Bollerslev (1990), the DCC of Engle (2002), and the RSDC of Pelletier (2006) deal with this problem by separating the variance–covariance matrix in two parts, one part for the univariate variances of the different marginal distributions, another part for the correlation coefficients. This separation allows them to estimate the model in two steps, first the marginal parameters on each individual series then the correlation parameters. Copulas offer a tool to generalize this separation while extending the linear concept of correlation to nonlinear dependence.

Thanks to the tail dependence formulation of asymptotic dependence, we show analytically that the multivariate GARCH or regime switching (RS) models with Gaussian innovations that have been used to address asymmetric dependence issues (see Ang and Bekaert, 2002; Ang and Chen, 2002) cannot in fact reproduce extreme asymmetric dependence. The key point is that these classes of models can be seen as mixtures of symmetric distributions and cannot produce asymptotically asymmetric dependence. The asymmetry produced by these models at finite distance disappears asymptotically. When we go far in the tails, we obtain a similar dependence for the upper and lower tails. Moreover, the asymmetry in RS models comes from the asymmetry created in the marginal distributions with regime switching in the mean. Hence it is not separable from the marginal asymmetry or skewness.[5] This is a fundamental issue that also affects the statistical extreme-value analysis that have been conducted to study extreme dependence.

We use our regime-switching copula model to investigate the dependence structure between international equity and bond markets. The model allows for a switching between a normal state where markets will be linearly and symmetrically correlated and an asymmetric dependence state to capture common crashes. In a normal regime it is difficult to make a difference between the level of dependence for joint positive moves and joint negative moves. When the economy is in the asymmetric regime, even with a stable correlation, a downside move in one market will increase the probability of a similar event in another market. The rise in the level of dependence during market downturns is characterized by asymmetry in the dependence structure. This regime can be interpreted as contagion since bad news spread quickly between markets. This crash dependence can coexist with low correlation and implies a reduction of an apparent diversification benefit.

We separately analyze dependence between the two leading markets in North-America (US and Canada) and two major markets of the Euro zone (France and Germany). Our empirical analysis shows that dependence between international assets of the same type is strong in both the symmetric and the asymmetric regimes, while dependence between equities and bonds is low even in the same country. Another finding is that the presence of a regime with extreme asymmetric dependence makes the correlation in the normal regime differ from the unconditional correlation. We also provide some evidence that exchange rate volatility seems to contribute to asymmetric dependence. With the introduction of a fixed exchange rate the dependence between France and Germany becomes less asymmetric and more normal than before. High exchange rate volatility is associated with a high level of asymmetry. These results are consistent with those of Cappiello et al. (2006) who find an increase in correlation after the introduction of the Euro currency.[6]

The rest of this paper is organized as follows. Section 2 reformulates the empirical facts about exceedance correlation in terms of tail dependence and shows how classical GARCH or regime-switching models fail to capture these facts. In Section 3 we develop a model with two regimes that clearly disentangles dependence from marginal distributional features and allows asymmetry in extreme dependence. As a result, we obtain a model with four variables that features asymmetry and a flexible dependence structure. Empirical evidence on the dependence structure is examined in Section 4, while conclusions are drawn in Section 5.

2. Extreme asymmetric dependence and modeling issues

In this section we present empirical facts about exceedance correlation in international equity market returns put forward by Longin and Solnik (2001) and the related literature. We next argue that these facts can be equivalently reformulated in terms of tail dependence. The latter formulation will allow us to explain why classical return-generating processes such as GARCH and regime-switching models based on a multivariate normal distribution fail to reproduce these empirical facts.

2.1. Empirical facts

Longin and Solnik (2001) investigate the structure of correlation between various equity markets in extreme situations by testing the equality of exceedance correlations, one obtained under a joint normality assumption and the other one computed using EVT. For the latter distribution, they model the marginal distributions of equity index returns with a generalized Pareto distribution (GPD) and capture dependence through a logistic function. Ang and Chen (2002) develop a test statistic based on the difference between exceedance correlations computed from the data and those obtained from GARCH or RS models.[7]

[4] The theory of this useful tool dates back to Sklar (1959) and a clear presentation can be found in Nelsen (1999). Well designed to analyze nonlinear dependence, copulas were initially used by statisticians for nonparametric estimation and measure of dependence of random variables (see Genest and Rivest, 1993 and references therein).

[5] Ang and Chen (2002) conclude that even if regime-switching models perform best in explaining the amount of correlation asymmetry reflected in the data, these models still leave a significant amount of correlation asymmetry in the data unexplained.

[6] Some related research focus on the dependence structure of bond and equity in European markets (see Kim et al., 2006; Cappiello et al., 2006; Abad et al., 2010). Panchenko and Wu (2009) investigate stock and bond return time-varying comovement in emerging markets, while Markwat et al. (2009) and Kumar and Okimoto (2011) analyze international integration in a global perspective.

[7] They define a test statistic $H = \left[\sum_{i=1}^{N} \frac{1}{N}(\rho(\vartheta_i) - \hat{\rho}(\vartheta_i))^2\right]^{1/2}$ which is the distance between exceedance correlations obtained from the normal distribution $(\rho(\vartheta_1), \ldots, \rho(\vartheta_N))$ and exceedance correlations estimated from the data $(\hat{\rho}(\vartheta_1), \ldots, \hat{\rho}(\vartheta_N))$ for a set of N selected thresholds $\{\vartheta_1, \ldots, \vartheta_N\}$. In the same way they define H^- and H^+ by considering negative points for H^- and nonnegative points for H^+ such that $H^2 = (H^-)^2 + (H^+)^2$. They can therefore conclude to asymmetry if H^- differs from H^+.