Journal of Banking and Finance 70 (2016) 1–22

Contents lists available at ScienceDirect

Journal of Banking and Finance

journal homepage: www.elsevier.com/locate/jbf

Extreme risk modeling: An EVT–pair-copulas approach for financial stress tests

Lyes Koliai*

Paris-Dauphine University (LEDa-SDFi), Place du Maréchal de Lattre de Tassigny, 75016 Paris, France

ARTICLE INFO

Article history:
Received 15 October 2014
Accepted 15 February 2016
Available online 8 March 2016

JEL classification:
C5
G11
G17

Keywords:
Financial time series
EVT
Pair-copulas
R-vine
Stress testing
Scenario

ABSTRACT

This paper presents a semi-parametric copula-GARCH risk model for financial return series with a stress testing perspective. The marginal distributions of the returns are specified using the Extreme Value Theory (EVT), putting a specific emphasis on extreme returns. The joint distribution is then built up using the pair-copulas theorem, based on the marginal distributions and the pair dependence structures. The model performance is assessed for three sets of assets, namely equity indices, exchange rates, and commodity prices. The empirical results support a better static and dynamic properties of the presented model compared to most common specifications used in practice. The proposed model and the alternative specifications are then carried out to perform stress testing exercises on hypothetical portfolios, where financial returns are considered as risk factors. The results show that the use of a wide range of risk models produce significantly different results, in terms of the corresponding stress scenario and in the corresponding impact on the portfolios. Hence, considering flexible and consistent specifications, as in the proposed model, allows ensuring a better credibility of the stress scenario and enhances the usefulness of the stress testing results.

1. Introduction

Until quite recently, predicting the impact of extreme events on financial portfolios and the design of related management actions have been led through a set of conventional tools, such as the Value at Risk (VaR). These tools are often based on simple hypotheses whose consistency has been seriously questioned after a recurrence of extreme events with losses exceeding all expectations. These failures are mainly due to the incoherence of some tools as risk measures and/or the unsuitability of some of their underlying hypotheses especially during turmoil periods (Alexander and Sheedy, 2008; Haldane, 2009). Such hypotheses concern the *risk model* assumed to assess the dynamics of risk factors and the *pricing model* used to assess their impact on the portfolio. In a stress test, which exactly focuses on the impact of extreme events on the portfolio, the relevance of both models is vital. The related specifications should then be chosen with caution.

This paper analyzes the relevance of the existing risk models for stress testing purposes to which we include a new specification that places a special emphasis on extreme events.[1] A risk model is made up of assumptions designed to define the statistical properties of the risk factors facing a variable of interest. For a financial portfolio, risk factors are usually given by the returns, the volatilities, and the dependence structure of the underlying financial assets. Technically speaking, the model specifies the marginal and the joint distribution functions of the risk factors. It is then fitted to some data and carried out to simulate a set of *scenarios* among which those supposed as *severe yet plausible* are used for stress testing purposes. Hence, the stress test results are strongly influenced by the prior choice of the risk model. The misleading results of stress tests conducted before and after the last financial crisis are often due to a misspecification of these models.[2] The considered scenarios have then turned to be harmless as

* Tel.: +33 613 322 416.
E-mail address: lyes.koliai@dauphine.fr

http://dx.doi.org/10.1016/j.jbankfin.2016.02.004

[1] The analysis of the risk model is of particular importance for both portfolio (or micro-) and systemic-based stress tests. The pricing model instead is more studied for the second category. It includes broad hypotheses related to endogenous phenomena such as risk transmission channels to the financial system, the impact of private and public response functions, contagion, second-round effects, feedback effects on the real economy, etc.

[2] Alongside with the use of incomplete pricing models and the unsuitability of the considered scenarios (Borio and Drehmann, 2009; Haldane, 2009; Breuer and Csiszár, 2013).

unexpected variations in risk factors and portfolio losses have been recorded.

Since the seminal works of Mandelbrot (1963a,b), the literature highlighted a set of stylized facts shared by most financial return series. For example, it is shown that the empirical distributions of financial returns are left-skewed and leptokurtic. The return series also exhibit serial dependences (weak autocorrelation, strong heteroscedasticity, volatility clusters) with asymmetry and leverage effects of past returns on present volatilities. In the multivariate case, extreme returns present strong, nonlinear, and dynamic dependences, especially for bear markets. To capture these stylized facts, various models have been proposed. However, due to practical issues (data, expertise, and time requirements, communication issues, etc.), only simple model specifications have been considered. The latter often lack of flexibility and omit one or more of the stylized facts, which explains the gaps between the expected and the observed losses.

The recurrent and increasing losses generated by these errors have motivated a crucial need for more reliable modeling frameworks. Recent advances in quantitative methods, such as econometrics and software programming, have favoured this kind of initiatives. In this paper, we propose a sequential risk model for financial return series that captures the individual and the joint stylized facts. We put a specific emphasis on extreme returns of most interest in stress tests. More specifically, we first specify the marginal distributions of returns within a semi-parametric approach, with an extreme value distribution in the tails and an empirical distribution in the interior. The joint distribution of the multivariate system is captured by an R-vine model based on the pair-copulas theorem associating the marginal distributions and bi-variate copulas. The model is evaluated with respect to common univariate and multivariate specifications used in practice. It is then carried out to perform univariate and multivariate stress tests in a dynamic framework.

The rest of the paper is presented as follows. Section 2 introduces financial stress tests and highlights the desired properties in the underlying risk model. Section 3 reviews the main approaches used in the literature to model financial returns. Section 4 presents the two stages of the sequential model. The data used for estimation, evaluation, and stress testing are presented in Section 5. Section 6 presents the estimation results for the marginal model, evaluates its performance with respect to alternative common specifications, and compares their properties in a stress testing exercise. The next section adopts a similar sequence for the multivariate model. Section 8 summarizes and concludes.

2. Financial stress tests

Financial portfolio stress tests consist in estimating the likely impact of *harmful yet plausible* events – or scenario – on a financial portfolio.[3] The scenario can be seen to as a possible realization of risk factors drawn by simulating the underlying risk model. The latter specifies the marginal and the joint distribution functions of the risk factors. For a financial portfolio, a scenario may then consist of variations in the returns, the volatilities or the correlations of financial assets. The impact of the scenario is assessed over a given horizon using an adapted pricing model. Financial stress tests have been designed to complement the conventional risk management framework mainly centered on the VaR. Compared to other pure statistical tools, they allow personifying all the events that make the scenario. By doing so, the portfolio exposures are explicitly identified and each potential outcome is associated to the generating scenario; hence guiding decision-making. Moreover, the scenario and the pricing model can be augmented to account for more realistic features, such as second-round and feedback effects, private investment strategies, public response functions, etc.

As for the VaR, stress tests need a risk model to draw the scenarios. Since, in most cases, stress scenarios consist of extreme variations of risk factors, the related risk model should also present strong in-sample and out-of-sample properties in the tails of the underlying marginal and joint distributions. This is a quantitative criterion required for all stress testing risk models. However, given the involvement of different parties in the exercise, this condition may be insufficient and the choice of the model trickier. Indeed, stakeholders' viewpoints are often influenced by internal and external considerations. Čihák (2007) and Haldane, 2009, among others, show that risk managers in a financial institution are generally pessimistic and often tend to overestimate the risks facing the different portfolios. They thus confer more plausibility to the most severe scenarios. That is, considering fat-tailed distributions. On the other hand, Management and the Board of Directors are more optimistic and deem implausible that kind of specifications. Any use in a stress test would therefore be unnecessary. The risk manager should then convince Management of the accuracy of the considered assumptions. This task is often critical because of the subjective character of certain assumptions and the practical implications resulting from the choice of the most severe scenarios. Having given his approval, Management shall be liable to take the necessary actions in response to the test results. Depending on the severity of the scenario, these actions may present significant opportunity costs for the institution, which may result in a negative impact on its profits. In such cases, only scenarios of moderate severity will be admitted. This aspect is one of the main criticisms levelled by researchers and market players against most tests carried out before and during the 2007–09 crisis (Haldane, 2009; Borio and Drehmann, 2009).

To deal with such an issue, the flexibility of the risk model is therefore of most importance in stress tests. Limiting subjective considerations in the underlying hypotheses eases the adoption of more relevant risk models. This also prevents from external criticisms which may put in question the credibility of the scenario and the utility of the results. A good trade-off between the performance of the model and its flexibility is therefore vital in a stress test risk model. This deeply influences our choice of the model specification we shall present in this paper.

The existing literature on financial stress tests can be split into four main topics. First papers, going back to the early 2000s, have been dedicated to a general presentation of the related conceptual aspects of stress tests at the time considered as a relatively new tool in financial risk management (Berkowitz, 2000; Blaschke et al., 2001; Čihák, 2007). A second body of the literature has focused on model-based scenarios for portfolio stress tests (Kupiec, 1998; Breuer and Krenn, 1999; Bee, 2001; Kim and Finger, 2000; Aragonés et al., 2001; Breuer et al., 2002; Alexander and Sheedy, 2008; McNeil and Smith, 2012; Breuer and Csiszár, 2013). Later on, due to the widespread repercussions of the 2007–2009 financial crisis, researches have been more concerned about systemic stress tests (Boss, 2008; Alessandri et al., 2009; Aikman et al., 2009; van den End, 2010; van den End, 2012; Engle et al., 2014; Acharya et al., 2014). A final wave of papers have made a first diagnostic of the realized exercises since the 2007–2009 financial crisis, by outlining their main limits and the remaining challenges

[3] To be considered as harmful a scenario should be designed to capture the most adverse events for the portfolio. The severity is often linked to the range of variations applied to the risk factors. The plausibility indicates the confidence level associated with the scenario. To be considered as such, the scenario should consist of likely variations in risk factors. When explicitly set, the plausibility is usually assessed by the probability of these variations. The analysis of the trade-off severity-plausibility and the selection of stress scenarios is beyond the scope of this paper. We refer the interested reader the works of Breuer et al. (2002), McNeil and Smith (2012) and Breuer and Csiszár (2013).