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Multivariate dependence risk and portfolio optimization: An application to mining stock portfolios

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A B S T R A C T

This study proposes an integrated framework to model and estimate relatively large dependence matrices using pair vine copulas and minimum risk optimal portfolios with respect to five risk measures within the context of the global financial crisis. We apply this methodology to two 20-asset mining (gold and iron ore-nickel) sector portfolios from the Australian Securities Exchange. The pair vine copulas prove to be powerful tools for the modeling of changing dependence risk under three different period scenarios combined with the optimization of portfolios that have complex patterns of dependence. The portfolio optimization results converge, on average, in some stocks.

1. Introduction

The recent global financial crisis (GFC) had contributed to global dependence shifts and portfolio losses, mainly due to changes in joint dynamics and network-dependence relationships, and the large increases in volatility spillovers between international financial markets (Brunnermeier, 2009; Moshirian, 2011; Florackis et al., 2014). Doubtlessly, the severe financial fluctuations, which resulted from this global crisis, have put into question the reliability and the estimation abilities of the *status quo* mathematical and statistical models used in dependence estimation and portfolio optimization. This in turn has led to the quest for finding techniques that more accurately approximate the underlying interactions of the variables and better optimize portfolios, while considering important risk factors other than the traditional ones.

The copula approach in the form of bivariate copula and pair vine copula models (e.g., c-vine, d-vine and r-vine) has recently been proposed to more accurately estimate the dependence matrix of financial variables (e.g., Chollete et al., 2009; Aloui et al., 2011; Low et al., 2013).[2] It overcomes the restrictive and deterministic features of the bilateral correlation coefficient approach, traditionally used in portfolio optimization algorithms, due to its suitability to capture the distributional characteristics of asset returns such as volatility clustering, fat tails, tail dependence and asymmetric correlation.[3] In the context of multivariate dependence modeling, the pair vine copulas, which are built on the theory of graphical models, provide greater flexibility than the bivariate copulas because they allow for dissections and decompositions, while capturing, in a more localized and specialized manner, the distributional characteristics of different forms (see,

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[2] C-vine, d-vine and r-vine refer to the canonical, the drawable and the regular vine copulas. These copula models have been found to outperform alternative models in terms of dependence structure estimation (e.g., Low et al., 2013).

[3] Asymmetric correlations between financial markets in bear and bull periods have been documented by, among others, Erb et al. (1994), Ang and Bekaert (2002), and Patton (2004). They refer to the fact that negative returns are more correlated than positive returns, suggesting that financial markets tend to be more dependent in crisis times characterized for low or no confidence in the financial markets. Aloui et al. (2011) find evidence of asymmetric dependence of stock returns between the BRIC and U.S. markets.

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e.g., Aas et al., 2009; Czado et al., 2012,2013).

This article deals with dependence structure estimation and optimal asset allocation with respect to the variance, the mean absolute deviation (*MAD*), the minimizing regret (*Minimax*), the conditional Value-at-Risk (*CVaR*) and the conditional Drawdown-at-Risk (*CDaR*) measures. The returns of the assets in the portfolios are random variables generated under various market conditions. We first contribute to the related literature by adopting a flexible pair vine copula approach to model the dependence risk and the risk features of Australian gold and iron ore-nickel stock portfolios. This task is carried out within the context of three financial period scenarios: the pre-GFC, the GFC and the post-GFC periods. The first distinction of this specific type of methodology and analysis is that it allows one to find out the market conditions under which one sector portfolio may be more volatile and risky than the other. Besides, it enables one to identify the type of vine copula model which better accounts for dependence in the tails.

Our second contribution stems from the integration of the pair vine copula and portfolio optimization models. This combined modeling approach is applied to investigate the portfolio allocation characteristics of the gold and iron ore-nickel stock portfolios under consideration. In practice, we introduce into the portfolio optimization models the pair vine copula estimates of the dependence structure which captures the linear and nonlinear dependence relationships between the gold stocks as well as between the iron ore-nickel stocks. We expect the use of pair vine copulas in portfolio optimization to provide an estimation edge over the rest of the models.

Our third contribution arises from the multi-angled portfolio optimization approach implemented. We specifically propose an alternative avenue to address the problem of investment confidence that the mining portfolio investors face when a variety of optimal weight allocations is presented to them for selection.[4] The proposed approach handles the multiple weight allocation investment possibilities in terms of "average model convergence". This means that while we are still interested in finding the best risk measure to be used for the optimization of portfolios, we particularly focus on identifying the stocks to which most of the alternative optimization models converge without a large deviation from a mean of weights. While this approach represents a shift of perspective in the analysis, evaluation and interpretation of multiple optimal weight allocations, it is also thought to be an effective way to deal with the problem of investment confidence.

Empirically, we illustrate the relevance of our analytical approach for dependence modeling and dependence shift detection by considering two mining portfolios (gold versus iron ore – nickel) of 20 stocks, which trade on the Australian Securities Exchange (ASX).[5] We select these two mining portfolios because they include highly important mineral commodities which are extracted, processed, and traded in and exported from Australia. During the 2008–2009 global financial crisis, for instance, the production and export of gold had contributed to softening the effect of the financial crisis on the Australian economy. On the other hand, the 2015 sharp decline in prices of iron ore has proven, in terms of the harsh domestic budgetary adjustments that took place, how important the iron-ore production and exports are to the Australian economy. In this context, the identification of stocks for investment and the stock portfolios' risk profile is important to portfolio managers, investors and policymakers since the obtained results could be used to manage the resource allocation risk, market downturn risk and market sector risk. Another important reason for selecting those mining portfolios is that they are different in terms of structure, volatility, uses and their importance in asset investment than other sectors, which enables one to test and analyze the behavior of different components in our integrated modeling framework (i.e., vine copulas, risk measures and portfolio optimization).[6] The gold stock sector, for instance, does not have a dominant company that has exceptionally high correlations with the rest of the stocks in the portfolio. Instead, there are a handful of companies having relatively high correlations with each other but none of them is dominant. This is not the case for the iron ore – nickel stock portfolio, which has BHP BILLITON (BHPX) as the dominant stock in the sense that it has high correlation values with the rest of the stocks in this portfolio. Through the modeling of the dependence structure of the portfolios, we are also able to address the question of whether the Australian gold stocks can serve as a hedge and safe haven during financial crisis periods.

With respect to the literature that uses copulas in portfolio optimization, our research is broadly linked to the contributions of Kakouris and Rustem (2014), Low et al. (2013) and Brechmann and Czado (2013) and Ye et al. (2012). The latter provided a measurement methodology for the subprime crisis contagion based on copula change point analysis, whilst Kakouris, Rustem (2014) employ a mixture of copulas to derive *CVaR* and the worse-case *CVaR* used for the optimization of a convex portfolio of stock indices. Low et al. (2013) make use of the bivariate Clayton and the Clayton canonical vine copulas to address the asset allocation for loss-averse investors through the minimization of *CVaR* in portfolios of up to 12 constituents. Brechmann and Czado (2013) develop a regular vine copula-based factor model which is applied to the asset returns of the Euro Stoxx 50 index constituents in order to investigate the Value-at-Risk forecasting and asset allocation. Compared to these studies, we use both the c-vine, d-vine and r-vine copulas to draw information about the dependence risk and the low and high risk features of the gold and iron ore-nickel stocks in specific market conditions. Our study also is differentiated from those studies by deliberately searching for average model convergence in the weight allocations resulting from the fit of various different portfolio optimization models with respect to multiple risk measures.

Other applications of vine copulas, which relate to our study in terms of dependence modeling, have explored the dynamic dependence behavior between financial markets (e.g., Chollete et al., 2009; Min and Czado, 2010; Mendes et al., 2010; Czado et al.,

[4] Investment confidence is the issue underlying any type of portfolio optimization approach. The abandonment of the single risk measure-based portfolio optimization is partially driven by the inability of that approach to adequately address the problem of investment confidence. Although the optimization of portfolios with respect to multiple risk measures to some extent successfully addresses the problem by providing more information and investment choices, which could cater to a wider variety of investors, it does not offer a generalized and quantitatively objective approach for the selection of stocks. Instead it adopts a relativistic and subjective perspective for the selection of stocks. On the contrary, the "average model convergence" approach proposed for the analysis, evaluation and interpretation of the multiple weight allocation scenarios does provide the investment confidence investors require by finding the models' points (i.e. stocks in our case) of convergence.

[5] As of December 2012, the mining stocks (including coal and uranium stocks in this category) which are listed on the ASX accounted for approximately 39% of the total market capitalization of the total market, with the gold and the iron-ore nickel sectors playing an important role in the functioning and development of the Australian economy. While the pair vine copula approach can handle a larger portfolio, we only illustrate its use by a 20-stock portfolio as the higher number of stocks will make the estimation of the dependence matrix truly complex, particularly due to the consideration of almost all existing bivariate copula families.

[6] Our empirical approach could be extended to modeling the mining sectors in other countries, including those from African countries such as South Africa which is a major producer of gold, platinum, diamond and coal. The mining sector in South Africa makes up about 60% of the country's exports where eight of the 10 largest individual export categories are commodities.