Analysis of International Trade, Exchange Rate and Crude Oil Price on Economic Development of Yunnan Province: A GARCH-Vine Copula Model Approach

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Abstract : In this paper, we attempted to use the GARCH-vine copula model to analyze the dependence structure of international trade, exchange rate, and crude oil price on the economic development of Yunnan Province. In the C-vine, the df of the student-t copula model is significant on C_{14} and $C_{25|1}$, and there is the least degree of freedom in C_{14}, which means that there is a greater probability of extreme values in industrial added value and export. In the Clayton copula, we find a strong significance with fminunc in C_{13} and $C_{45|123}$. With fminunc in C_{13}, the Clayton copula can catch left tail dependence. This means that a decrease in the crude oil spot price is inclined to retard Yunnan's industrial added value growth. In the D-vine, we find that the df of the student-t copula model varies considerably and significantly in C_{23} and C_{34}, respectively. Finally, in the Clayton copula, we conclude that there exists a strong significance with fminunc in C_{45} (export-import) and $C_{13|2}$.

Keywords : exchange rate; industrial added value; crude oil; GARCH-Vine copula model

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1   Introduction

In the present age, international trade and exchange rate risk management is an issue of utmost importance for the economic development of Yunnan Province. Alongside this issue, the uncertainty arising from crude oil price volatility may also contribute to reducing the value of international trade and raising the risks faced by both importers and exporters.

From 2001 to 2012, the industrial added value (IAV) of the Yunnan Province development was rapid: the IAV rose from \$6.70 billion to \$53.6 billion and the international trade for the development of Yunnan rose from approximately \$1.989 billion to approximately \$12.1 billion (source: National Bureau of Statistics of China and Department of Commerce of Yunnan Province). From the mid 1960s onward, there existed a widely held belief in the role of the government via its trade policies in fostering the economic growth of the country. In a country where there are economies of scale, both the scale of its production and the variety of goods that a country can produce are constrained by the size of the market. By trading with each other and therefore forming an integrated world market that is bigger than any individual national market, nations can successfully loosen these constraints (Paul R. Krugman, 2006). Moreover, it is worthy of mention here that most Asian countries developed in this manner –forming a group that the World Bank now refers to as the high performance Asian economies (HPAEs)[2]. With Yunnan Province being a part of an ASEAN country which has neighboring ASEAN countries, the trade superiority in comparison is obvious. The ASEAN Free Trade Area will go a long way in enhancing Yunnan's market size.

On July 21, 2005, China began to implement the market supply and demand as the foundation of the floating exchange rate system. In the floating exchange rate system, the exchange rate changes with the foreign exchange market supply and demand. In international economics, exchange rate is a key determinant when it comes to international trade, and the popular theory regarding the correlation between trade balance and exchange rate is the elasticity approach. The body of elasticity approach literature has reference to the *J*-curve, which points out that devaluation may initially cause worsening effects on the trade balance in the short run, but that there will be an increase in trade balance in the long

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[2]For an extremely useful survey of the growth of the HPAEs, see World Bank, *The East Asian Miracle: Economic Growth and Public Policy* (Oxford: Oxford University Press, 1993).

run. The exchange rate undergoing frequent fluctuation and uncertainty has a tremendous influence on the Yunnan Province's international trade enterprise cash flow, balance sheet, and daily management.

Crude oil is a non-renewable natural resource, and fluctuations in its price have extraordinary ramifications for the transportation costs in international trade; also, crude oil is the most traded commodity in the world. Transportation costs do not change the fundamental principles of comparative advantage of the gains from trade. Because transportation hassles pose obstacles to the movement of goods and services, problems faced in transportation have important implications on the way a trading world economy is affected by a variety of factors such as foreign aid, international investment, and balance of payment problems. It is costly to transport goods and services - so much so that in some cases, the cost of transportation is enough to lead countries into self-sufficiency in creation sectors[3].

Trade plays a pivotal role in economic growth while oil has been consolidating its status as the most traded commodity in the world. Fluctuations in oil prices, coupled with uncertainty about the future path of the oil price, are causing consumers or firms to postpone irreversible purchases and investments in petroleum products.

Due to the economic backwardness of Yunnan Province, the ability to avoid exchange rate risk and the fluctuations in oil prices is markedly incompatible with other developed provinces. China's exchange rate reform and the continued appreciation of the RMB, coupled with the uncertainty arising from the oil price volatility, will pose many problems for the international trade enterprise of Yunnan Province.

The logarithms of import, export, exchange rate data, and oil prices almost have certain limits in increasing and continuous transformations. Linear correlation analysis method is the commonly used correlation analysis method, but this kind of method can only analyze the linear situation of the correlated variables. A linear correlation of the corresponding elliptical distribution and its coefficient can only describe the linear correlation degree between the variables and the symmetrical correlation model. It cannot achieve accurate results when addressing non-linear correlations.

The contribution of this paper is threefold. First, in this paper, we attempt to use the GARCH-vine copula model to analyze the dependence structure of international trade, exchange rate, and crude oil price on the economic development of Yunnan Province. The higher dimensions are challenging to dynamic and static copulas. Copula vines provide greater flexibility compared to the traditional dy-

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[3]*International Economics: Theory and Policy* (seventh edition) by Paul R. Krugman and Maurice Obstfeld (2006)

namic and static copulas because some of the restrictions of the dynamic and static copulas do not apply and restrict in the case of the copula vines. Second, in the C-vine copula, we find that there is a strongly significant correlation on C_{13} in the Clayton copula. Unlike what was concluded in most of the studies conducted, as is given in the existing literature, as an oil importing country, an increase in world oil price should have increased the production costs of China or Yunnan Province. The Clayton copula can catch left tail dependence; therefore, a decrease in the crude oil spot price is inclined to retard Yunnan's industrial added value growth. Lastly, in the D-vine copula, we conclude the existence of a strong significance with fminunc in C_{45} (export-import) in the Clayton copula. This is the reason for the significant relationship between export and import. Lower demands for raw material and services import tend to retard the growth of production and export.

The structure of the remainder of this paper is as follows. Section 2 gives a description of the GARCH-vine copula model. Section 3 discusses the main features of date and empirical result. The last section summarizes the results.

In recent times, there have been many studies conducted about international trade. K.S Ding and Y.Y Pang (2010) notes in his study that the Yunnan and Guangxi provinces within the region should increase cooperation and interaction.

Bianling Ou (2012) observes that Chinese interest rates and interbank offered rates have been raised after the crude oil price shock. Tu Niansong and Li Deyan (2010) found out that the trade value between Yunnan and ASEAN is inversely proportional to the distance between them. The trade between Yunnan and other countries of ASEAN is relatively small. Xiaoqian Wen (2012), using the WTI oil spot price, analyzed whether a contagion effect existed between energy and stock markets during the recent financial crisis and found that the contagion effect is found to be much weaker for China than for the United States by using the time-varying copulas. Shiu-Sheng Chen (2012) found out that oil price volatility hurts international trade flows. Thai-Ha Le (2012) found out the existence of relationships between overall trade balances and oil price shocks, like the relationship between oil price shocks and trade components that keeps varying considerably from year to year.

The first literature review to be presented about the copula model was Sklar's (1959) theorem (Longin & Solnik, 2001; Poon et al., 2004), which proposed that between two markets in the asymmetric co-movements, multivariate normality assumption is not suitable for measuring the dependence structure of equity returns. Chih-Chiang Wu (2011) used time-varying copula GARCH models to evaluate the dependence structure between the oil price and the U.S. dollar exchange rate. Juan C. Reboredo (2012) found that there is no extreme market dependence between exchange rates and oil prices. Riadh Aloui (2012) analyzed the dependence

structure between crude oil prices and U.S. dollar exchange rates, and found by using a copula-GARCH model that the rise in the price of oil is found to be associated with the depreciation of the dollar. Pierre-André Maugis (2010) showed the asymptotic normality of the vine copula parameter. Nikoloulopoulos (2010) compared different vine copulas to forecast extreme quantile and explained it in terms of likelihood fit. Dorota Kurowicka (2011) involved all the principles of the vine-copula methodology

2 GARCH-Vine Copula Model

In recent times, there have been many studies about the elasticity approach used in the GARCH model. In the elasticity approach, some series have leptokurtosis and fat tails, and don't follow normal distribution. Therefore, in this paper, we will use the GARCH-copula model to analyze the dependence structure between the values of imports, exports, exchange rate, and oil prices on the economic development of Yunnan Province. This provides an effective way to make up for the defects and limitations of the traditional multivariate statistical hypothesis.

2.1 GARCH (1, 1) model

We review the basic properties of a bivariate copula ($K = 2$). According to Wu, Chung and Chang (2012), the GARCH (1, 1) model can be expressed as follows:

$$y_{i,t} = z_{i,1} + z_{i,2}y_{i,t-1} + z_{i,3}p_{i,t}^2 + \mathrm{e}_{i,t}$$
$$p_{i,t}^2 = \omega_{i,t} + \alpha_i \mathrm{e}_{i,t-1}^2 + \beta_i p_{i,t-1}^2 \qquad (2.1)$$
$$\mathrm{e}_{i,t}|\Psi_{t-1} = p_{i,t}k_{i,t}, k_{i,t} \sim \mathrm{SkT}(k_i|\eta_i, \lambda_i)$$

z_{i2} captures the impact of the nonsynchronous effects. When using the GARCH model, the parameter in the variance equation needs to satisfy the conditions $(1)\omega_i > 0$; $(2)\alpha_i, \beta_i \geq 0$; and (3) $\alpha_i + \beta_i < 1$. The error term of $\mathrm{e}_{i,t}$ is assumed to be a skewed-t distribution, which can be used to capture the heavy tailed characteristics and be asymmetric. The Hansen density function (1994) is given as follows:

$$\mathrm{skewed} - t(k|\eta, \lambda) = \begin{cases} qc(1 + \dfrac{1}{\eta - 2}(\frac{qk+d}{1-\lambda})^2)^{-(\eta+1)/2}, k < -\frac{d}{q} \\ qc(1 + \dfrac{1}{\eta - 2}(\frac{qk+d}{1-\lambda})^2)^{-(\eta+1)/2}, k \geq -\frac{d}{q} \end{cases} \qquad (2.2)$$

The value of d, q and c are given as follows:

$$d \equiv 4\lambda c\frac{\eta - 2}{\eta - 1}, q^2 \equiv 1 + 2\lambda^2 - d^2 \text{ and } c \equiv \frac{\tau(\eta + 1/2)}{\sqrt{\pi(\eta - 2)\tau(\eta/2)}} \qquad (2.3)$$

The λ and the η are the parameter asymmetry and the kurtosis parameters, respectively. λ is restricted within (-1,1). When $\lambda < 0$ that it implies skewness to the left. When $\lambda > 0$, it implies skewness to the right.

2.2   Copula function

We will employ two different families of the copula model to describe the dependence structure between the values of imports, exports, exchange rate,IAV and oil prices. The Gaussian and Student-t copulas (elliptical's copula model) and Gumbel, Clayton, Plackett and Frank copulas (Archimedean's copula model) were used to capture the different dependence structures. The Gaussian and Student-t copulas can specify different levels of correlation between the marginal. In contrast to elliptical copulas, the Gumbel and Clayton copulas can capture the right tail dependence and left tail dependence, respectively.

By following Jondeau and Rockinger (2002). The Gaussian copula can be defined as follows:

$$C^{\mathrm{Gau}}(m, w|\rho) = \Phi_\rho\left(\phi^{-1}(M), \phi^{-1}(W)\right) \qquad (2.4)$$

Where the joint distribution function of Φ_ρ is the bivariate standard normal cumulative distribution function, with the correlation p between m and w, and $\rho \in (-1, 1)$ measures the dependence between w and m.

The bivariate Student-t copula is

$$C^T(m, w|\rho, n) = t_{\rho,n}[t_n^{-1}(w), t_n^{-1}(m)] \qquad (2.5)$$

A Student-t copula is student-t distribution with degree of freedom n and correlation ρ; also the Student-t copula has the inherent advantage of capturing tail dependence. When $n \to \infty$, the Student-t copula converges to the Gaussian with zero dependence on both tails (Embrechts et al., 2003).

The Gumbel copula was first proposed by Gumbel (1960). The biggest advantage of Gumbel copula is that it can capture the right tail dependence. The bivariate Gumbel copula is

$$C_\theta^{\mathrm{Gum}}(m, w|\theta) = \exp\{-[(-\ln m)^\theta + (-\ln w)^\theta]^{\frac{1}{\theta}}\} \qquad (2.6)$$

$\theta \in [1, +\infty)$is the dependence degree between m and w. when $\theta = 1$ implies no dependence, when $\theta > 1$ shows positive dependence, The Gumbel can the capture right-tail dependence with $\lambda^R = 2 - 2^{\frac{1}{\theta}}$.

The Clayton family has been introduced by Clayton (1978). The bivariate Clayton copula is

$$C_\theta{}^{\text{Clay}}(m, w|\theta) = \left(m^{-\theta} + w^{-\theta} - 1\right)^{-\frac{1}{\theta}} \tag{2.7}$$

$\theta \in [0, +\infty)$ is the dependence degree between m and w. when $\theta = 0$ implies no dependence. The Clayton can capture the left-tail dependence with $\lambda^L = 2 - 2^{\frac{1}{\theta}}$.

The Frank family has been introduced by Frank (1979). The bivariate Frank copula is

$$C^{\text{Fra}}(m, w|\tau) = \tau \log\left(\frac{[(1 - e^\tau) - (1 - e^{\tau m})(1 - e^{\tau w})]}{(1 - e^{-\tau})}\right) \tag{2.8}$$

$t \in (-\infty, +\infty)$ is the dependence degree between m and w. when $t = 0$ implies that m and w are independence. when $\tau > 0$, they are positively dependence and when $\tau < 0$, they are negatively dependence.

The bivariate Plackett copula has been introduced Nelsen(1999,2006), The bivariate Plackett copula is

$$\begin{aligned} C^{\text{Pla}}(m, w|\tau) = &\frac{1}{2(\tau - 1)}\left(1 + (\tau - 1)(m + w)\right) \\ &- \sqrt{\left(1 + (\tau - 1)(m + w)\right)^2 - 4\tau(\tau - 1)mw} \end{aligned} \tag{2.9}$$

$t \in (-\infty, +\infty)$ is the dependence degree between m and w. when $t = 1$ implies that m and w are independence. when $\tau \to 0$ represents negative dependence and when $\tau \to \infty$ indicates positive dependence.

2.3 Estimation and calibration of copula

We estimate the parameters of the copulas, we proposed using a semi parametric two-step estimation method (Genest et al [1995]), namely the Canonical Maximum Likelihood (CML) method.

We adopt the Canonical Maximum Likelihood method because the copula parameters estimated without specifying the marginal by the "empirical probability integral transform" method in order to obtain the uniform marginal [0, 1] and because the CML can use the empirical distribution. Also an incorrect specification of the marginal distribution may negatively influence the estimation of the copula parameters, what with CML having no assumptions on the parametric form of marginal distributions. The estimation process is implemented via a two-stage procedure, as follows.

In the first step, we transform the standardized residuals into uniform variables by using the empirical Cumulative Distribution Function

$$F_i(x) = \frac{1}{T + 1}\sum_{j=1}^{T} I(x_{ij} \le x) \tag{2.10}$$

Where $I(x_{ij} \leq x)$ denoted the indicator function: $I(x_{ij} \leq x) = 1$ if the expression is true and $I(x_{ij} \leq x) = 0$ if expression is false.

In the second step, we estimate the copula parameters by using MLE

$$\hat{\theta}_c = \text{argmax}_\theta \sum_{t=1}^{T} \ln c_{it}(F_{1t}(x_{1,t}), \ldots, F_{nt}(x_{n,t}), \theta_c) \qquad (2.11)$$

2.4   Vine copula

The higher dimensions are challenging for the dynamic and static copulas. Vine copula is a fairly new concept in dependence modeling. The GARCH-vine copula models have the inherent advantage of being multivariate copulas and are able to overcome such limitations. Vine copulas have been presented in many literature reviews, including those by Kurowicka (2011) who introduced two special cases of regular vines: the C-vine and the D-vine.

An n-variate copula $C(u_1, \ldots, u_n)$ is a cumulative distribution function (cdf) with uniform marginals on the unit interval. For the C-vine and D-vine copulas, by following Aristidis, K. N (2012), we find the pairs at level 1 to be i and $i+1$ for $i = 1, \ldots, n-1$, and the pairs for level $l (2 < l < n)$ are i and $i+l|i+1, \ldots, i+l-1$ for $i = 1, \ldots, n-l$ for the n-dimensional D-vine. For the n-dimensional C-vine, the pairs at level 1 are 1 and i, for $i = 2, \ldots, n$, and the pairs for level $l (2 < l < n)$ are $l, i|1, \ldots, l-1$ for $i = l+1, \ldots, n$.
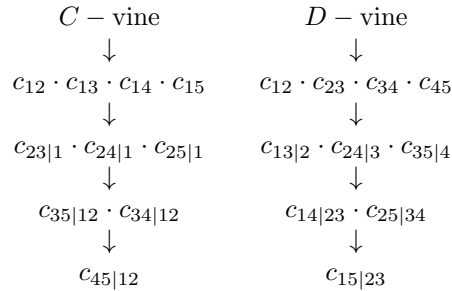
$$f(y) = \prod_{k=1}^{n} f_k(y_k) \prod_{l=1}^{n-l} \prod_{i=1}^{n-l} c_{i,i+l|i+1,\ldots,i+l-1}(F_{i|i+1,\ldots,i+l-1}(y_i|y_{i+1:i+l-1}),$$
$$F_{i+lj|i+1,\ldots,i+l-1}(y_{i+l}|y_{i+1:i+l-1}))$$
$$(2.12)$$

where $y_{k_1:k_2} = (y_{k_1}, \ldots, y_{k_2})$ are

$$f(y) = \prod_{k=1}^{n} f_k(y_k) \prod_{l=1}^{n-l} \prod_{i=1}^{n-l} c_{i,i+l|i+1,\ldots,i+l-1}(F_{l,i+l|1,\ldots,l-1}(y_l|y_1, \ldots, y_{l-1}),$$
$$F_{i+lj|i+l-1}(y_{i+l}|y_1, \ldots, y_{l-1})) \qquad (2.13)$$

Here, l and i denotes the level /tree and runs over the edges in each tree, respectively.

In tow flow charts, there are C-vine and D-vine copulas with five variables and four trees/levels.

Chart 1. C-vine and D-vine copulas with 5 variables and 4 trees/levels

$$C - \text{vine} \qquad\qquad D - \text{vine}$$
$$\downarrow \qquad\qquad\qquad \downarrow$$
$$c_{12} \cdot c_{13} \cdot c_{14} \cdot c_{15} \qquad c_{12} \cdot c_{23} \cdot c_{34} \cdot c_{45}$$
$$\downarrow \qquad\qquad\qquad \downarrow$$
$$c_{23|1} \cdot c_{24|1} \cdot c_{25|1} \qquad c_{13|2} \cdot c_{24|3} \cdot c_{35|4}$$
$$\downarrow \qquad\qquad\qquad \downarrow$$
$$c_{35|12} \cdot c_{34|12} \qquad\quad c_{14|23} \cdot c_{25|34}$$
$$\downarrow \qquad\qquad\qquad \downarrow$$
$$c_{45|12} \qquad\qquad\quad c_{15|23}$$

3   Date and Empirical Results

3.1   Data selection

In order to explore the dependent structure between international trade, exchange rate, and crude oil on the economic development of Yunnan Province, we first collect the monthly data regarding the import, export, and industrial added value of Yunnan Province which are obtained from the National Bureau of Statistics of China (sample period from January 2000 to March 2013). The WTI crude oil spot price was obtained from the U.S. Energy Information Administration (sample period from January 2000 to March 2013). The Chinese Yuan/U.S. dollar monthly average exchange rates were taken from the International Financial Statistics of the International Monetary Fund and Financial Statistics of the Federal Reserve Board (sample period from January 2000 to March 2013), each yielding 159 observations. As we can see from Figure 1, the monthly data of import, export, industrial added value of Yunnan Province, exchange rate, and crude oil spot price exhibit a permanent deterministic pattern of the long-term upward trend with cyclical and seasonal patterns (import, export, IAV), in spite of some fluctuations. As we can see from the line graph, there is a sharp decrease in the time of the global financial crisis (2008 and 2009). To avoid seasonal fluctuations, we should seasonally adjust the import, export and IAV using the X-12-ARIMA method, as demonstrated in Figure 2.

We can use the GARCH model to estimate the conditional correlation of the monthly value of import, export, and industrial added value of Yunnan Province with the exchange rate and crude oil spot price, respectively. So, it is imperative that the data should be stationary and that the data should be transformed to the logarithmic form $R_{1,t} = \ln(Y_t/Y_{t-1})$. We can utilize the data in the first difference as the incremental rate with the monthly data of import, export, industrial added
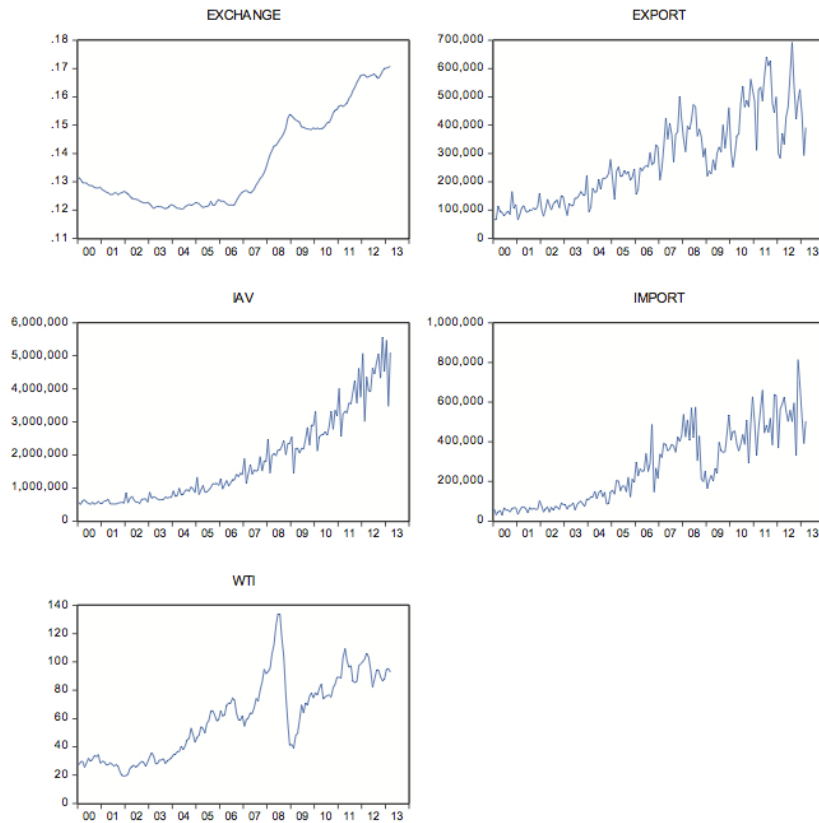
Figure 1: The monthly data of import, export, industrial added value of Yunnan Province, exchange rate, and WTI crude oil spot price

value of Yunnan Province, exchange rate, and crude oil spot price, respectively. The monthly incremental rates are plotted in Figure 3. As we can see from the line graph, there is a conditional variance process in the data. So, we can utilize the GARCH model to estimate the monthly values of import, export, industrial added value of Yunnan Province, exchange rate, and crude oil spot price.

We can see from Table 2 that the results support the null hypothesis of unit-root for the first difference of the log-transformation.

Table 3 presents the results of the distributions for the residuals of the AR(1)-GARCH(1, 1) with the skewed student-t model (Hansen, 1994) based on the monthly values of import, export, industrial added value of Yunnan Province,
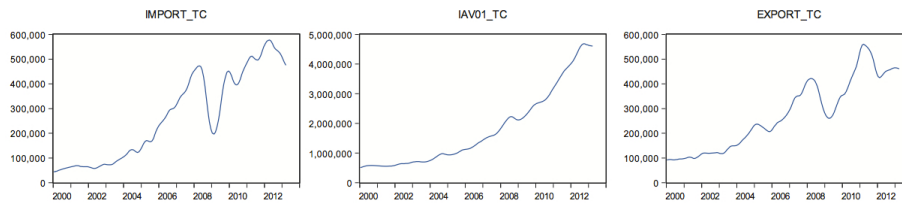
Figure 2: The seasonal adjustment of the monthly data of import, export and IAV using the X-12-ARIMA method

RMB/USD monthly average exchange rates and crude oil spot price during the sample period from January 2000 to March 2013. The choice of the skewed student-t distribution is justified due to the fact that five series have the characteristic features of financial time series like leptokurtosis and fat tails, and also from the fact that the Jarque-Bera statistics and the normality hypothesis have been rejected for four series. α_i is significant in import, export, and WTI. The autoregressive coefficients β_i are highly significant in industrial added value, import, and WTI. These results imply that import, export, and WTI have short-run persistence and long-run persistence in industrial added value, import, and WTI. The results of the conditional variance equations are $\hat{\alpha} + \hat{\beta} = 0.9937, 0.4887, 0.5691, 0.9951$, and 0.7924 for the monthly values of industrial added value, exchange rates, export, import, and WTI, respectively. As can be seen in the variance equation, the asymmetry parameters λ_i are negative and significant for the values of import and WTI.

3.2   Vine copula results

We compared the following six families for all the bivariate observations in terms of the values of AIC: Gaussian, student-t, Clayton, Gumbel, Frank, and Plackett. The t-copula exhibits better explanatory ability than the other dependence structures. Therefore, we assume a bivariate student-t for each pair.

Since the *df* parameters vary considerably, indicating that a multivariate t-copula with a common df parameter is not sufficient to describe a dependence structure with the use of the traditional copula analysis in standard multivariate copulas, in this research, we consider different vine specifications because of their inherent advantage of computation.

As shown in the Table 5, in the C-vine copula, the *df* of the student-t copula model is significant on C_{14} and $C_{25|1}$, and there is the least degree of freedom in
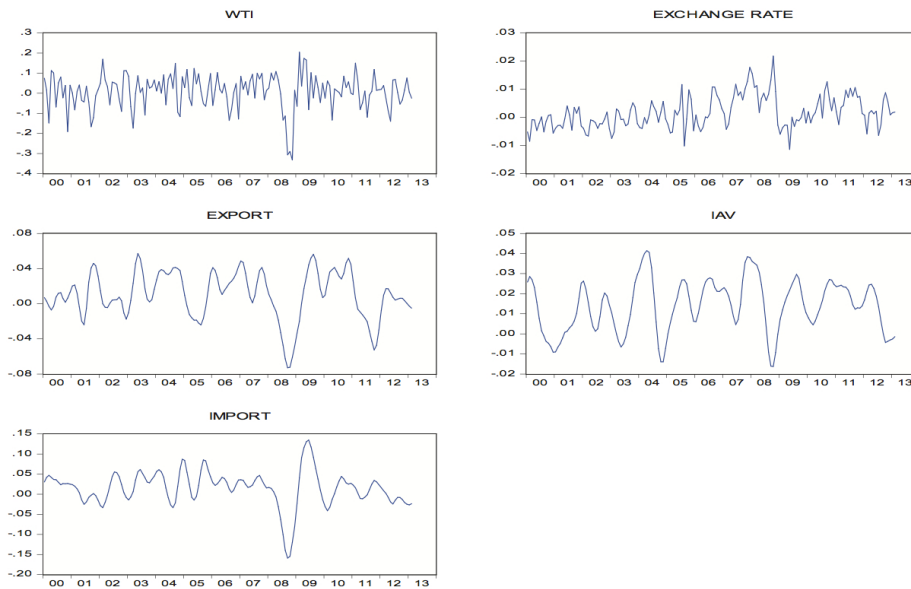
Figure 3: The monthly value incremental rates

C_{14} –which means that there is greater probability of extreme values in industrial added value and export. In the Clayton copula, when fminunc was the solver C_4 and C_5 given C_1, C_2, and C_3 is 0.2065, we find a strong significance with fminunc in C_{13} and $C_{45|123}$. The model includes industrial added value, exchange rates, and crude oil spot price. As the industrial added value, exchange rates, and crude oil spot price decrease, the demand for goods and imports, the production, and the exports also decrease; therefore, there exists a significant relationship between industrial added value, exchange rate, and crude oil spot price and international trade. We also find that there is a strongly significant correlation on C_{13}. Yunnan is a province of China, and all of China's provinces have the same macroeconomic environment. Unlike what has been recorded in most of the studies in the existing literature reviews, as an oil importing country, an increase in world oil price should have increased the production costs of China or Yunnan Province. The Clayton copula can catch left tail dependence; therefore, a decrease in crude oil spot price is inclined to retard Yunnan's industrial added value growth. In terms of the values of AIC from the four copula vines, we can see that the AIC of the Clayton dependence is larger than that of the student-t dependence, which means that the student-t dependence structure exhibits better explanatory capabilities than the

Table 1: Summary Statistics for Import, Export, Industrial Added Value, Exchange Rate, and WTI

	EXCHANGE RATE	IMPORT	EXPORT	Industrail Added Value	WTI
Mean%	0.001652	0.015095	0.010156	0.013909	0.007763
Median	0.000877	0.021617	0.009750	0.015183	0.017127
Maximum%	0.021754	0.134611	0.057242	0.041416	0.204084
Minimum%	-0.011411	-0.159058	-0.072880	-0.016253	-0.331981
Std. Dev.%	0.005703	0.044036	0.026832	0.013191	0.087290
Skewness	0.602785	-0.898134	-0.696342	-0.188310	-0.997503
Kurtosis	3.313186	6.554203	3.468631	2.316443	5.040905
Jarque-Bera	10.21395	104.4047	14.21464	4.009859	53.62351
Probability	0.006054	0.000000	0.000819	0.134670	0.000000

Note: The descriptive statistics of the incremental rate are presented. As can be seen, the standard deviation of $R_{EX,t}$, $R_{IM,t}$, $R_{IAV,t}$ and $R_{WTI,t}$ is higher than $R_{ECH,t}$. It can be observed that five variables exhibit the characteristic features of the financial time series. The skewness statistics for import, export, industrial added value, and WTI are less than 0. The kurtosis value of export, import, WTI, and exchange rate are higher than 3, which indicates that five series have leptokurtosis and fat tails. By looking at the value of the Jarque-Bera statistics, we can conclude that they do not follow normal distribution.

Clayton dependence structure.

In the D-vine copula, we find that the df of the student-t copula model varies considerably and significantly in C_{23} and C_{34}, and that there is the least degree of freedom in C_{34} –which means that there is a greater probability of extreme values in WTI and export, in the student-t copula model. Finally, in the Clayton copula, we conclude the existence of strong significance with fminunc in C_{45} (export-import) and $C_{13|2}$. This is the reason for the significant relationship between export and import. Lower demands for raw material and services import tend to retard the growth of production and export. We also found that there are strongly significant correlations between industrial added value, exchange rate, and crude oil spot price.

4   Conclusions

In this paper, we attempted to use the GARCH-vine copula model to analyze the dependence structure of international trade, exchange rate, and crude oil price on the economic development of Yunnan Province. We collected the monthly data of import, export, industrial added value of Yunnan Province, Chinese Yuan/U.S. dollar monthly average exchange rates, and crude oil spot price. The higher dimen-

Table 2: Tests of Hypotheses of Unit-root

Variables	ADF Level	Log of First Difference
Exchange Rate	-6.522706**	-12.25769**
Import	-4.565657**	-8.907536**
Export	-3.276834*	-10.60121**
Industrial Added Value	-4.919837**	-6.622938**
WTI	-9.599120**	-19.47799**

Note: The Augmented Dickey-Fuller can perform the test for unit-root. The critical values for the rejection of the null hypothesis of a unit-root are -4.018349 and -3.439075 for 1% and 5%, respectively. The "**" and "*" denote rejection of the null hypothesis at the 1% and 5% significance levels, respectively.

sions are challenging for the dynamic and static copulas, whereas the GARCH-vine copula models have the inherent advantage of being multivariate copulas and are able to overcome such limitations.

In the results obtained for the distribution of the residuals of the AR(1)-GARCH(1, 1) with the skewed student-t model (Hansen, 1994), the choice of the skewed-t distribution is justified because five series have the characteristic features of financial time series like leptokurtosis and fat tails, and also because the Jarque-Bera statistics and the normality hypothesis have been rejected for the four series. α_i is significant in import, export, and WTI. The autoregressive coefficients β_i are highly significant in industrial added value, import, and WTI. These results imply that import, export, and WTI have short-run persistence and long-run persistence in industrial added value, import, and WTI. The results of the conditional variance equations are $\hat{\alpha} + \hat{\beta} = 0.9937, 0.4887, 0.5691, 0.9951$, and 0.7924 for the monthly values of industrial added value, exchange rates, export, import, and WTI, respectively.

In the C-vine copula, the df of the student-t copula model is significant on C_{14} and $C_{25|1}$, and there is the least degree of freedom in C_{14} –which means that there is a greater probability of existence of extreme values in industrial added value and export. In the Clayton copula, when fminunc was the solver C_4 and C_5 when given C_1, C_2, and C_3 is 0.2065, we find strong significance with fminunc in C_{13} and $C_{45|123}$. The model includes industrial added value, exchange rates, and crude oil spot price. As industrial added value, exchange rates, and crude oil spot price decrease, the demand for goods and imports, the production, and the exports also decrease. We also find that there is a strongly significant correlation on C_{13}. Yunnan is a province of China, and all of China's provinces have the same macroeconomic environment. Unlike what was concluded in most of the studies conducted, as is given in the existing literature, as an oil importing country, an

Table 3:   Results of GARCH Model Analysis

	IAV	Exchange Rate	WTI	Export	Import
Z_1	0.0079	0.0005	0.0827***	0.0105*	0.0092
	(0.006)	(0.00)	(0.016)	(0.005)	(0.006)
Z_2	-0.5***	0.5***	0.5***	0.5***	0.0674
	(0)	(0.094)	(0.000)	(0.153)	(0.077)
ω_i	0	0***	.0076***	0	.0014***
	(0)	(0)	(0.002)	(0)	(0)
α_i	0	0.2245	0.5***	0.5***	0.1056**
	(0.001)	(0.154)	(0.001)	(0.117)	(0.044)
β_i	0.9937***	0.2642*	0.0691	0.4951***	0.6868 ***
	(0.030)	(0.158)	(0.142)	(0.171)	(0.077)
η_i	4.5208***	99.2732	100***	99.0212***	34.7105
	(1.733)	(320.492)	(0.000)	(28.260)	(71.653)
λ_i	-0.1618	0.0273	0.5***	-0.4996***	-0.3883***
	(0.126)	(0.110)	(0.000)	(0.173)	(0.113)
AIC	-414.4894	-1254.2834	-201.0844	-806.3938	-342.1662
BIC	-393.0512	-1232.8452	-179.6462	-784.9556	-320.7280
$\ln(L)$	214.245	634.142	107.542	410.197	178.083

Note: The standard errors are in the parentheses. When $|t| > 1.64$, 1.96, or 2.576. Note that "*," "**," and "***" denote rejection of the null hypothesis at the10%, 5%, and 1% significance levels, respectively.

increase in world oil price should have increased the production costs of China or Yunnan Province. The Clayton copula can catch left tail dependence; therefore, a decrease in the crude oil spot price is inclined to retard Yunnan's industrial added value growth. As Barsky and Kilian (2004), Hamilton (2009), and Du (2010) have pointed out, the possible reason is that China's GDP growth is highly dependent on exports, and more than 40% of the country's exports are to the United States and the EU countries; thus, China's economic activity is greatly related to the fluctuations in the economic activities in the United States and EU countries. As for the oil price decrease, it is more likely to be related to the depression in the economic activities in the United States and the EU countries. Thus an oil price decrease is inclined to reduce the exports of China or Yunnan province, and this, in turn, pulls down the growth rate of China's economy. In terms of the values of AIC from the four copula vines, we can see that the AIC of the Clayton dependence is larger than the student-t dependence, which means the student-t dependence structure exhibits a better explanatory capability than the Clayton dependence structure.

In the D-vine copula, we find that the df of the student-t copula model varies considerably and significantly in C_{23} andC_{34}, and that there is the least degree of freedom in C_{34} –which means that there is a greater probability of extreme values

Table 4: Degrees of Freedom Parameters for Each Pair

	IAV	Exchange Rate	WTI	Export	Import
IVA	0	190.2538***	199.5592***	198.7582***	8.4261
		(25.176)	(18.902)	(1.073)	(8.031)
		7.5571)	10.5576	185.3113	1.0492
Exchange Rate			34.4052	199.5124***	45.7132
			(225.518)	(49.687)	(35.465)
			0.1526	4.0154	1.2890
WTI				3.2379***	7.6343
				(1.137)	(6.546)
				2.8481	1.1693
Export					7.4443
					(5.626)
					1.3233

Note: The standard errors are in the parentheses. When $|t| > 1.64$, 1.96, or 2.576. Note that "*," "**," and "***" denote rejection of the null hypothesis at the10%, 5%, and 1% significance levels, respectively. It can be observed that the degrees of freedom parameters vary considerably. Therefore, it is advantageous to select the vine copula to explain the dependence structure

in WTI and export, in the student-t copula model. Finally, in the Clayton copula, we conclude the existence of a strong significance with fminunc in C_{45} (export-import) and $C_{13|2}$. This is the reason for the significant relationship between export and import. Lower demands for raw material and services import tend to retard the growth of production and export. We also found that there exists a strongly significant correlation between industrial added value, exchange rate, and crude oil spot price.

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Table 5: Canonical Vine and D-vine Results

We use the following abbreviations: C_1 = Industrial Added Value, C_2 = Exchange Rate, C_3 = WTI, C_4 =Export, C_5 = Import

	Canonical vine			D vine	
	Student-t	Clayton		Student-t	Clayton
C_{12}	50.9416	0.0000	C_{12}	148.1196	0.0456
	(190503.7)	(0.000)		(10041.564)	(0.047)
	0.0003	0.9133		0.0148	0.9731
C_{13}	114.4370	0.1218***	C_{23}	18.3780***	0
	(1361.560)	(0.044)		(0.811)	(0)
	0.0840	2.7647		22.6707	0.2718
C_{14}	8.8791**	0.0639	C_{34}	2.8959 ***	0.0842*
	(4.177)	(0.052)		(1.012)	(0.051)
	2.1256	1.2204		2.8612	1.6465
C_{15}	136.1576	0.0320	C_{45}	115.2548	0.2078 ***
	(511.022)	(0.047)		(1315.170)	(0.037)
	0.2664	0.6771		0.0876	5.5733
$C_{23\|1}$	98.2714	0	$C_{13\|2}$	195.2221*	0.1360 ***
	(14400.4)	(0)		(112.164)	(0.040)
	0.0068	0.3263		1.7405	3.4280
$C_{24\|1}$	10.5101	0	$C_{24\|3}$	193.3791	0.0000
	(151.670)	(0)		(146.173)	(0.000)
	0.0693	0.0455		1.3229	0.1744
$C_{25\|1}$	20.5323***	0	$C_{35\|4}$	174.4345	0.0265
	(0.041)	(0)		(862.242)	(0.053)
	497.7781	0.3641		0.2023	0.4971
$C_{34\|12}$	3.0058	0.0631	$C_{14\|23}$	10.5416	0.0436
	(22.975)	(0.048)		(9.475)	(0.059)
	0.1308	1.3084		1.1126	0.7343
$C_{35\|12}$	9.0894	0.0377	$C_{25\|34}$	8.1311	0.0000
	(114.457)	(0.046)		(7.130)	(0.000)
	0.0794	0.8247		1.1404	0.0359
$C_{454\|123}$	55.9373	0.2065***	$C_{15\|234}$	41.9023	0.0223
	(19851.449)	(0.042)		(430.947)	(0.040)
	0.0028	4.8591		0.0972	0.5582
$\ln(L)$	37.477	17.337	$\ln(L)$	38.288	17.902
AIC	-54.9540	-14.6748	AIC	-56.5758	-15.8043
BIC	-24.3281	15.9512	BIC	-25.9498	14.8217

Note: (1) The following abbreviations have been used in the table: C_1 = Industrial Added Value, C_2 = Exchange Rate, C_3 = WTI, C_4 =Export, and C_5 = Import. (2) This table shows the results of two canonical vine and D-vine models. In the decomposition, $C_{i|j}$ denotes the parameter of the vine copula. The standard errors are in the parentheses. A "0" value in a parameter indicates that the estimated parameter was less than 0.0001 when $|t| > 1.64$, 1.96, or 2.576. Note that "*," "**," and "***" denote rejection of the null hypothesis at the 10%, 5%, and 1% significance levels, respectively.

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