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Pricing Collateralized Debt-Commodity Obligation

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Abstract

The purpose of this paper is to price Collateralized Debt-Commodity Obligation (CDCO) based on the structure of Synthetic CDO, which combine both credit risk and commodity price risk. Since commodity investments display a low to negative correlation with debt investments, this paper uses Gaussian and T copulas to capture the dependence structure of debts and commodities. Numerical results show that the premium's difference of CDCO and Synthetic CDO depends on the trade-off between the price risk of spot commodity, which is related positively to the valuation of CDCO, and the benefits of diversifying portfolio risk, which is related negatively to the valuation of CDCO.

Keywords: Synthetic CDO, Copula, Credit Risk, Commodity Price Risk

1. Introduction

In recent years, credit-linked products have grown rapidly, especially for the CDO which is one of the fastest-growing fixed-income sectors. According to the Bond Market Association (BMA) report, CDO market amounted to \$250.9 billion in 2003, and was increase to \$291.4 billion in the first quarter of 2006. Besides, commodities markets are still in a rising momentum recently. Futures markets have been the traditional vehicle for participating in the commodities markets and in recent years, the OTC market for commodity derivatives has also expanded rapidly. BIS (2006) reports that the notional amount outstanding of OTC commodity derivative contracts was US\$590 billion in June 2001, and increases to US\$3608 billion in December 2005.

This paper attempts to price a securitization product combining both credit risk and commodity price risk, and it is defined as Collateralized Debt-Commodity Obligation (CDCO). The structure of CDCO is based on the one of Synthetic CDO. Different with Synthetic CDO, CDCO brings together two products, bonds and commodities, whose implied spread or price movements diverge significantly from actual default rates or asset returns. Hence, the valuation of CDCO depends on two inverse effects. One effect is the commodity price risk, which is related positively to the valuation of CDCO. Another is the benefits of diversifying portfolio risk, which is related negatively to the valuation of CDCO.

There are currently several approaches to CDO pricing, including binomial expansion technique (BET), Factor copula and copula. BET originally proposed by Moody's has evolved as a standard technique financial institutions and Cifuents and O'Connor (1996) use to rate tranches of collateralized bond obligations (CBOs) and collateralized loan obligations (CLOs). The principal reason for the model's popularity is its simplicity and low implementation cost. However, the technique relies significantly on the assumption that recovery rates are constant across collateral pools. This assumption is not supported by empirical observation.

The factor approach is quite standard in credit risk modeling. Hull and White (2004) use multi-factors copula model and Fourier transform to obtain the conditional default probability and the unconditional default loss distribution through numerical integration. This topic is also discussed by Lee, Kuo, and Urrutia (2004). The advantage of this approach depends on the calculation tranche premium without Monte Carlo simulation. However, the critical drawback lies on the failure in calculating loss distribution function of collateral pools. More precisely, this approach could not compute VaR thus it influences the performance of risk management.

The copula approach directly specifies the dependence structure. While the Gaussian copula model with constant default intensity, introduced to the credit field by Li (2000) has become an industry standard model. Since the default correlation and loss distribution function of collateral pools can be accurately and rapidly captured through the copula approach, under the consideration of completeness of default correlation structure and risk management, this paper uses copula approach to calculate the premium of CDCO. Therefore, this paper follows the models of Jarrow and Yildirim (2002) and Black and Cox (1976) to obtain the probability of individual credit event and individual commodity trigger event, respectively. Further, Gaussian copula and T copula functions are used to generate dependence structure among the reference names.

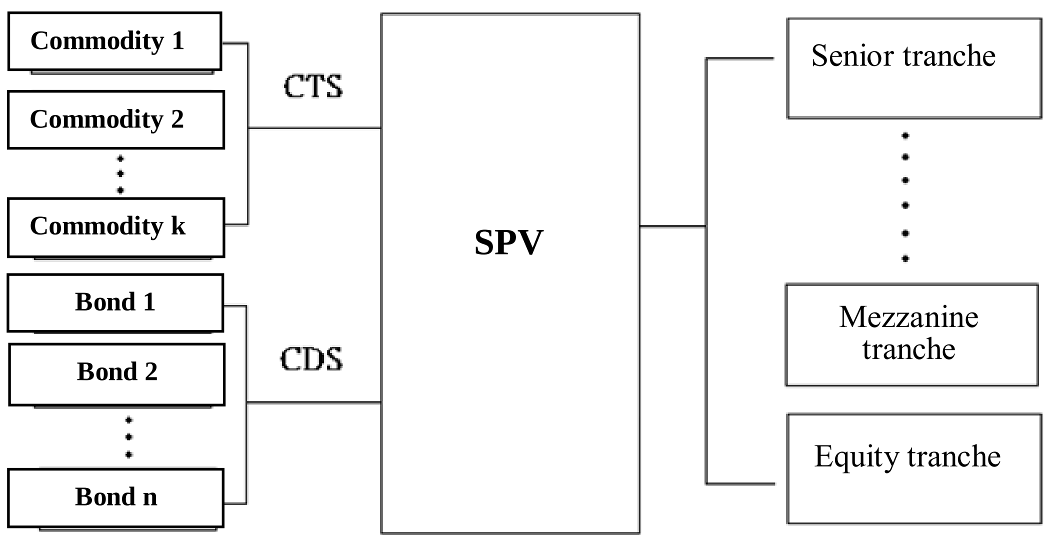
The paper is organized as follows: An exact product description of a CDCO and some important features comparing to Synthetic CDO are given in Section 2. Pricing a CDCO is investigated in Section 3. Numerical results to describe the two inverse effects that influence tranche premium of CDCO are presented in Section 4 and Section 5 concludes the paper.

2. Product Description

Synthetic CDO is credit risk product backed by a pool of all debt obligations. The structure of CDCO is based on the one of Synthetic CDO. The structure of CDCO is described as Figure 1. Different with Synthetic CDO, CDCO is composed of two products, credit and commodities, whose implied spread or price movements diverge significantly from actual default rates or asset returns. In this transaction of the contract, the originator pays the premiums to special purpose vehicle (SPV) for credit default swaps (CDS) and Commodity Trigger Swaps (CTS), respectively. The commodity contracts are structured as CTS, which contracts involve two parties – a protection seller and a protection buyer. Analogous to a CDS contract, once a strike (i.e. default) is set, the protection buyer pays regular premiums in arrears to the protection buyer. The underlying commodities have three major categories: Agricultural products-fibers, grains, food, livestock; Energy- crude oil, heating oil, natural gas; Metals- copper, aluminum, gold, silver, platinum. In the event that the underlying commodity price level is below the strike, the protection seller must pay the protection buyer a notional amount equal to the contract size (0% or otherwise fixed recovery rate). Tranches are categorized as senior, mezzanine, and equity, according to their degree of commodity and credit risks. Hence, multiple tranches of securities are issued by the CDCO held by SPV, offering investors various commodity and credit risk characteristics.

In practice, in 12 September 2005, a 5-year CDCO was issued by Barclays Bank. Barclays enters into a series of 90 CDS and 10 CTS selling protection on 100 entities and buying protection through a full capital structure deal or via bespoke tranche creation. Through historical analysis and in agreement with S&P, Barclays Capital selected 10 commodities and set price triggers so far below spot prices that the probability of spot existing below such levels in 5 years is equal to that of 'AAA' bonds defaulting over the same period. Because there is often no active commodity futures market that extends out to 5 years, Barclays uses a short averaging period immediately prior to maturity to determine the final commodity level and hence the determination of a CTE.

Figure 1: The Structure of CDCO

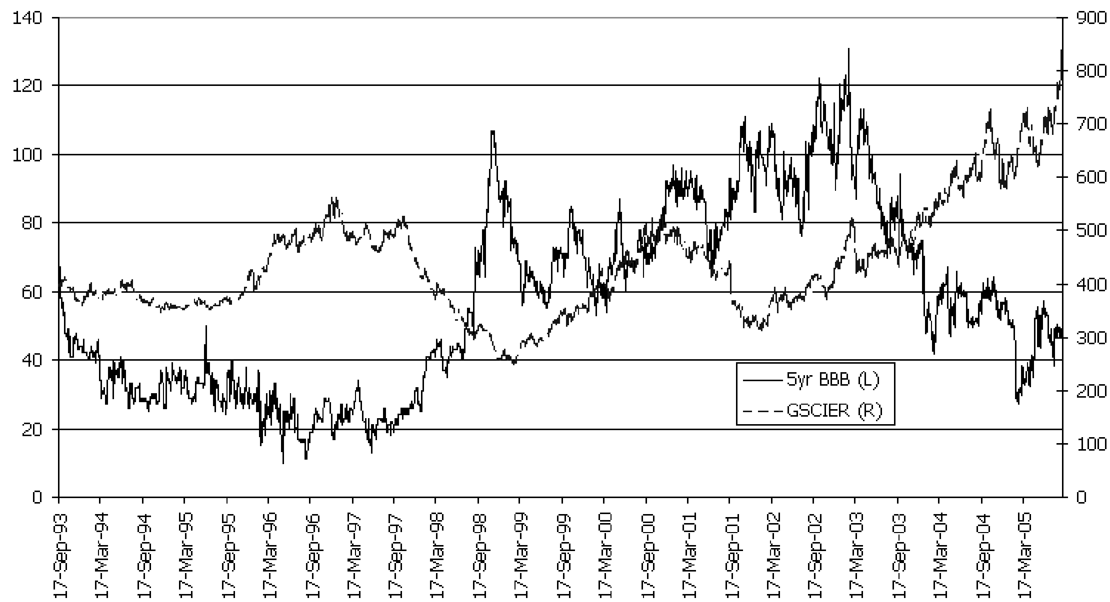


Features of CDCO comparing with Synthetic CDO are showed as follows:

1. Hedging: The issuer could simultaneously hedge the risk of credit and commodity price volatility through issuing CDCO. Further, they could increase the efficiency of financial markets by utilizing capital more effectively, thus this benefit reduces the cost of capital and the cost of insurance through issuing CDCO.
2. Higher Yield: Compared with similarly rated AAA bonds, AAA CTS offers a higher yield. Thus, adding CTS into the Synthetic CDO structure provides investors with a higher return than the traditional Synthetic CDO.
3. Diversification: CDCO provides investors with a valuable opportunity to access dynamics of both debt and commodity markets in a fixed-income format. Historically, commodity investments display a low to negative correlation with traditional asset classes. For example, Figure 2 displays the historical comparison between the GSCIER index and the BBB Industrial bond yields. It displays that there is an inverse correlation between commodities and credit spreads. Hence, for the investors, the CDCO has attractions to financial institutions, such as banks, pension funds, and long-term investors. Those institutions always attempt improving their risk-expected return trade-offs by portfolios diversification. Fortunately, the CDCO are particularly desirable because default risk has no even inverse correlations with commodity price risk. According to Markowitz theory, by adding some commodity bucket into the debt investment, the diversification portfolio can reduce their overall risk exposure under no loss of expected return. Hence, combining credit and commodities in the form of a CDCO offers investors the benefits of diversification but with higher returns. Further, if the investors have a view that prospective future volatility of commodity price is likely to be different with the currently widely believed, the CDCO also

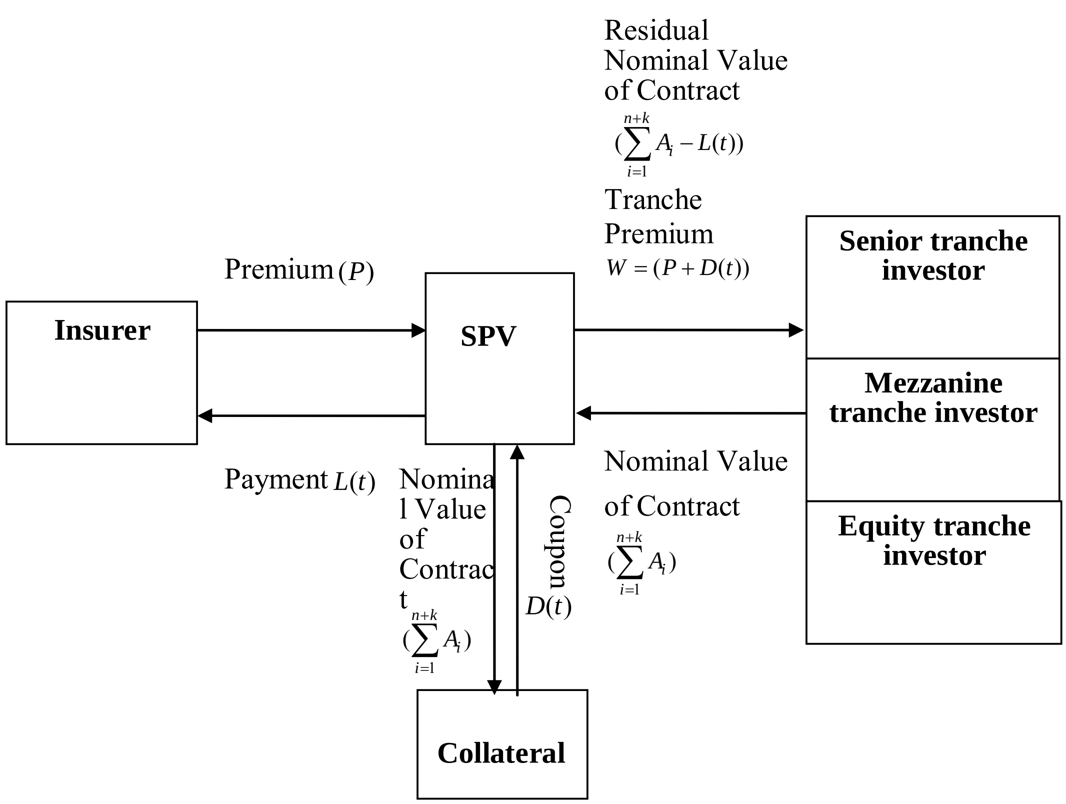
offer the investors as the tool to speculate on commodity price risk and takes advantage of arbitrage opportunities.

Figure 2: A Historical Comparison between the GSCIER Index and the BBB Industrial Bond Yields



Source: Bloomberg

Figure 3: CDCO Cash Flow Diagram



3. Pricing a CDCO

3.1. Payoff of a CDCO

In this section, we introduce the valuation of a CDCO. The payoff of CDCO is similar to Synthetic CDO. Using the Gaussian copula and Student T copula functions, the default time of individual bond and the time of individual commodity trigger event and cumulated loss distribution functions can be obtained by Monte Carlo simulation, respectively. Under the no-arbitrage mechanism, i.e., expected returns equals to expected loss, the fair value of each tranche for CDCO is calculated. CDCO Cash Flow Diagram is showed in Figure 3.

Let us consider the reference portfolios including n firms' obligations and k underlying commodities. Let $L_i = (1 - R_i)A_i$ denote the net loss of insurer as the firm i defaults, $i = 1,...n$, where R_i is recovery rate in the event of default of firm i and A_i is nominal value of firm i. Set $Q_i^A(t) = 1_{\{t_i^A \le t\}}$ be the counting process which jumps from 0 to 1 at default time of the firm i. Hence, $L^n(t)$ displays the total default loss of all firms at t:

$$L^n(t) = \sum_{i=1}^{n} L_i Q_i^A(t)$$

which is thus a pure jump process.

Similarly, let R_j denote the commodity j price of the portfolio and K_j is the constant strike, thus $L_j = A_j(K_j - R_j)$ represents the net loss of commodity j for insurer companies as the trigger event time of commodity j $Q_j^B(t) = 1_{\{t_j^B \le t\}}$ occurs, $j = 1,...k$, where A_j is nominal value of underlying commodity j. Then $L^k(t)$ shows the portfolio spot commodity loss at t:

$$L^k(t) = \sum_{j=1}^{k} L_j Q_j^B(t) \cdot$$

Hence, we can obtain the total portfolio loss $L(t)$ equal to $L^n(t)$ plus $L^k(t)$.

Let us consider a tranche of a CDCO, where the death payment leg pays all losses that occur on the collateral portfolio, above a lower attachment point C and below an upper attachment point D where $0 \le C \le D \le \sum_{i=1}^{n+k} A_i$ and $\sum_{i=1}^{n+k} A_i$ is initial nominal value of contract. We consider the equity tranche when $C = 0$; if $C > 0$ and $D < \sum_{i=1}^{n+k} A_i$, we speak of the mezzanine tranches, and as $D = \sum_{i=1}^{n+k} A_i$, we consider senior or super-senior tranches. Given the portfolio loss $L(t)$, we can use the expression for $L_m(t)$ to translate the portfolio loss into a tranche loss. These losses on given tranche are equal to zero if $L(t) \le C$, to $L(t) - C$, if $C < L(t) \le D$ and to $D - C$ if $L(t) > D$. This can be summarized as:

$$L_m(t) = \left(L(t) - C\right)1_{\{C,D\}}L(t) + (D - C)1_{\left\{D,\sum_{i=1}^{n+k} A_i\right\}}L(t)$$

where $L(t) = L^n(t) + L^k(t)$, and $L_m(t)$ is a pure jump process.

Using these two quantities of $L(t)$ and $L_m(t)$, we can calculate the expected loss from defaults, i.e. the default leg, and the expected premium payments, i.e. the payment leg, and, we can then calculate the fair tranche spread. More rigorously, under the risk-neutral probability measure P , we get for the default leg

$$\mathbf{DL} = E^{\mathbf{P}}\left[\int_0^T B(0,t)\,dM(t)\right] \tag{1}$$

where $B(0,t)$ denotes the discount factor, and T is the maturity of the CDCO.
and the payment leg

$$\mathbf{PL} = W \cdot E^{\mathrm{P}} \left[\int_0^T B(0,t)\, g\left(L(t)\right) dt \right] \tag{2}$$

where $g\left(L(t)\right) = \min\left\{\max\left[D - L(t), 0\right], D - C\right\}$ and $D - C$ is the tranche size at inception, W is the fair premium, $D - L(t)$ is the outstanding tranche notional at time $t \in [0,T]$, and, clearly $0 \le M(t) \le D - C$ since $0 \le L(t) \le \sum_{i=1}^{n+k} A_i$ for all t.

Under the condition of no arbitrage market, using equation (1) and (2), the fair premium W on different level of tranche can be solved as:

$$W = \frac{E^{\mathrm{P}}\left[\int_0^T B(0,t)\, dM(t)\right]}{E^{\mathrm{P}}\left[\int_0^T B(0,t)\, g\left(L(t)\right) dt\right]}.$$

3.2. Valuation of a CDCO

This paper uses the approach of Jarrow and Yildirim (2002) to obtain the default probability of individual bond. Further, through the first passage time model of Black and Cox (1976), the probability of individual commodity trigger event can be also acquired. When pricing structured credit products, such as CDO and CDCO, it affects the likelihood of extreme outcomes in portfolio of debt instruments, thus default dependence of debt instruments portfolio should also be emphasized. Besides, Figure 2 displays that GSCIER index tends to rise up from 2002 up to 2005. Thus it seems to have a higher correlation among the commodities. Therefore, we choose the industry standard and well-documented Gaussian copula and Student T copula framework to link the joint default probability of the default times of all defaultable bonds, and joint probability of commodity trigger events. Finally, using two kinds of joint probability, we simulate the default time of individual bond and the time of individual commodity trigger event and then value the fair value of CDCO.

3.3. Multivariate Copula

By Sklar's Theorem (1959), let $\tau_1^A, \tau_2^A, .., \tau_n^A$ be default time of n firms, with $F_1^A, F_2^A, ..., F_n^A$ their marginal cumulative distribution function. Besides, $\tau_1^B, \tau_2^B, .., \tau_k^B$ is the time of trigger event of k commodities respectively, with $F_1^B, F_2^B, ..., F_k^B$ their marginal cumulative distribution function. Hence, considering the joint default probability of n firms and probability of commodity trigger events of k commodities, we have

$$\begin{aligned}
&F(t_1^A, t_2^A, ...t_n^A, t_1^B, t_2^B, ...t_k^B) \\
&= \mathrm{P}(\tau_1^A \le t_1^A, ...\tau_n^A \le t_n^A, \tau_1^B \le t_1^B, ...\tau_k^B \le t_k^B) \\
&= C(F_1^A(t_1^A), ..., F_n^A(t_n^A), F_1^B(t_1^B), ..., F_k^B(t_k^B)).
\end{aligned}$$

To calculate the default probability of individual bond i, $F_i^A(t_i^A)$, $i = 1, ..., n$, this paper uses the reduced-form approach, which has been widely considered by Jarrow and Turnbull (1995, 2000), Lando (1994, 1998), Jarrow and Yu (2001) and Jarrow and Yildirim (2002). For simplify, this paper follows the model of Jarrow and Yildirim (2002). They assume that point process is modeled as a Cox process with an intensity function, thus the default time of bond i is defined as:

$$\tau_i^A \equiv \inf\left\{t > 0 : t \in T, \int_0^t \lambda_i(u)\, du \ge E\right\}, \; i = 1, ..., n.$$

where E is exponential distribution and i is the number of bonds.

They assume that an intensity function is a linear is in the spot rate of interest as the following representation:

$$\lambda^i(u) = \max\left[\lambda_0^i + \lambda_1^i r(u), 0\right].\ i = 1, 2..n$$

where λ_0^i is a deterministic function of time and λ_1^i is a constant.

The stochastic processes of $r(t)$ follows extended Vasieck model as follows:

$$d\,r(t) = [\theta(t) - \alpha(t) r(t)]dt + \sigma_r dW_t^r\ ,$$

where $\theta(t)$ represents the long-term equilibrium value of the process; $\alpha(t)$ is a nonnegative mean reversion speed; and σ_r is the volatilities of spot rate. W_t^r is Brownian motion under the risk neutral probability P . Hence, the default probability of individual bond i is:

$$F_i(t_i^A) = \mathrm{P}(\tau_i^A \le t_i^A)\ ,\ = 1 - \exp\left[-\lambda_0^i t_i^A - (1+\lambda_1^i)\mu(0, t_i^A) + \frac{(1+\lambda_1^i)^2}{2}\sigma^2(0, t_i^A)\right]\ i = 1, 2, ..n\ .$$

where $\mu(0,t_i^A) = \int_0^{t_i^A} f(0,u)du + 0.5\int_0^{t_i^A} b(u,t_i^A)^2 du$, $\sigma^2(0,t_i^A) = \int_0^{t_i^A} b(u,t_i^A)^2 du$,

and $b(u,t_i^A) = \dfrac{\sigma_r(1 - e^{-\alpha(t_i^A - u)})}{\alpha}$.

Besides, for the estimation on probability of individual commodity trigger events j, let R_j denote the spot commodity j price of the portfolio and K_j is the constant strike of commodity j. In order to compute $F_j(t_j^B)$, we assume trigger events can occur at any time throughout the life of the transaction causing intermediate capital structure losses, thus we follow the first passage time model of Black and Cox (1976) to obtain the probability of individual commodity trigger events. The time of trigger events τ_j^B is defined as:

$$\tau_j^B \equiv \inf\left\{t > 0 : t \in T, R_j \le K_j\right\}, j = 1, ..., k\ .$$

Therefore, the model to value the probability of individual commodity trigger event is given by,

$$F_j(t_j^B) = \mathrm{P}(\tau_j^B \le t_j^B) = \mathrm{P}(\underset{s \le t_j}{m}\ R_s < K_j, R_T \ge K_j) + \mathrm{P}(\underset{s \le t_j}{m}\ R_s < K_j, R_T < K_j)$$

$$= \frac{K_j}{R_0}\exp\left[\frac{2(r - 0.5\sigma^2)}{\sigma^2}\right] N(d_j^1) + 1 - N(d_j^2),\ \ j = 1, 2, ..k\ ,$$

where $d_j^1 = \dfrac{\ln(\frac{R_j^0}{K_j}) + (r - 0.5\sigma^2)t_j^B}{\sigma\sqrt{t_j^B}}$, $d_j^2 = \dfrac{\ln(\frac{K_j}{R_j^0}) + (r - 0.5\sigma^2)t_j^B}{\sigma\sqrt{t_j^B}}$, and K_j is a constant strike of commodity j。

4. Numerical Analyses

This section examines the difference of fair tranche premium of CDCO and Synthetic CDO using Gaussian Copula and T Copula, respectively. Further, we report some numerical values of the CDCO by varying the correlation of underlying asset and the numbers of spot commodity. The parameters for the numerical example are:

1. A four-year CDCO referring to a pool of 10 names, including 7 bonds and 3 spot commodities, each with the same notional amount, 1 million.
2. Each reference credit has a constant recovery rate of 34%.
3. Hazard rate of each reference credit is 5%.

4. Asset correlations between any two credits and any two spot commodities are all equal to 40%. Asset correlations between credit and spot commodity are -0.01%.
5. We compute these premiums for three tranches of different seniority: an equity piece covering the first 30% of the portfolio losses; a mezzanine tranche exposing the investor to the 30%-60% slice of the losses; and a senior tranche absorbing the remaining defaults.
6. Initial commodity price and constant strike of CTS is 150 and 145, respectively.
7. The risk-free interest rate is 2.07% and the volatility of commodity price is 40%.
8. Degree of freedom of T Copula is 10.
9. 50,000-path Monte Carlo simulation.

4.1. Tranche Valuation of CDCO and Synthetic CDO

Figure 4 shows the relationship between reference correlation and each tranche premium of CDCO, keeping the remaining parameters at the levels fixed in this case. The result is consistent with Synthetic CDO. The equity tranche spread is negatively related to reference correlation. Further, the tranche premium of mezzanine appears to a U-shape. On the contrary, as reference correlation rises up, the tranche premiums of mezzanine and senior get wider.

However, different with Synthetic CDO which is included all bonds, CDCO is composed of bonds and spot commodities. Thus the investors of CDCO should suffer the price risk of spot commodity. On the other hand, under the no even inverse relationship between the bonds and spot commodities, they also possess the benefits of diversifying portfolio risk. Hence, the premium's difference of CDCO and Synthetic CDO depends on the trade-off between the price risk of spot commodity and the benefits of diversifying portfolio risk.

Since the equity investor will have to suffer the price risk of spot commodity at the earliest, the effect of the price risk of spot commodity is higher than the benefits of diversifying portfolio risk. Hence, the premium of CDCO would be higher than Synthetic CDO. Similarly, the mezzanine investor will also have to cover the price risk of spot commodity in very few scenarios. When the price risk of spot commodity is higher than the benefits of diversifying portfolio, the result is the same with equity tranche. On the contrary, for the senior investor, the price risk of spot commodity is absorbed already by the equity and mezzanine investors, whereas the benefits of diversifying portfolio risk can be held completely. Therefore, the premium of CDCO would be lower than Synthetic CDO.

4.2. Tranche Valuation of CDCO with Various Commodity Numbers

In Figure 5, we reveal the relationship between the numbers of spot commodity and each tranche premium of CDCO. Keeping the remaining parameters at the levels fixed, as the numbers of spot commodity increases, the investor should absorb higher price risk. In addition, the investor could hold more advantages of diversifying portfolio risk when the numbers of bonds and spot commodities are similar approximately. Hence, the tranche premium also depends on the commodity price risk -benefit of diversifying portfolio risk trade-offs.

If the price risk induced by the increasing commodity numbers is covered by the range of equity tranche, increasing commodity numbers could face more price risk for equity tranche investors. This is because that equity tranche investors first absord commodity price risk. Further, this price risk dominates the benefit of diversifying portfolio risk. Therefore, equity tranche investors could require higher premiums if commodity numbers rises up. On the other hand, since the commodity price risk is absorbed completely by equity tranche, mezzanine and senior tranches could only possess the benefit of diversifying portfolio risk through increasing commodity numbers. Thus these two tranches investors would acquire lower premium when commodity numbers increases.

Contrarily, if the price risk induced by the increasing commodity numbers is exceed by the range of equity tranche, increasing commodity numbers could hold adequately the benefit of diversifying portfolio risk rather than enhance price risk of equity tranche investors. Since the equity tracnhe is unable to suffer commodity price risk, the price risk generated by increasing commodity numbers is absorbed by mezzanine and senior tranches investors. Hence, the premium of mezzanine and senior tranches is higher than equity tracnhe. Figure 4 and 5 also show that different dependence structures (Gaussian or T copula functions) do not affect the application of the proposed results.

Figure 4: The Relationship between Reference Correlation and Each Tranche Premium

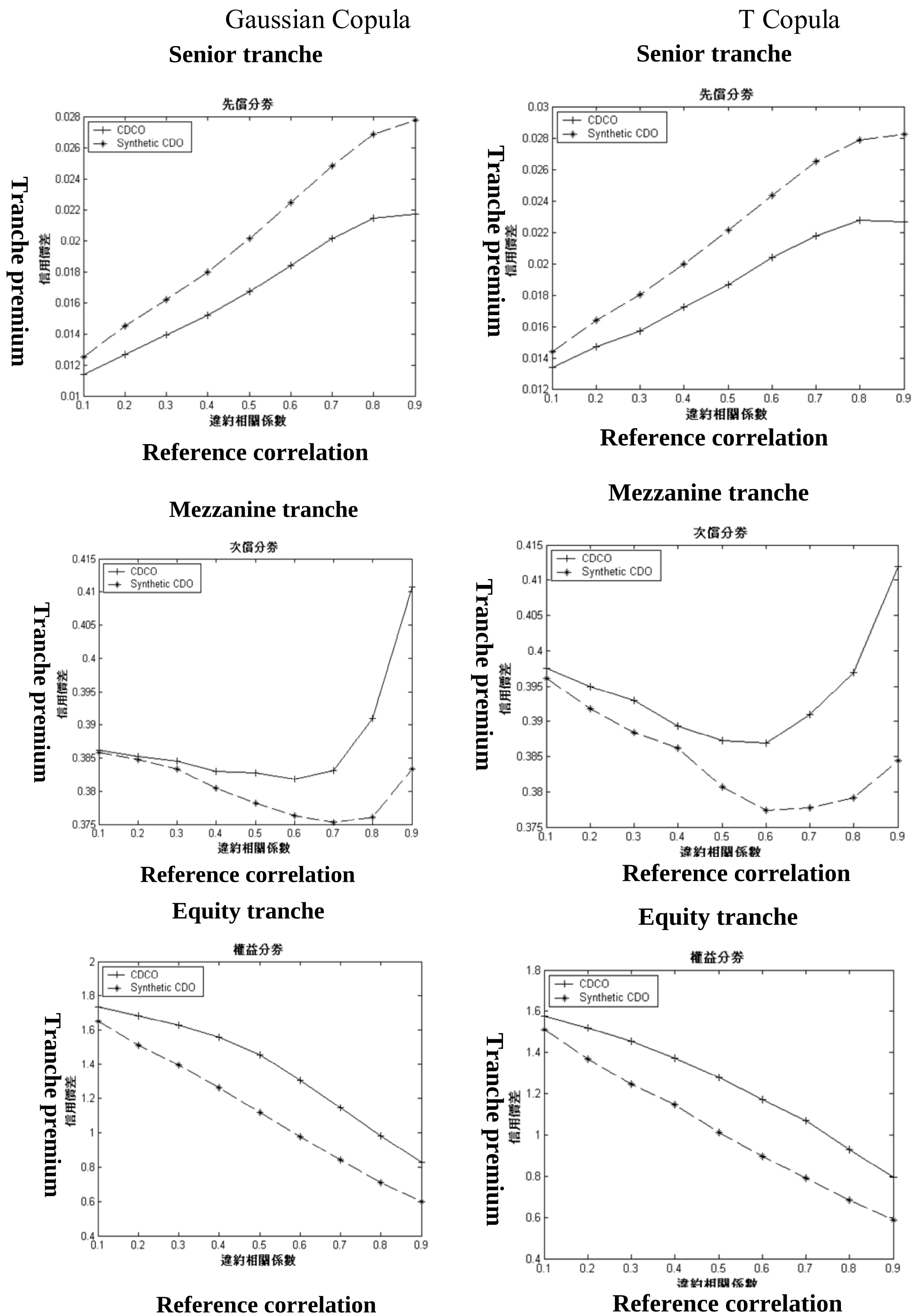
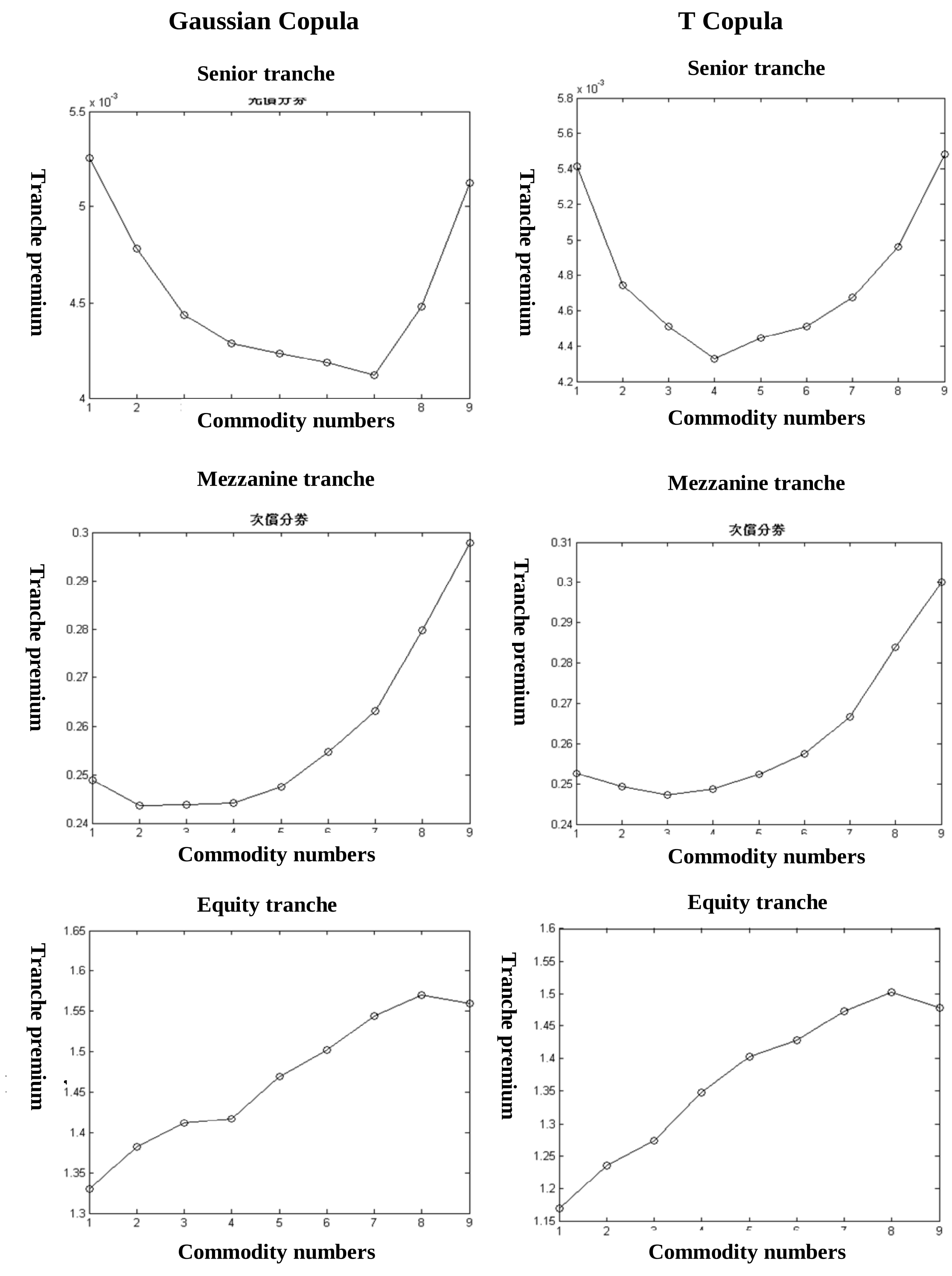


Figure 5: The Relationship between Commodity Numbers and Each Tranche Premium



5. Conclusions

Portfolio diversification is very important for the investors, especially for financial institutions, such as banks, pension funds. Based on the structure of Synthetic CDO, this paper provides an alternative innovative product, CDCO, which include two inverse correlation products: credit of debt obligations and commodities. The numerical results shows that tranche premium of CDCO depends on two inverse effects. One effect is the price risk of spot commodity and another is the benefits of diversifying portfolio risk. If the price risk of spot commodity dominates the benefits of diversifying portfolio risk, the tranche premium rises up as commodity numbers increases, whereas the tranche premium reduces as commodity numbers increases.

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