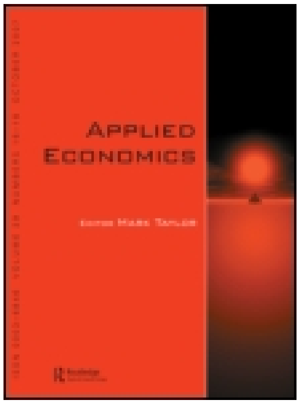

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Default correlation at the sovereign level: evidence from some Latin American markets

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Default correlation at the sovereign level: evidence from some Latin American markets

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Using the eruption of Argentina debt crisis in 2001 as a natural experiment, we investigated the correlated default at the sovereign level for some Latin American countries. Daily closing market quotes for sovereign Credit Default Swaps (CDS) of Argentina, Brazil, Mexico and Venezuela were obtained from *CreditTrade* database. Using copula approach, we observed increased dependences among sovereign CDS markets during the crisis period. Their dependence structures were found to be asymmetric. Moreover, the degree of credit contagion was related to the creditworthiness of the country. This study also discussed the implications of these findings for policymakers.

I. Introduction

In a world of increasing economic interdependencies the issue of credit contagion is of critical concern, particularly in the presence of economic distress. (Han *et al*., 2003; Forbes, 2004; Bekaert *et al*., 2005; Caporale *et al*., 2005; Elkinawy, 2005; Gelos and Wei, 2005). Credit contagion refers to the credit deterioration of one country that indirectly leads to similar deterioration of other countries (Avellaneda and Wu, 2001). The propagation of this distress is accompanied by a sudden jump in sovereign spreads, reflecting the market re-assessment of all countries affected by the default.

In order to characterize the comovements that may exist among sovereign bonds during a financial crisis, we collected data on sovereign Credit Default Swaps (CDS) spread for some Latin American markets and used copula method to analyse the nature of credit contagion in that region. Embrechts *et al*. (1999) first discussed the dangers of using linear correlation in studying dependence. Copula method overcomes the problem that data is nonnormal and nonlinear and provides robust measures of dependence structures. It contains all the information that researchers need to know about the dependence structures between variables. Furthermore, it offers the modelling flexibility due to the separation of marginals from dependence in its functional form.

Recent literature has shown evidence for contagion in equity markets (Longin and Solnik, 2001; Forbes and Rigobon, 2002; Bekaert *et al*., 2005; Jondeau and Rockinger, 2006). Relatively, few studies focus on bond and credit derivative markets (Kan, 1998; Beattie, 2000; Copeland and Jones, 2001; Han *et al*., 2003; Sander and Kleimeier, 2003; Yang, 2005).

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Ene and Vlad (2002) pointed out that credit derivatives are largely used to protect against subgrade debts, so they have gained popularity in the emerging market, which tend to be more volatile. Neftci *et al.* (2005) argue that in emerging markets financial crises are never caused by market risk. Instead, they are precipitated by events such as currency devaluation or sovereign bond default. Compared with the cases in equity, foreign exchange and domestic money markets, comovement in bond markets, particularly for sovereign bonds, is strongest during times of distress. According to the findings of Kaminsky and Reinhart (2002), there is a great degree of international comovement among sovereign bond markets, which often share common lenders and foreign investors. This phenomenon appears to be increasing. As Mauro *et al.* (2002) have found, sovereign spreads across emerging markets comove significantly more than they did historically (1870–1913).

In this context, it is important to understand how dependence between sovereign bond markets can be measured. A thorough understanding of correlated defaults at sovereign level is of critical importance. First, mutual fund managers require higher premiums to compensate their exposures to correlated sovereign risk. If there is a credit contagion, the sovereign bond spread which reflects the country risk premium may be affected. Kraay *et al.* (2004) take sovereign risk into account when modelling net foreign asset positions and empirically show that modest amounts of sovereign risk can lead to substantial reductions in both bond price and flow of foreign investments. From the bank's perspective, higher credit premiums are required in order to offset potential losses caused by correlated default.

In addition, the likelihood of a contagious sovereign debt crisis should influence the monetary policies. Because CDS reflect the sovereign risk[1] and they are used by investors to assess a country's economic and political fundamentals, the increased joint default probabilities in sovereign CDS may imply a forthcoming financial crisis. We think that the comovement in sovereign credit default swaps can serve as an important indicator of financial crises and can be used to supplement other indicators, many based on fundamental variables, which have been criticized for poor predictive power (Berg and Patillo, 1999; Edison, 2003). For example, International Monetary Fund (IMF) can use it to predict the possibility of a forthcoming contagious crisis.

The rapid growth in Latin American bond market is frequently affected by financial crises (Bustillo and Velloso, 2000). Compared with Asia, Europe and G-7 countries, Latin America exhibits the most significant comovement in bond markets (Kaminsky and Reinhart, 2002). The 2001 Argentina crisis provided a unique opportunity to design a natural study of the effect of correlated default among Latin American countries, since Argentina debts represented from one-fifth to one-quarter of tradable issues in the emerging bond markets at that time and according to IMF, a loss of confidence in Argentina can rapidly become contagious.

In this study, we first test whether dependences in sovereign CDS market increase during the crisis period. We hypothesize that countries whose sovereign CDS spread exhibited a high degree of dependence with that of Argentina would be more vulnerable to contagion during crisis. A copula-based measure is used to specify the structure of dependence as well as the degree of dependence, which would not only take the nonlinear property into account but would also allow a more comprehensive understanding of correlated default. Hu (2006), Turgutlu and Ucer (2009) and Genius and Strazzera (2008) all showed that the copula approach is especially beneficial under strong departures from normality assumption, which is the case for our sample data.

Second, we examine whether the dependence structures during the crisis were asymmetric or not. Copula can efficiently capture the tail dependence arising from the extreme observations caused by asymmetry. Longin and Solnik (2001) and Bae *et al.* (2003) have emphasized the relationship between the tails of CDS spread distributions. However, the top- and bottom-tail, which are coexceedances in their models, were arbitrarily identified and separately estimated, thereby not able to provide consistent results.

Finally, we explore whether the degree of credit dependence is related to the credit quality of the sovereign bonds. Higher ratings can attract more confident investors, so the magnitude of credit contagion in such countries may be reduced.

Our results show that dependence in sovereign CDS spread is increased among sample countries during the debt crisis. The sudden default by Argentina accelerated the degree of comovement in Latin America. Before the crisis, there was no tail dependence between Argentine CDS spreads and those of other countries. However, we observed right

[1] For example, as mentioned in Ene and Vlad (2002), 2 months before the actual news of the collapse of Enron was out, the default swap markets had already begun pricing it.

tail dependences with Brazil and Venezuela during that crisis, indicating that once the contagion happened, impact on Brazil and Venezuela might have been more severe than it was on Mexico. The degree of this dependence is probably related to a sovereign's creditworthiness. As a result, Mexico, whose credit rating was higher at that time, seemed immune to the impact of contagion from the 2001 Argentina crisis.

The rest of this article is organized as follows. Section II describes the data and methodology. Empirical results are analysed in Section III. Finally, Section IV concludes.

II. Data and Methodology

The trading of credit derivatives in Latin America accounts for 50–60% of the overall market shares for emerging countries (Ranciere, 2002). According to a 2005 survey[2] by The Federal Reserve Bank of New York, sovereign single-name CDS are the most liquid credit derivative instruments. A single-name sovereign CDS is a contract that provides protection against the default risk of a sovereign entity. The protection buyer makes periodic payments, i.e. the CDS spread, to the protection seller until the contract matures or a credit event occurs. In return, the protection seller must buy the bonds at its par when a credit event occurs before the CDS contract matures.

We collected the daily closing mid-market quotes in the year of 2001 for sovereign CDS with a 2-year maturity from *CreditTrade* database. Due to liquidity consideration, we only consider those of Argentina, Brazil, Mexico and Venezuela. Sovereign CDS markets in other Latin American countries are much less liquid to provide reliable results. We chose only CDS with the same maturity to make it easier to compare across countries. Although these sovereign CDS are popular with investors and are relatively liquid, large withdrawals of deposits from Argentine banks in July 2001 caused the sales of CDS to stop temporarily until the government announced a 'zero-deficit' plan, a measure that was endorsed by the IMF. We therefore divided our 2001 sample period into: (1) *the pre-crisis period*, which covered the time period from March to June 2001 and (2) *the crisis period*, which covered the period from August to October, 2001. After October no trading was being done of Argentine CDS, since very few protection sellers would sell in a market in which the default risk was so high. By mid-November, due to the severe losses of foreign exchange reserves, the IMF finally refused to lend any more financial support. The Argentine default was officially announced in December 2001.

Dealing with the possible misspecification of the dependence relationship[3] for nonnormal data, we used the copula technique to provide robust measures of dependence structures based on the joint distributions of variables. The structure rather than the degree of dependence gives a more comprehensive understanding for relationship between these variables. Moreover, copula can more readily capture the tail dependence arising from the asymmetric extreme observations.

Recent researchers have been concerned over the methodology used to identify the effects of contagion (Longin and Solnik, 2001; Forbes and Rigobon, 2002). Longin and Solnik (2001) have suggested that the Extreme Value Theory (EVT) should be used to study the dependence structure of international equity markets. In this method, the tails of the distribution need to be identified first before the dependence structure of extreme observations can be estimated. Choosing an optimal threshold to identify the extreme values can be difficult.[4] The dependence function used to estimate the threshold may not be well defined. And another problem is the number of parameters in the dependence structures.[5] Typically, logistic function is used to make the estimations, though this solution is less than ideal. For example, Bae *et al.* (2003) develop a multinomial logistic regression model for Asian markets to measure the joint occurrences of large returns. The extreme returns in their model are arbitrarily defined as fifth and ninety-fifth quantiles of return distribution. However, they found it difficult to apply to other markets like in Latin America.

[2] See Dages *et al.* (2005), an overview of the emerging market credit derivatives market, Federal Reserve Bank of New York Working Paper.
[3] Correlations calculated with equal weights assigned to small and large returns are not appropriate for evaluation of return dependence on which extreme values may have different impacts.
[4] Choosing a high value of threshold leads to few observations of return exceedances, and implies inefficient parameter estimates with large SEs. On the other hand, choosing a low value of threshold leads to many observations of return exceedances, though it induces biased parameter estimates. Hence, Longin and Solnik (2001) applied Monte Carlo simulation to determine the optimal threshold values.
[5] For bivariate model in the EVT, there are typically seven parameters to be estimated: two tail probabilities, two dispersion parameters, two tail indexes, and the dependence parameter.

In the present study, we fit the joint distribution of sovereign CDS spreads with various copulas in order to find the best dependence structure to describe their relationship. Specifically, three different copula types were examined: *Gaussian*, *Student's t* and *Gumbel copula*. Of these, the Student's *t*-copula was used to catch the fat-tailed phenomena and the Gumbel copula, an Archimedean-form copula, to capture the right tail dependence. The Gaussian copula served as the benchmark. The functional forms of these copulas are described as follows.

Bivariate Gaussian copula

$$C^{\mathrm{Gau}}(u,z) = \Phi_{\rho_{\mathrm{Gau}}}(\Phi^{-1}(u), \Phi^{-1}(z)) = \int_{-\infty}^{\Phi^{-1}(u)} \int_{-\infty}^{\Phi^{-1}(z)} \frac{1}{2\pi\sqrt{1-\rho_{\mathrm{Gau}}}} \times \exp\left\{ \frac{-\left(x^2 - 2\rho_{\mathrm{Gau}}xy + y^2\right)}{2\left(1-\rho_{\mathrm{Gau}}^2\right)} \right\} \mathrm{d}x\,\mathrm{d}y \tag{1}$$

where u, z are standard uniform variables, ρ_{Gau} is the correlation coefficient and $\Phi^{-1}(u)$ denotes the inverse of the cumulative normal distribution function.

Bivariate Student's t-copula

$$C^t(u,z) = T_{\rho_t,v}\left(t^{-1}(u), t^{-1}(z)\right) = \int_{-\infty}^{t^{-1}(u)} \int_{-\infty}^{t^{-1}(z)} \frac{1}{2\pi\sqrt{1-\rho_t^2}} \left(1 + \frac{x^2 + y^2 - 2\rho_t xy}{v(1-\rho_t^2)}\right)^{-(v+2)/2} dxdy \tag{2}$$

where ρ_t is the correlation coefficient, v is the degrees of freedom and $t^{-1}(u)$ denotes the inverse of the cumulative Student's t distribution function.

Gumbel copula

$$C_\theta^{Gum}(u,z) = \varphi^{-1}[\varphi(u) + \varphi(z)] = \exp\left\{-[(-\ln u)^\theta + (-\ln z)^\theta]^{1/\theta}\right\} \tag{3}$$

where $\theta \in [1, \infty)$ measures the degree of dependence between u and z. $\theta = 1$ implies an independent relationship while $\theta \to \infty$ represents perfect dependence.

Tail dependence refers to the relationship between random variables resulting from extreme observations from the upper and lower quadrants of the joint distribution function. Many evidence indicate that high level of dependence tend to happen during the period of feverish financial market. We expect similar phenomenon for correlated defaults in the sovereign CDS markets.

To measure this dependence, suppose (X, Y) is a bivariate vector of continuous random variables with marginals F_X and F_Y. The coefficient of upper tail dependence, λ_{U}, is defined as:

$$\lambda_{\mathrm{U}} = \lim_{u \to 1} \Pr\left[Y > F_Y^{-1}(u) \middle| X > F_X^{-1}(u)\right] \tag{4}$$

provided that the limit $\lambda_{\mathrm{U}} \in [0, 1]$ exists and the coefficient of lower tail dependence, λ_{L}, is:

$$\lambda_{\mathrm{L}} = \lim_{u \to 0} \Pr\left[Y \le F_Y^{-1}(u) \middle| X \le F_X^{-1}(u)\right] \tag{5}$$

provided that the limit $\lambda_{\mathrm{L}} \in [0, 1]$ exists. The coefficient of tail dependence can be calculated for each tail of the distribution specified by a certain copula function. We summarize below the relevant propositions that can be used to evaluate how the correlated defaults among Latin American countries are related to the Argentina crisis.

Proposition 1: *For bivariate Gaussian copula with linear correlation, ρ_{Gau}, as described in Equation* 1, *the coefficient of tail dependence is null.*

Proposition 2: *For continuously distributed random variables with t-copula $T_{\rho_t,v}$ as described in Equation* 2, *the coefficient of tail dependence is given by*

$$\lambda_{\mathrm{U}} = \lambda_{\mathrm{L}} = \lambda_t = 2 - 2t_{v+1}\left(\sqrt{v+1}\sqrt{\frac{1-\rho_t}{1+\rho_t}}\right) \tag{6}$$

Proposition 3: *For continuously distributed random variables with Gumbel copula C_θ^{Gum} as described in Equation* 3, *the coefficient of upper tail dependence is given by*[6]

$$\lambda_{\mathrm{U}} = 2 - 2^{1/\theta} \tag{7}$$

To estimate and calibrate the parameters in the copula models, we apply Canonical Maximum Likelihood (CML) estimation taking into account the computational efficiency and the nonnormality in our dataset. Using empirical transformation, these parameters can be estimated without specifying the marginals. The sample data can be transformed into uniform variables that can then be used to estimate copula parameters.

[6] Gumbel copula has only upper tail dependence.

Table 1. Summary statistics of CDS spreads before and during the crisis

	Argentina			Brazil			Mexico			Venezuela		
	Pre-crisis period	Crisis period	Ratio of change	Pre-crisis period	Crisis period	Ratio of change	Pre-crisis period	Crisis period	Ratio of change	Pre-crisis period	Crisis period	Ratio of change
Min	470	1288	1.740	140	655	3.679	80.5	142.5	0.770	557.5	612.5	0.099
Q1[a]	1050	1999	0.904	438.8	691.3	0.575	162.5	155	−0.046	572.5	710.6	0.241
Median	1121	1999	0.783	512.5	751.9	0.467	175	158.8	−0.093	590	715	0.212
Mean	1150	2548	1.216	479.3	812.7	0.696	164.5	178.6	0.086	587.8	734.4	0.249
Q3[b]	1263	3325	1.633	572.5	917.5	0.603	175	200	0.143	595	813.4	0.367
Max	2025	3775	0.864	720	1046	0.453	175	246.3	0.407	662.5	815	0.230
p-value[c]	0	0.02		0	0.01		0	0.005		0.004	0.596	

Notes: [a]Q1 represents the first quantile of CDS spread distribution.
[b]Q3 represents the third quantile of CDS spread distribution.
[c]p-value is for normality test in CDS spread distribution of each country.

The CML method is implemented in two stages. First, we transform the sample data into uniform variables using empirical marginal transformation:

$$\hat{u}_{it} = \hat{F}_i(x_{it}) = \frac{1}{T+1}\sum_{j=1}^{T} I\{x_{ij} < x_{it}\} \quad \forall t,\ i = 1, \ldots, n \tag{8}$$

where $I\{\cdot\}$ is an indicator function and x_{ij} is the CDS spread for the sovereign bond i at time j. The CDS spreads can be transformed into uniform variables, $\{\hat{u}_{it}\}$ and then empirical marginals, $\hat{F}_i(x_{it})$, can be obtained. Second, we estimate the copula parameter, $\hat{\delta}$, by maximizing a *pseudo log-likelihood function*.

$$\hat{\delta} = \arg\max \sum_{t=1}^{T} \ln c\Big(\hat{F}_1(x_{1t}), \hat{F}_2(x_{2t}), \ldots, \hat{F}_n(x_{nt});\ \delta\Big) \tag{9}$$

III. Empirical Results

For each of the sample countries, we first summarized their sovereign CDS spreads for the periods before and during the Argentina crisis. As can be seen in the descriptive statistics shown in Table 1, before the crisis, the highest CDS spread was for Argentina. During the crisis, all sovereign CDS spreads increased simultaneously while Argentina's remained the highest. We also calculated the ratios of changes in sovereign CDS spreads over the crisis period for sample countries. Argentina was found to have the greatest change, followed by Brazil. Mexico changed the least. Hence, markets observed higher sovereign risk during the crisis and requested more credit spreads, presumably because the number of protection buyers exceeded the number of protection sellers in the CDS market. A simultaneous increase in all sovereign CDS spreads indicates the higher possibility of joint defaults. In particular, the large increase in Brazil and small increase in Mexico reflect the relationships described in dependence structures we found, which will be discussed in the following text.

To study the relationship of CDS spreads between Argentina and other sovereigns, their scatter diagrams were plotted in Fig. 1. We observed two relevant findings. First, before the crisis period, the relationship of spreads between Argentina and Brazil was almost linear, while no clear relationship was seen between Argentina and Mexico or Venezuela. Second, we found that during the crisis period there was tail dependence for CDS spreads, no matter which country was paired with Argentina. The clusters appeared in both right and left tails. This finding is consistent with results from the nonlinear contagious models recently developed by Longin and Solnik (2001), Bae *et al.* (2003) and Dungey and Tambakis (2003).

We performed Jarque–Bera test to access the normality of distribution of the CDS spread (Table 1). Our samples were found to have non-normal distributions, consistent with the result of previous studies. Because we observed both nonnormal and nonlinear properties, we calculated Pearson's ρ[7], Kendall's τ and Spearman's ρ to further

[7] We understand that Pearson correlation indicates the strength of a linear relationship between two variables. Its value alone is not sufficient to evaluate the relationship in our dataset. We use it to enquire whether correlations are under- or overstated, if data are nonlinear. Similarly, the nonparametric rank correlations, Kendall and Spearman measures, are less sensitive to the observations in the tails. We calculate all these measures as preliminary tests of correlations and mainly for the purpose of comparison. It strengthens the need for copula analysis.

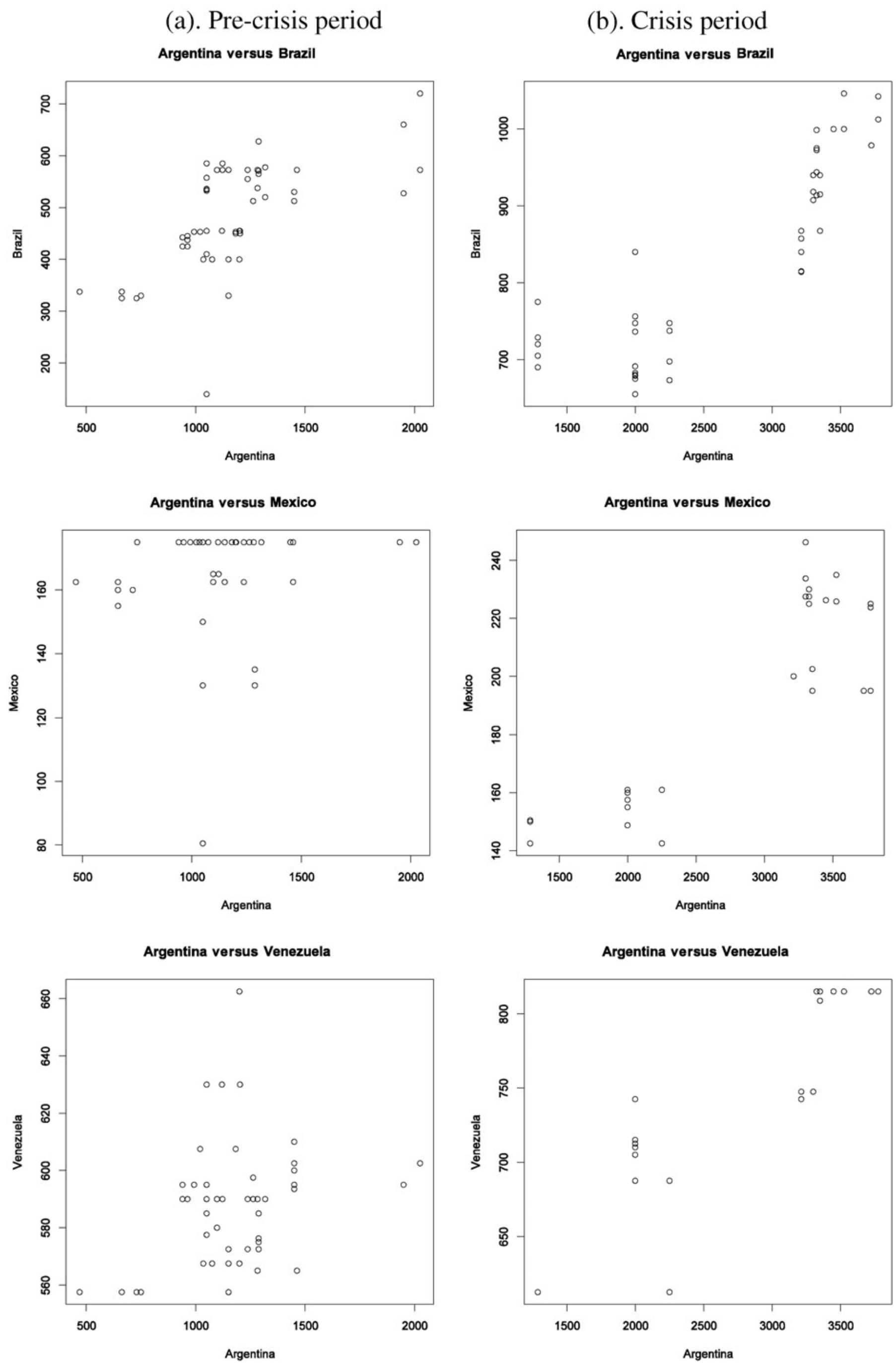

Fig. 1. (a) Shows the relationship of CDS spreads between Argentina and other sovereigns during pre-crisis period, while (b) shows their relationships during the crisis period

analyse the biases (Table 2). Pearson's ρ, compared with the other two measures, seems to overstate all the correlations during the crisis period, indicating possible misspecifications of the dependence structures. Meanwhile, the association between Argentine CDS spreads and those of any other country was higher during the crisis than before it, supporting Forbes and Rigobon's (2002) argument that contagion exists if cross-market comovement increases significantly after the shock.

Because of the nonnormal property of our data, we used the semi-parametric CML procedure to estimate and calibrate the parameters in copula models. Both before and during the crisis, all three models had positive copula parameters (Panel A of Table 3), suggesting that sovereign CDS spreads of Argentina

Table 2. Measure of association between pair countries before and during the crisis

Paired countries	Pre-crisis period, Argentina versus			Crisis period, Argentina versus		
	Brazil	Mexico	Venezuela	Brazil	Mexico	Venezuela
Pearson ρ^{a}	0.556	0.205	0.303	0.883	0.900	0.889
Kendall τ^{b}	0.443	0.267	0.188	0.671	0.570	0.723
Spearman ρ^{c}	0.587	0.336	0.267	0.800	0.758	0.840

Notes: [a]Pearson's ρ is a measure of linear dependence.
[b]$\tau = 4\iint_{I^2} C(u_1, u_2)\mathrm{d}C(u_1, u_2) - 1$.
[c]$\rho = 12\iint_{I^2} u_1 u_2 \mathrm{d}C(u_1, u_2) - 3$

Table 3. Parameter estimations and goodness-of-fit test for copula functions

Paired countries	Pre-crisis period, Argentina versus			Crisis period, Argentina versus		
	Brazil	Mexico	Venezuela	Brazil	Mexico	Venezuela
Panel A: Copula estimation						
Gaussian						
$\rho_{\mathrm{Gau}}{}^{a}$	0.579 (0.0000)	0.174 (0.0005)	0.293 (0.0024)	0.729 (0.0000)	0.701 (0.0101)	0.772 (0.0023)
ln L	22.108	5.939	4.613	28.292	23.767	36.544
Student'st						
$\rho_t{}^{b}$	0.443 (0.0005)	0.267 (0.0023)	0.188 (0.0471)	0.671 (0.0000)	0.570 (0.0041)	0.723 (0.0014)
v	114	114	114	5	86	86
$\ln L$	19.818	3.952	3.845	28.689	21.278	35.645
Gumbel						
θ^{c}	1.427 (0.0002)	1.054 (0.099)	1.070 (0.654)	2.198 (0.0000)	1.615 (0.0052)	1.834 (0.0013)
$\ln L$	14.483	3.991	0.501	38.067	13.661	37.517
Panel B: Goodness-of-fit test (AIC)[d]						
Gaussian	−42.217	−9.877	−7.226	−54.584	−45.535	−71.088
Student'st	−35.637	−3.905	−3.691	−53.379	−38.556	−67.290
Gumbel	−26.967	−5.982	0.998	−74.134	−25.321	−73.034
Panel C: Goodness-of-fit test (SBC)[e]						
Gaussian	−39.479	−7.141	−4.489	−52.129	−43.079	−68.633
Student'st	−34.899	−3.167	−2.953	−52.923	−38.101	−66.835
Gumbel	−24.229	−3.245	3.734	−71.679	−22.867	−70.579

Notes: [a]ρ_{Gau} is the correlation parameter of Gaussian copula.
[b]ρ_t is the correlation parameter of Student's *t*-copula. v is the degree of freedom of the Student's *t*-copula.
[c]θ is the dependence parameter of Gumbel copula.
[d]The choice of the best fit in Panel B is based on the value of AIC, $\mathrm{AIC} = -2L(\hat{\theta}; x) + 2q$, where q is the number of parameters to be estimated in each specific model.
[e]The choice of the best fit in Panel C is based on the value of SBC, $\mathrm{SBC} = -2L(\hat{\theta}; x) + q \ln T$, where q is the number of parameters to be estimated in each specific model and T is the sample size.

positively comoved with those of other countries in Latin America. Furthermore, the degree of this association increased more during the crisis period than before. For example, ρ_{Gau} of the Gaussian copula increased from 0.579 to 0.729 for Argentina with Brazil, from 0.174 to 0.701 with Mexico and from 0.293 to 0.772 with Venezuela. Results were similar when the Student's t or the Gumbel copula was used.

Financial integration and mutual trading among Latin American countries may be the reason for the strong comovement during the crisis. Most of the effects of the Argentine debt crisis were transmitted through financial channels because these countries have common lenders and foreign investors (Kaminsky and Reinhart, 2002). The default of Argentine sovereign bond may have caused correlated defaults of other sovereign bonds. Once the crisis occurred in Argentina, the investors started adjusting their holdings in other related countries to respond to the changes in liquidity and asset quality.

As a result, sovereign CDS spreads can serve as one of the leading indicators for externally-induced financial crisis. Therefore, this spread can be used by policymakers to prepare their countries for imminent turmoil and mitigate it. The IMF need consider the impact of credit contagion when assessing the effectiveness of interventions for a particular country. It can also be expected that banks and fund managers will ask higher credit premiums to compensate for potential correlated default.

Moreover, regardless of the sample periods and copula functions, estimated parameters of dependence for Brazil are larger than those for Mexico or Venezuela, meaning that Brazil would be more vulnerable to credit contagion from Argentina. During the crisis period, the Brazilian currency devaluation against the dollar accelerated. The Brazilian real fell 2.3% in June, 5.5% in July and 10% in late September. Although there were five increases of interest rate that occurred during 2001, the Brazilian real fell by 23%. The big drop in exchange rate devastated Brazil's dollar-denominated debt. Hence, Brazil's vulnerability during the financial crisis was very similar to that of Argentina.

In contrast, Mexico was better able to maintain its overall economic growth since it is related to the United States more through the North American Free Trade Agreement than to other countries in Latin America. This link has made its economy the brightest in the Latin American region. Our results showed that Mexico stayed on the sideline of turbulence. Regardless of the copula functions used, the estimated parameter of dependence appeared to be the smallest for Mexico during the crisis period.

Moody's rating of Mexico's sovereign credit was upgraded to Baa3 in early 2000. Since that time, comovements between Mexico's sovereign bonds and those of other Latin American countries were less correlated (Rigobon, 2002). Actually, investors could have expanded their Mexican holdings for portfolio reasons.[8] despite the shocks in Argentina. Due to this relative immunity to the contagion from Argentine crisis, three rating agencies rated Mexico's long-term foreign currency sovereign debt as investment grade in 2002.[9]

The choice of the best fit of copula function is based on the value of Akaike Information Criterion (AIC). From the maximized log-likelihood values ($\ln L$) in Panel A of Table 3, we compute the AIC for each copula and then rank the copula models accordingly. Panel B of Table 3 shows the AIC values for three chosen copulas. For the sample period before the crisis, we found that the Gaussian copula showed the lowest AIC value for each pair of dependences. They were −42.217, −9.877 and −7.226, respectively, indicating that the Gaussian copula was the best fitting model before the crisis and that there was no tail dependence between CDS spreads of Argentina and those of other countries. During the crisis period, however, the Gumbel copula represented the lowest AIC value for Brazil and Venezuela, but not for Mexico. The consistent results can also be found using Schwartz Bayesian Criteria (SBC). The evidence suggests that the right tail dependence is presented for Brazil and Venezuela. The sovereign CDS of Brazil and Venezuela were found to be significantly dependent on those of Argentina with such extreme increases in Argentina's sovereign spread.

In contrast, for Mexico where the Gaussian was still the best model, there was no tail dependence with Argentina, even during that crisis. The right tail dependences we observed for Brazil and Venezuela indicate that once contagion happens, these two countries will be more severely affected than Mexico. The impact will be underestimated if only Pearson correlation or Ordinary Least Square (OLS) regression are used. The insignificant spillover from Argentina to Venezuela found in Chan-Lau (2003) may be caused by such conventional methods.

To further examine the dependence in the tails, we compared the coefficients of tail dependence in the Student's t and the Gumbel copulas computed based on Propositions 2 and 3. Since the t distribution was symmetric, its estimated coefficients capture the tail dependence on both sides. The coefficients from the Gumbel copula, on the other hand, represent only the upper tail dependence. As shown in Table 4, tail

[8] Investment-grade rating promotes holdings from investors such as mutual funds or pension funds with restricted investment policies

[9] Fitch first upgraded Mexican sovereign bond from double B plus to triple B minus in January 2002, while Moody's upgraded it from Baa3 to Baa2 in February 2002. Standard and Poor (S&P) reacted promptly the next day after Moody's announcement.

Table 4. Coefficients of tail dependence

	Pre-crisis period			Crisis period		
	Argentina versus			Argentina versus		
Paired countries	Brazil	Mexico	Venezuela	Brazil	Mexico	Venezuela
Student's t λ_t [a]	0.000	0.000	0.000	0.319	0.000	0.000
Gumbel λ_U [b]	0.375	0.070	0.089	0.629	0.464	0.541

Notes: [a]

$$\lambda_t = 2 - 2t_{v+1}(\sqrt{v+1}\sqrt{\frac{1-\rho_t}{1+\rho_t}}).$$

[b] $\lambda_U = 2 - 2^{1/\theta}$, where θ is its dependence parameter. If $\lambda_U > 0$, Gumbel copula has upper tail dependence.

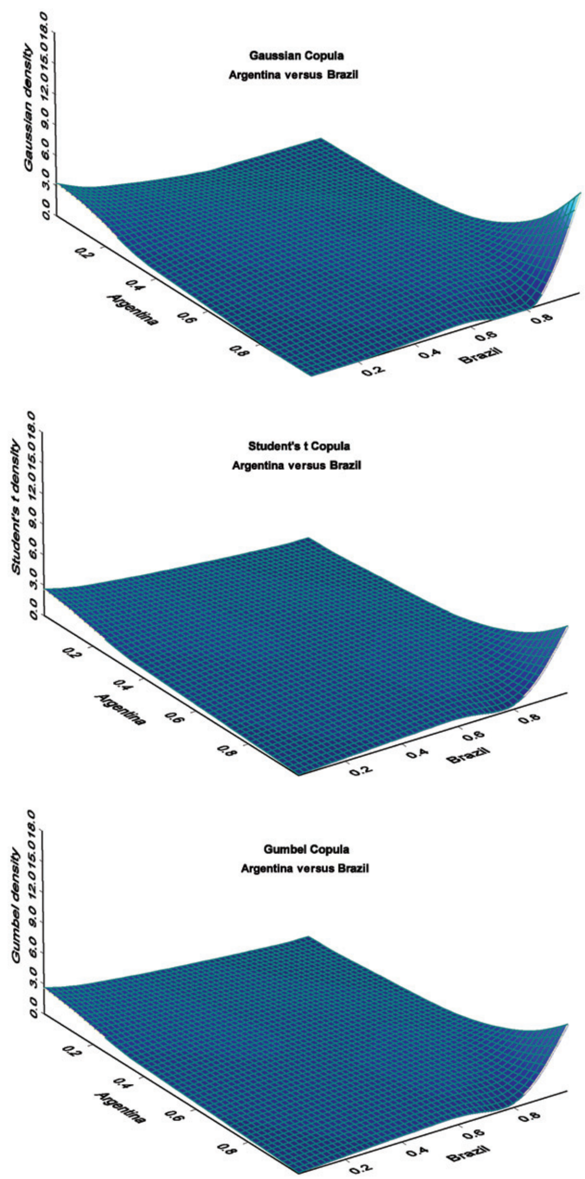

Fig. 2. Copula density plots for the pre-crisis period

Note: A three-dimensional figure which contains Argentine empirical marginals in x-axis, Brazilian empirical marginals in y-axis and their joint default probabilities, specified by the Gaussian, Student's t and Gumbel copulas, respectively, in z-axis for the pre-crisis period.

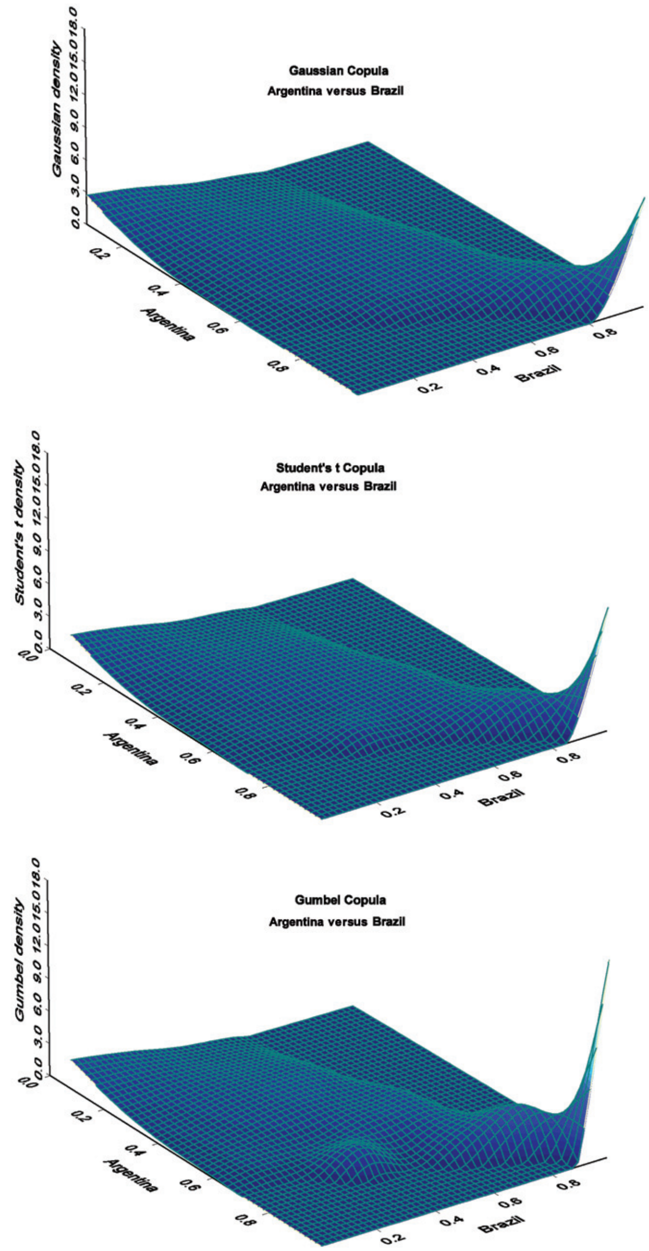

Fig. 3. Copula density plots for the crisis period
Note: A three-dimensional figure which contains Argentine empirical marginals in x-axis, Brazilian empirical marginals in y-axis and their joint default probabilities, specified by the Gaussian, Student's t and Gumbel copulas, respectively, in z-axis for the crisis period.

dependences were not significant before the crisis. However, during the crisis, we found remarkable Gumbel coefficients of 0.629 and 0.541 for Brazil and Venezuela, respectively. We conjecture that sovereign bond investors perceive these countries as a group when crisis occurs.

Given the estimated copula parameters, the surface of the copula densities can be expressed by Equations 1–3. Comparing the densities for Argentina and Brazil before the crisis (Fig. 2) and during the crisis (Fig. 3), we could clearly observe their joint probability distributions and dependence structures. For all copula densities, there were no tail dependences before the crisis. However, remarkable spikes in the right tails for all copulas were observed during the crisis. As can be seen in Fig. 4, where the Gumbel copula for each pair of countries is plotted, there was notable right tail dependence for Brazil, whereas, as we have expected, none for Mexico.

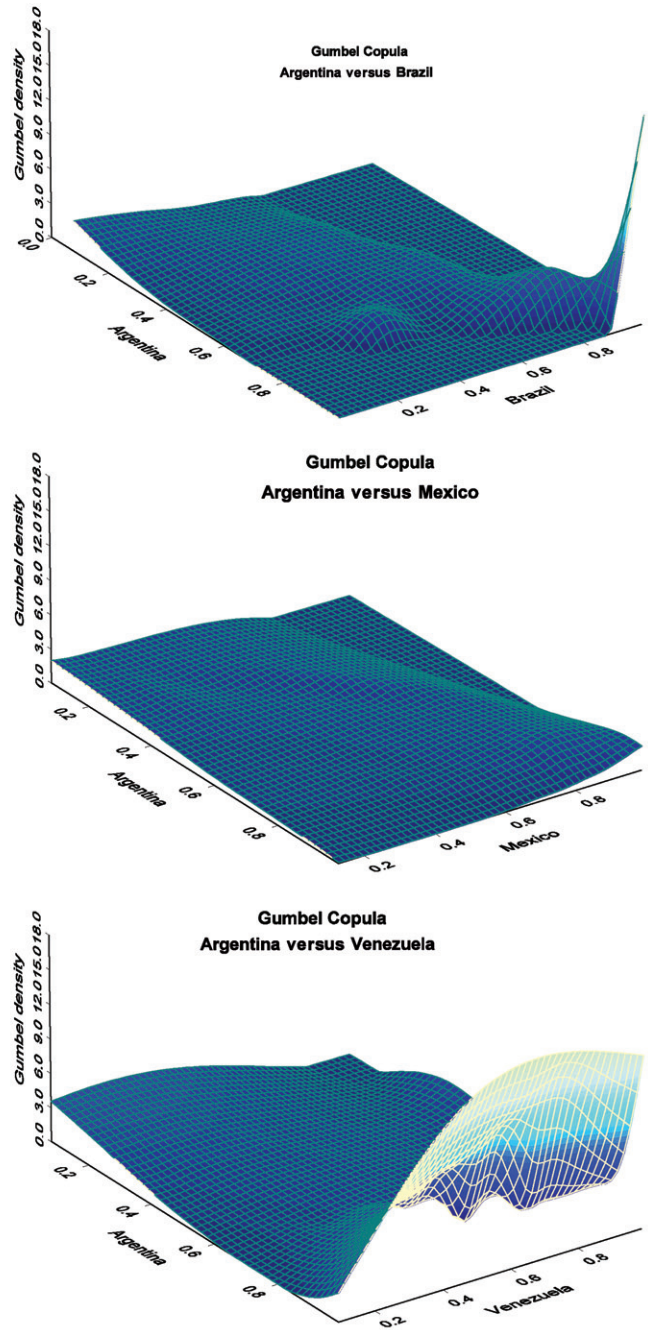

Fig. 4. Tail dependence display from the Gumbel copulas (crisis period)
Note: Focus on the Gumbel copula in the crisis period where Argentine empirical marginals in x-axis, other sovereigns' empirical marginals in y-axis and their joint default probabilities in z-axis.

IV. Conclusion

Research on sovereign CDS has important implications for a better understanding of sovereign risk behaviour. Because default expectation can be extracted from CDS spreads, their dependence structures help us specify how sovereign risks are correlated. Increasing integration of international markets makes credit contagion more common than before, especially in times of financial crisis. In this study, we measured the dependence structure of sovereign defaults using the copula method, a method able to consider the nonlinear relationship and evaluate the different impacts from extreme observations. Our results should be useful for policymakers, foreign investors as well as the international bankers.

Using daily closing quotes of sovereign CDS of Argentina, Brazil, Mexico and Venezuela for the periods before and during the crisis, we found that dependences between sovereign CDS spreads increased significantly during the crisis period. Before the crisis, there was no tail dependence between Argentina and other countries, making the Gaussian copula the best fitting model for that period. However, during the crisis, the Gumbel copula performs best for Brazil and Venezuela, but not for Mexico, reflecting the different credit risk relationship. The right tail dependence we observed indicated that Brazil and Venezuela were more seriously impacted by the Argentina crisis than Mexico once contagion started. This effect would have been underestimated had it been specified by the linear correlation. The difference in credit dependence among these countries is related to sovereign's creditworthiness. The higher the credit ranking the country has, the milder the contagion effect it suffers.

Understanding the correlated default at sovereign level is important in pricing sovereign bond, designing sovereign risk derivatives, managing country risk, analysing portfolio allocations and supervising financial markets. Besides the nature of correlation, how is the credit relationship affected? What are the factors determining this dependence structure? How long does this contagious effect take place? These are interesting issues left to be explored in future studies.

References

Avellaneda, M. and Wu, W. (2001) Credit contagion: pricing cross-country risk in Brady debt markets, *International Journal of Theoretical and Applied Finance*, **4**, 921–38.

Bae, K. H., Karolyi, G. A. and Stulz, R. M. (2003) A new approach to measuring financial contagion, *Review of Financial Studies*, **16**, 717–63.

Beattie, J. (2000) Contagion in Latin America: an analysis of credit derivatives, Duke University Working Paper, Durham, NC.

Bekaert, G., Harvey, C. R. and Ng, A. (2005) Market integration and contagion, *Journal of Business*, **78**, 39–69.

Berg, A. and Patillo, C. (1999) Are currency crises predictable? A test, *IMF Staff Papers*, **46**, 107–38.

Bustillo, I. and Velloso, H. (2000) Bond markets for Latin American debt in the 1990s, *Temas de Coyuntura Series*, **12**, 1–41.

Caporale, G. M, Cipollini, A. and Spagnolo, N. (2005) Testing for contagion: a conditional correlation analysis, *Journal of Empirical Finance*, **12**, 476–89.

Chan-Lau, J. A. (2003) Anticipating credit events using credit default swaps, with an application to sovereign debt crises, IMF Working Paper.

Copeland, L. and Jones, S. A. (2001) Default probability of European sovereign debt: market-based estimates, *Applied Economics Letters*, **8**, 321–4.

Dages, B. G., Palmer, D. and Turney, S. (2005) An overview of the emerging market credit derivatives market, report of Federal Reserve Bank of New York.

Dungey, M. and Tambakis, D. (2003) *Identifying International Financial Contagion: Progress and Challenges*, Oxford University Press, USA.

Edison, H. J. (2003) Do indicators of financial crises work? An evaluation of an early warning system, *International Journal of Finance and Economics*, **8**, 11–53.

Elkinawy, S. (2005) Mutual fund preferences for Latin American equities surrounding financial crises, *Emerging Market Review*, **6**, 211–37.

Embrechts, P., McNeil, A. and Straumann, D. (1999) Correlation: pitfalls and alternatives, *Risk Magazine*, **May**, 69–71.

Ene, R. and Vlad, S. (2002) Forecasting spreads in emerging markets debts using credit default swaps: a Kalman filter approach, Thesis of University of Lausanne.

Forbes, K. J. (2004) The Asian flu and Russian virus: the international transmission of crises in firm-level data, *Journal of International Economics*, **63**, 59–92.

Forbes, K. J. and Rigobon, R. (2002) No contagion, only interdependence: measuring stock market comovements, *Journal of Finance*, **57**, 2223–61.

Gelos, R. G. and Wei, S. J. (2005) Transparency and international portfolio holdings, *Journal of Finance*, **60**, 2987–3020.

Genius, M. and Strazzera, E. (2008) Applying the copula approach to sample selection modeling, *Applied Economics*, **40**, 1443–55.

Han, K. C., Lee, S. H. and Suk, D. Y. (2003) Mexican peso crisis and its spillover effects to emerging market debt, *Emerging Markets Review*, **4**, 310–26.

Hu, L. (2006) Dependence patterns across financial markets: a mixed copula approach, *Applied Financial Economics*, **16**, 717–29.

Jondeau, E. and Rockinger, M. (2006) The copula-GARCH model of conditional dependencies: an international stock market application, *Journal of International Money and Finance*, **25**, 827–53.

Kaminsky, G. L. and Reinhart, C. M. (2002) Financial markets in times of distress, *Journal of Development Economics*, **69**, 451–70.

Kan, K. (1998) Credit spreads on government bonds, *Applied Financial Economics*, **8**, 301–13.

Kraay, A., Loayza, N. and Serven, L. (2004) Country portfolio, The World Bank Working Paper.

Longin, F. and Solnik, B. (2001) Extreme correlation of international equity market, *Journal of Finance*, **56**, 649–76.

Mauro, P., Sussman, N. and Yafeh, Y. (2002) Emerging market spreads: then versus now, *The Quarterly Journal of Economics*, **117**, 695–733.

Neftci, S., Santos, A. O. and Lu, Y. (2005) Credit default swaps and financial crisis prediction, Working Paper of ISMA Center, University of Reading.

Ranciere, R. G. (2002) Credit derivatives in emerging markets, IMF Working Paper.

Rigobon, R. (2002) The curse of non-investment grade countries, *Journal of Development Economics*, **69**, 423–49.

Sander, H. and Kleimeier, S. (2003) Contagion and causality: an empirical investigation of four Asian crisis episodes, *Journal of International Financial Markets, Institutions and Money*, **13**, 171–86.

Turgutlu, E. and Ucer, B. (2009) Is global diversification rational? Evidence from emerging equity markets through mixed copula approach, *Applied Economics*, in press.

Yang, J. (2005) Government bond market linkages: evidence from Europe, *Applied Financial Economics*, **15**, 599–610.