Default correlation at the sovereign level: Evidence from Latin American markets

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Abstract: 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 *Credit Trade database*. Using copula approach, we observed increased correlations 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 in the governments.

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1. Introduction

Sovereign risk plays an important role in the international financial market, particularly in the presence of economic distress. In a world of increasing economic interdependencies, especially for emerging markets, the issues of credit contagion are of critical concern when one country is undergoing a financial crisis. (Gelos and Wei , 2005; Bekaert, et al., 2005; Elkinawy, 2005; Caporale, et al, 2005; Forbes, 2004; Han et al., 2003). Credit contagion refers to the credit deterioration of a country that indirectly leads to credit 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 bond default. In order to characterize the correlations that may exist among sovereign bonds during a financial crisis, we collected data on sovereign CDS spread from *Credit Trade* database for Latin American markets and used copula method to analyze the possible correlations among them and the nature of the credit contagion in that region.

Recent literature has shown evidence of contagion in equity markets (Jondeau and Rockinger, 2006; Bekaert et al., 2005; Longin and Solnik, 2001; Forbes and Rigobon, 2002). Relatively few studies focus on bond and credit derivative markets (Han et al., 2003; Sander and Kleimeier, 2003; Beattie, 2000). Neftci (2005) argues that financial crises are never caused by market risk in emerging markets. Instead, they are precipitated by events such as currency devaluation or sovereign bond default. Compared with comovement in equity, foreign exchange, and domestic money markets, comovement in bond markets, particularly in the case of sovereign bonds, is strongest during times of distress in emerging markets. According 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 be increasing, for, as Mauro et al. (2002) have found, sovereign spreads today comove across emerging markets significantly more than they did historically (1870-1913). Finally, bond spread may not only be a response to economic conditions. Like stocks, it is also a response to market sentiment (Bustillo and Velloso, 2000). Although each country has different economic fundamentals, Latin American countries are often lumped into the same risk group, making issues of financial volatility and contagion particularly important to them.

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, managers of the mutual funds control their exposure to correlated sovereign risk by either diversifying allocations or charging higher premiums. Those correlated charges embedded in sovereign bond spreads are regarded as part of the country risk premium (Baek, et al., 2005). So if there is a credit contagion, the market premium for sovereign risk may be affected. Kraay et al. (2004) take sovereign risk into account when modeling 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 national and international monetary policies. At the national level, we argue that the comovement in sovereign credit default swaps can serve as an important indicator of financial crises and can be used to compensate for other indicators, many based on fundamental variables, which have been proven to have poor predictive power (Berg and Patillo, 1999; Edison, 2003).

At the international level, the comovement in sovereign credit default swaps could be used by the IMF to predict the possibility of a forthcoming contagious crisis. Since an emerging market crisis can potentially create turbulence in international financial markets, we first empirically study the possible correlation between sovereign bonds of Argentina during its 2001 debt crisis and those of other Latin American countries at that time.

The rapid growth in Latin American bond market is frequently affected by financial crises (Bustillo and Velloso, 2000). Compared with Asia, Europe, and G-7countries, Latin America exhibits the most significant comovement in bond markets (Kaminsky and Reinhart, 2002). The Argentina debt crisis provided a unique opportunity to design a natural study of the effect of correlated default among Latin American countries, because the Argentina debt represented from one-fifth to one-quarter of tradable issues in the emerging bond markets at that time. Latin American sovereign bonds are held by investors worldwide, and according to IMF, a loss of confidence in Argentina can rapidly become contagious. Because credit default swaps reflect sovereign risk and because they are used by investors to assess a country's economic and political fundamentals, we use them to directly examine sovereign risk contagion in the region.

In this study, we first test whether correlations 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. Typically, empirical distributions of financial asset returns are noted to be non-normal and to exhibit fat-tail behavior, which may be best analyzed using a non-linear model (Longin and Solnik, 2001; Bae et. al., 2003; Dungey and Tambakis, 2003; Quintos et. al., 2001; Favero and Giavazzi, 2002). Therefore, we used a copula-based measure to specify the structure of dependence as well as the degree of dependence to test this correlation, which would not only take the non-linear property into account but would also allow a more comprehensive understanding of correlated default. Second, we examined whether the dependence structures 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 estimated separately, thereby not able to provide consistent results. Finally, we examined whether the credit quality of sovereign bonds was related to the degree of credit dependence in these countries. Higher ratings may indicate that investors are better informed and more stable. Because such investors are less easily shaken, the magnitude of credit contagion in countries where they have invested is reduced.

We found significant correlation in sovereign CDS spread among these Latin American countries during the Argentina debt crisis. The sudden Argentine sovereign default 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 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.

Empirical studies on sovereign risk of emerging countries are few and most of them focus on bond issues. We limit our study to CDS markets because credit risk is our primary concern (Blanco et al., 2005; Norden and Weber, 2004; Benkert, 2004). Our findings can provide insights useful to both policymakers and potential investors in emerging markets. Methodology we use to identify the contagion is a response to the calls by Bae et. al. (2003) and Dungey and Tambakis (2003) for the need to develop nonlinear models of relationship.

The rest of the paper is organized as follows. Section 2 describes the data and methodology. Empirical results are analyzed in Section 3. Finally Section 4 concludes.

2. Data and methodology

The trading of credit derivatives in Latin America accounts for 50-60% of the overall market shares available in credit derivatives markets in emerging countries

(Ranciere, 2002). According a survey[1] by Federal Reserve Bank of New York in 2005, sovereign single-name credit default swaps appear to be the most liquid of the major products in these credit derivatives markets. 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 obligation of the protection seller is to buy the bonds issued by the reference country at its par value when a credit event occurs before CDS contract matures.

We collected the daily closing mid market quotes in the year of 2001 for sovereign CDS of Argentina, Brazil, Mexico and Venezuela with a two-year maturity from *Credit Trade* database. 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 stopped 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

[1] See Dages et al. (2005), an overview of the emerging market credit derivatives market, Federal Reserve Bank of New York Working Paper.

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.

When studying the contagion caused by Argentina crisis to its Latin American neighbors, we would be faced with the possibility that measurements based on linear correlation would lead to misspecification of the dependence relationship, particularly if data was found to be non-normal. Therefore, we used the copula technique to take advantage of its ability 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, due to possible asymmetry, copula can more readily capture the tail dependence arising from the extreme observations.

Recent researchers have been concerned over the methodology used to identify the effects of contagion (Forbes and Rigobon, 2002; Longin and Solnik, 2001). They argue that, because sensitivity to contagion is highly non-linear, 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. Longin and Sonik (2001) have suggested that the Extreme Value Theory (EVT) be used to study the dependence structure of international equity markets. To use EVT, 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 in this theory can be difficult[2]. The dependence function used to estimate the threshold may not be well defined. Typically, logistic function is used to make this estimation, though this solution is less than ideal. Another problem is the number of parameters in the dependence structures[3]. Bae et al. (2003) concentrate on measuring the joint occurrences of large returns to develop a multinomial logistic regression model[4]. They found that their model, which was used to explain the distribution of co-exceedance of index returns for Asian markets, was not easily applied to the markets of Latin America. In the present study, we apply a copula method in order to develop a model capable of capturing the nonlinearities in the dependence structure and endogenizing the threshold issue in EVT.

We fit the joint distribution of sovereign CDS spreads with various copulas in order to find the dependence structure best able to describe their relationship.

[2] Choosing a high value of threshold leads to few observations of return exceedances, and implies inefficient parameter estimates with large standard errors. 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 Sonik (2001) applied Monte Carlo simulation to determine the optimal threshold values.

[3] 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.

[4] The extreme returns in their model are defined arbitrarily as 5th and 95th quantiles of return distribution.

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

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

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

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

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

Gumbel Copula

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

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. Much evidence indicates that high level of dependence tends 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:

$$\lambda_U = \lim_{u \to 1} \Pr\left[Y > F_Y^{-1}(u) \mid X > F_X^{-1}(u)\right], \tag{4}$$

provided that the limit $\lambda_U \in [0,1]$ exists, and the coefficient of lower tail dependence, λ_L, is:

$$\lambda_L = \lim_{u \to 0} \Pr\left[Y \le F_Y^{-1}(u) \mid X \le F_X^{-1}(u)\right], \tag{5}$$

provided that the limit $\lambda_L \in [0,1]$ 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

$$\lambda_U = \lambda_L = \lambda = 2 - 2t_{v+1}\left(\sqrt{v+1}\frac{\sqrt{(1-\rho_t)}}{\sqrt{(1+\rho_t)}} \right) \tag{6}$$

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[5]

$$\lambda_U = 2 - 2^{1/\theta} \tag{7}$$

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 non-normality in our data set. 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. The CML method is implemented in two stages. First, we transform the sample data into uniform variables using the above-mentioned empirical marginal transformation:

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

[5] Gumbel copula only has upper tail dependence.

where $I\{.\}$ is the indicator function and x_{ij} CDS spread for sovereign bond i at time j. In this way, the CDS spreads can be transformed into uniform variables, $\{\hat{u}_{it}\}$, and 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*.

$$\hat{\delta} = ArgMax_{\delta}\sum_{t=1}^{T}\ln c\left(\hat{F}_1(x_{1t}),\hat{F}_2(x_{21t}),.......,\hat{F}_n(x_{nt});\delta\right) \tag{9}$$

3. 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. The simultaneous increases in all sovereign CDS spreads suggest the possibility of credit contagion among these countries. 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 below, for Argentina and these countries.

[Insert Table 1 here]

To study the relationship of CDS spreads between Argentina and other sovereigns, their scatter diagrams were plotted in Figure 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 non-linear contagious models recently developed by Longin and Sonik (2001), Bae et. al. (2003), Dungey and Tambakis (2003).

[Insert Figure 1 here]

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 non-normal and non-linear properties, we calculated Pearson’s rho, Kendall’s tau and Spearman’s rho to further analyze our data (Table 2). Pearson’s rho, compared with the other two measures, seems to overstate all the correlations during the crisis period, indicating possible misspecifications of the dependence structures. Meanwhile, regardless of which coefficient was used, 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.

[Insert Table 2 here]

Because of the non-normality property of our data, we used *Canonical Maximum Likelihood* (CML) procedure, a semi-parametric method, to estimate and calibrate the parameters in copula models. Both before and during the crisis, all three models had positive copula parameters (Panel A Table 3), suggesting that sovereign CDS spreads of Argentina 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 Gaussian copula increased from 0.579 to 0.729 for Argentina with Brazil, Mexico (0.174 to 0.701) and Venezuela (0.293 to 0.772). Results were similar when Student's t or Gumbel copula was used.

[Insert Table 3 here]

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 changes in liquidity and asset quality. However, the scope of contagion was limited to the Latin American region, further confirming the linkage of financial channels to the contagion when crisis is anticipated (Didier et. al., 2006).

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 must 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 correlation 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 percent in June, 5.5 percent in July and 10 percent in late September. Although there were five increases of interest rate that occurred during 2001, the Brazilian real fell by 23 percent. 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 its southern neighbors. 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 correlation appeared to be the smallest for Mexico during the crisis period.

Moody's rating of Mexcio'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[6] 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[7]. The choice of the best fit of copula function is based on

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

[7] 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. S&P reacted promptly the next day after Moody's announcement.

the value of Akaike information criterion (AIC)[8]. From the maximized log-likelihood values (lnL) 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 Gaussian copula showed the lowest AIC value for each pair of dependences. They were -42.217, -9.877 and -7.226, respectively, indicating that 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 evidence suggests that the right tail dependence is present 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, in 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 impacted than Mexico. The impact may be underestimated if only conventional linear methods such as Pearson correlation or OLS

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[8] $AIC = -2L(\hat{\theta}; x) + 2q$. where q is the number of parameters needed to be estimated in each specific model. Both Gaussian and Gumbel copulas need to estimate one parameter, i.e., ρ_{Gau} and θ, respectively, while the Student's t copula has two correlation parameters ρ_t and degree of freedom ν.

regression are used. The insignificant spillover from Argentina to Venezuela found by Chan-Lau (2003) may be because such conventional estimations were used.

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

[Insert Table 4 here]

Given the estimated copula parameters, the surface of the copula densities can be expressed by equation (1), (2) and (3). Comparing the densities for Argentina and Brazil before the crisis (Figure 2) and during the crisis (Figure 3), we could easily and 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 Figure 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.

[Insert Figure 2 here]

4. Conclusion

Research on sovereign CDS has important implications for a better understanding of sovereign risk behavior. 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 significant than before, especially in times of financial crisis. Thus, the issue of correlated sovereign defaults has critical implications for policymakers, foreign investors and international bankers. In this study, we measured the dependence structure of sovereign defaults using the copula method, a method able to consider the non-linear relationship and evaluate the different impacts from extreme observations.

The Argentina debt crisis provided us a unique opportunity to study the effect of correlated default among countries in Latin America, the largest regional credit market in the world. Using daily closing quotes of sovereign CDS of Argentina, Brazil, Mexico and Venezuela for the periods before and during the crisis, we found that correlations between sovereign CDS spreads increased significantly during the crisis period. Before the crisis, there was no tail dependence between Argentina and other countries, making Gaussian copula the best fitting model for that period. However, during the crisis period, 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 Brazil and Venezuela was more seriously impacted by the Argentina crisis than Mexico once credit contagion started in Argentina. This effect would have been underestimated if it had been specified by linear correlation alone. The difference in credit dependence among these countries is probably related to sovereign's creditworthiness, with the higher the credit ranking the country has, the milder contagion it suffers.

A comprehensive understanding of correlated default at sovereign level is an important component in sovereign bond pricing, design of sovereign risk derivatives, country risk management, portfolio credit analysis, and supervision of financial markets. Besides the nature of correlated default, 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.

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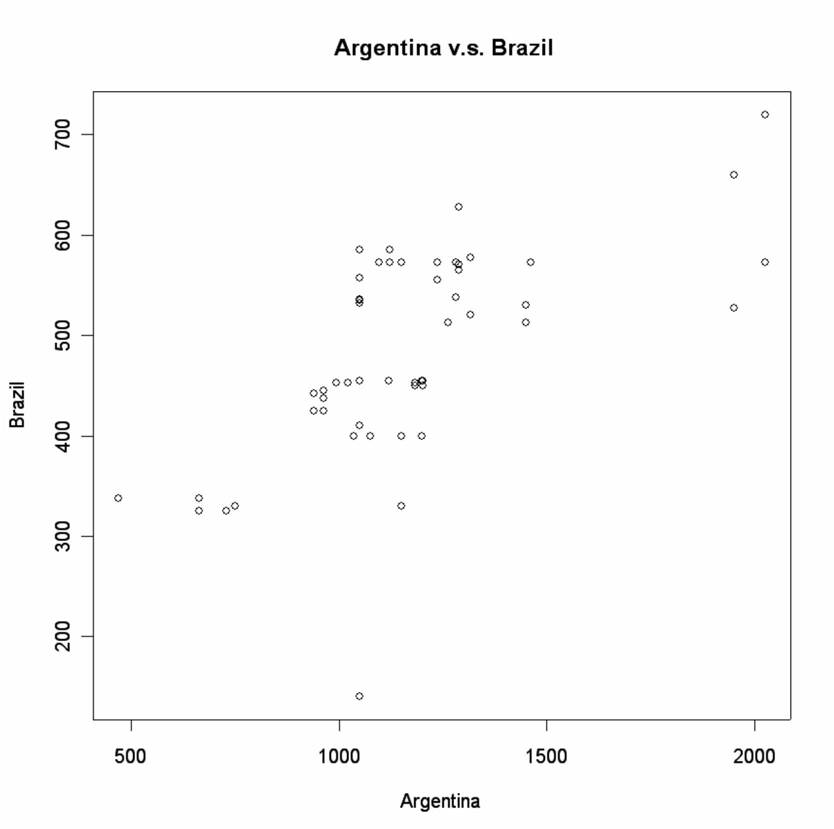
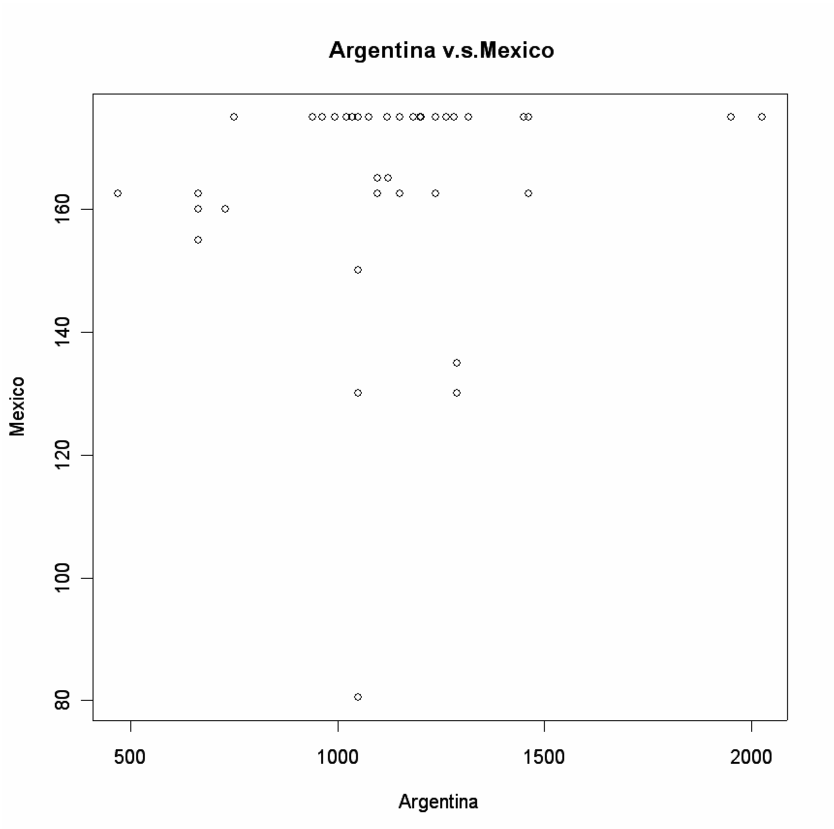
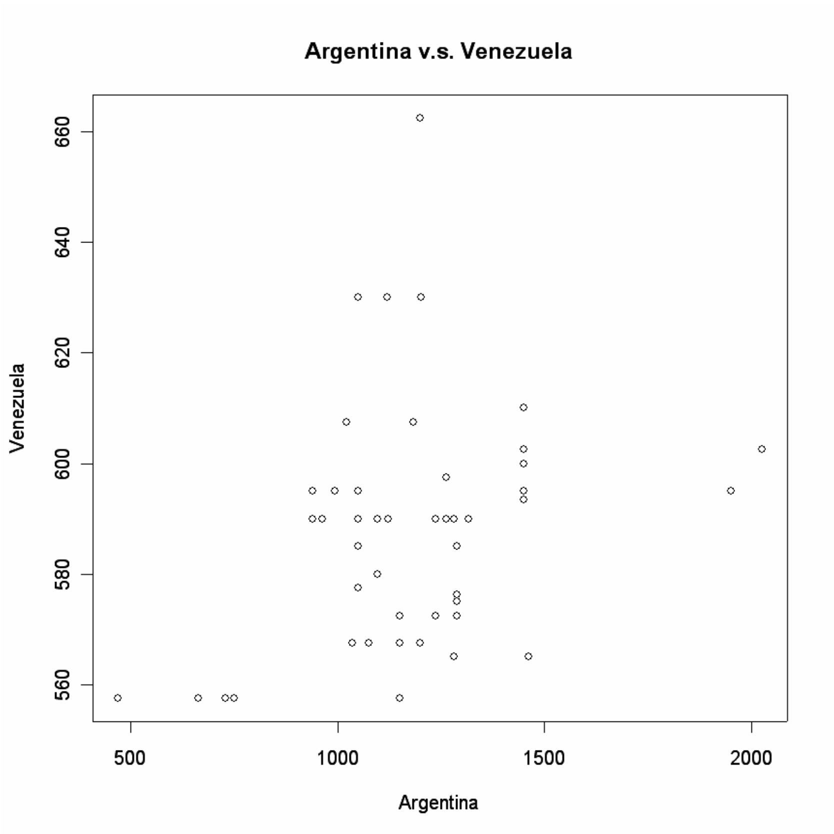
Fig. 1. Scatter Plots for Pairs of Sovereign CDS Spreads

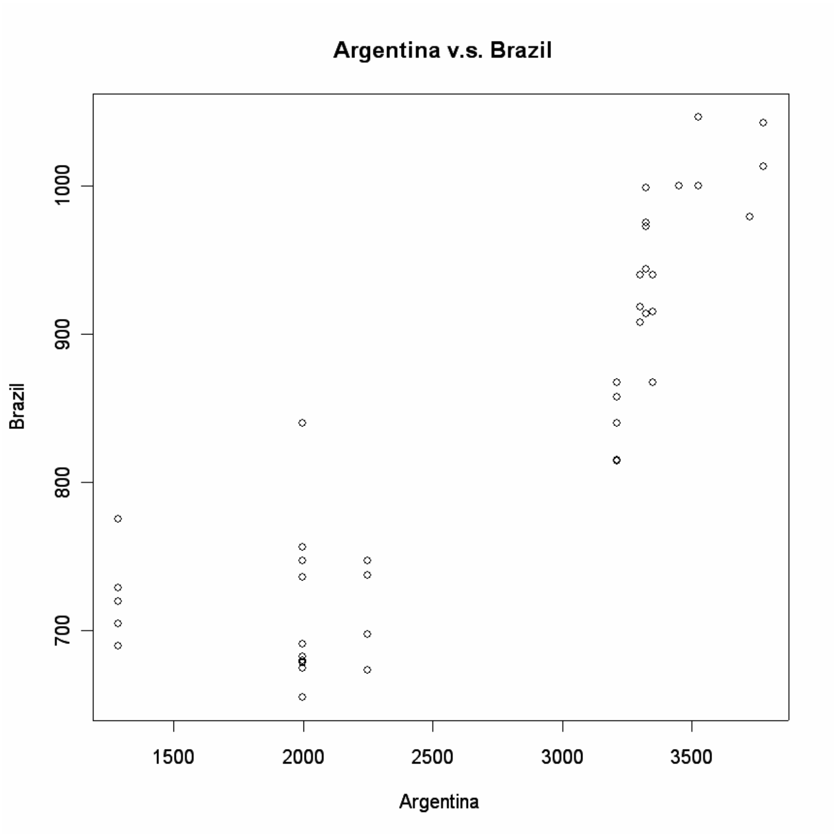
(A). Pre-Crisis Period

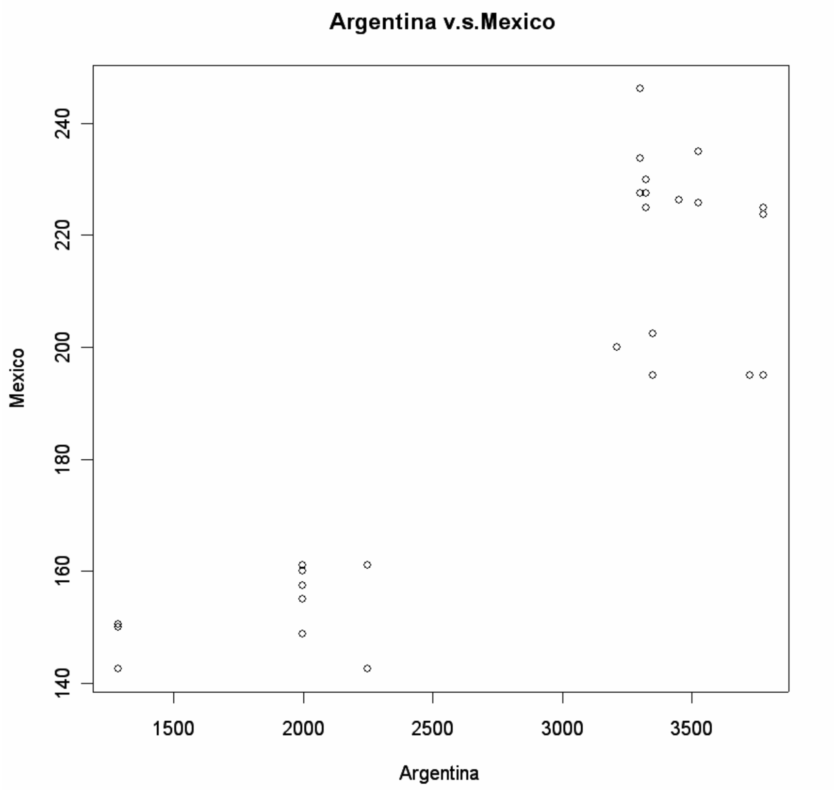






(B). Crisis Period




Argentina v.s.Mexico
Mexico
140
160
180
200
220
240
1500
2000
2500
3000
3500
Argentina

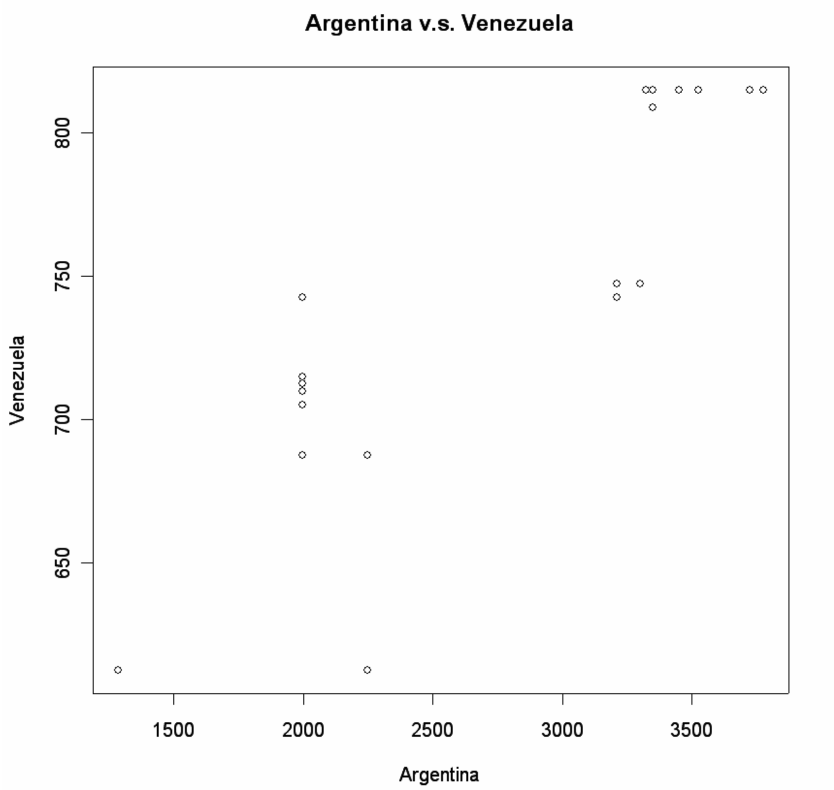
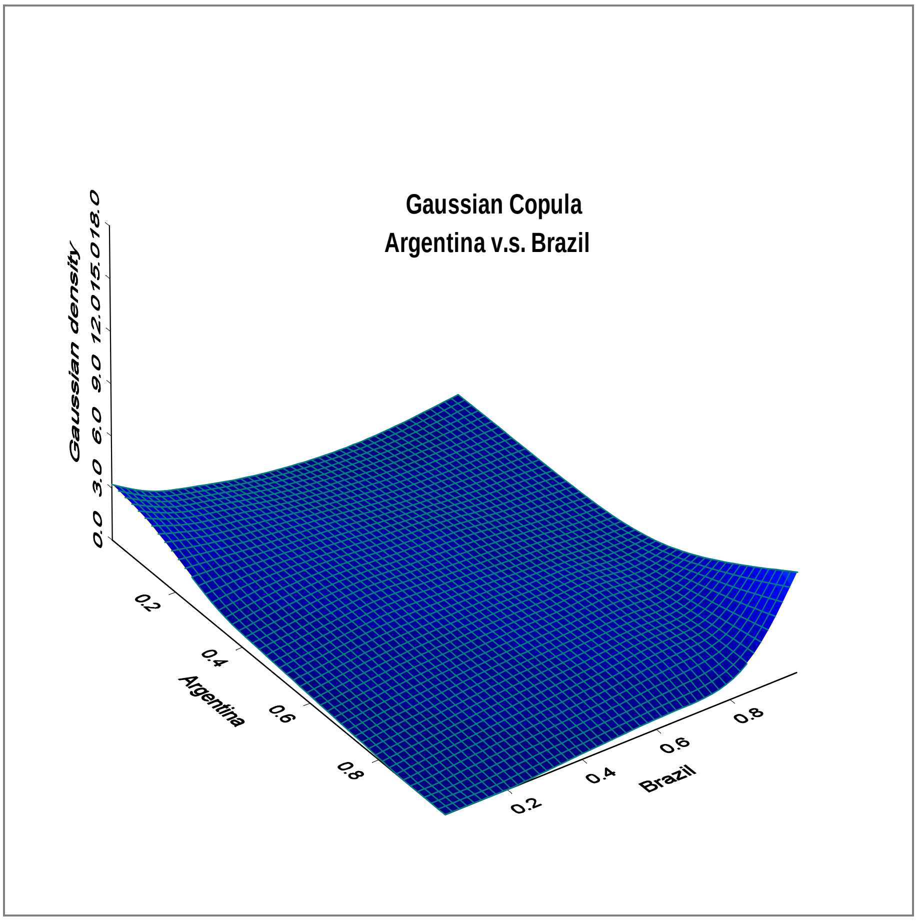
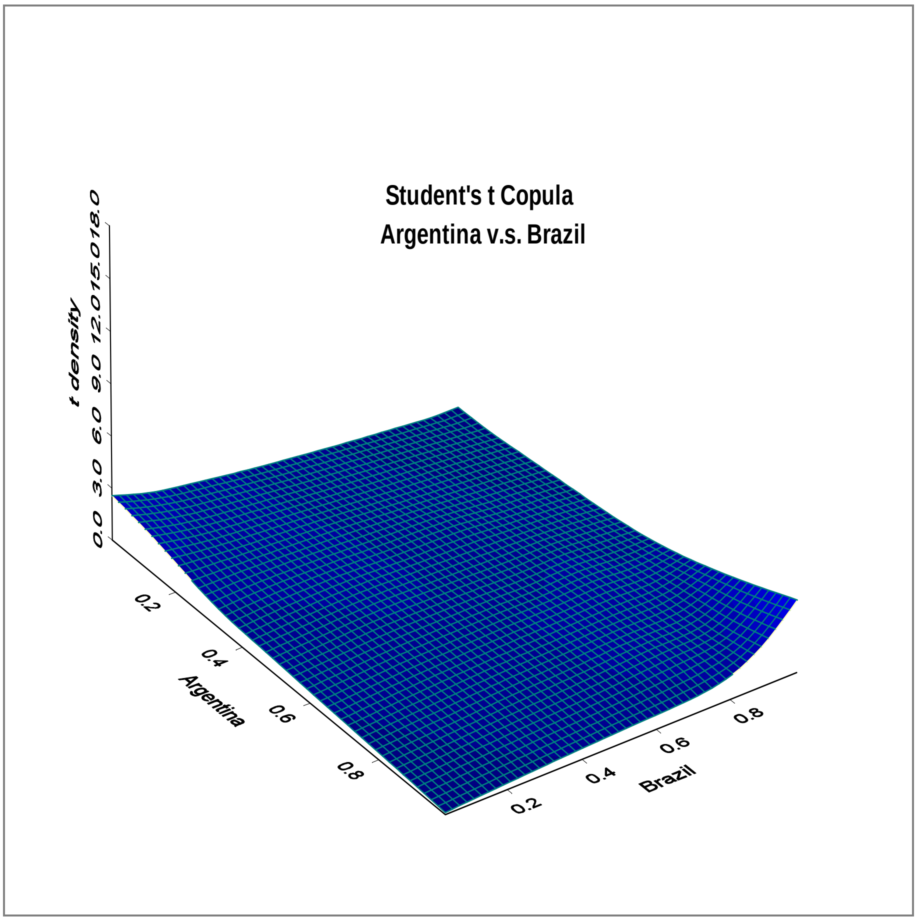

Argentina v.s. Venezuela
Venezuela
650
700
750
800
1500
2000
2500
3000
3500
Argentina

Fig. 2. Copula Density Plots for the Pre-Crisis Period





Student's t Copula
Argentina v.s. Brazil
t density
0.0 3.0 6.0 9.0 12.0 15.0 18.0
Argentina
0.2 0.4 0.6 0.8
Brazil
0.2 0.4 0.6 0.8

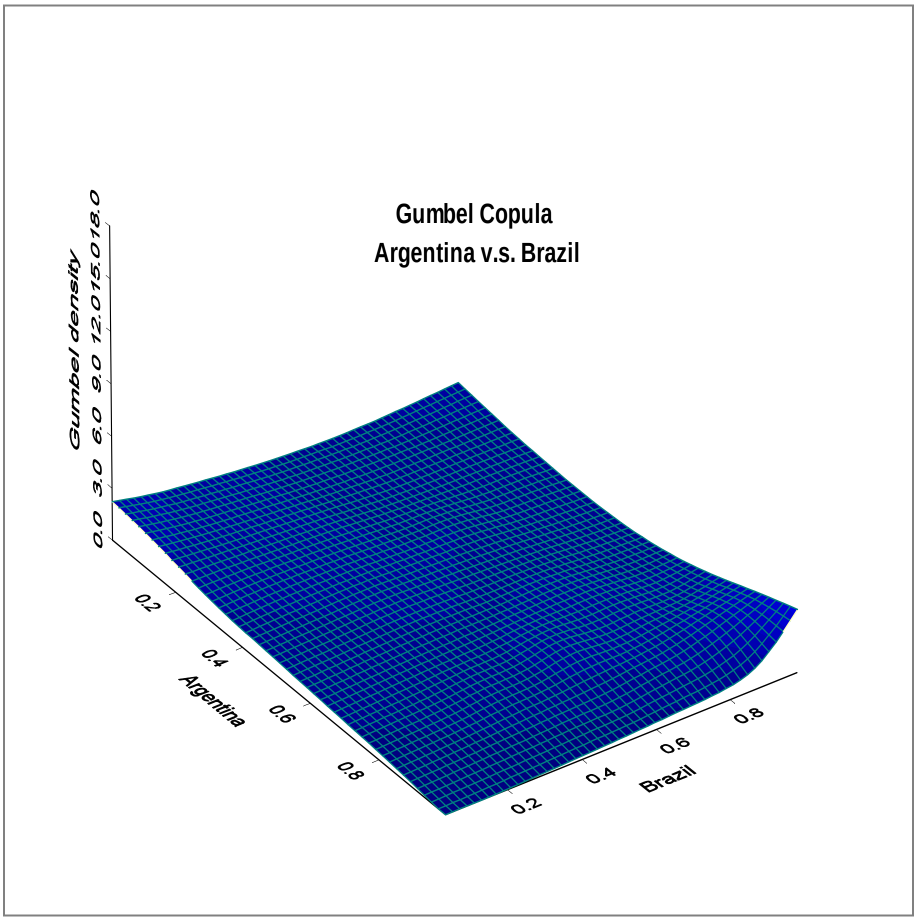
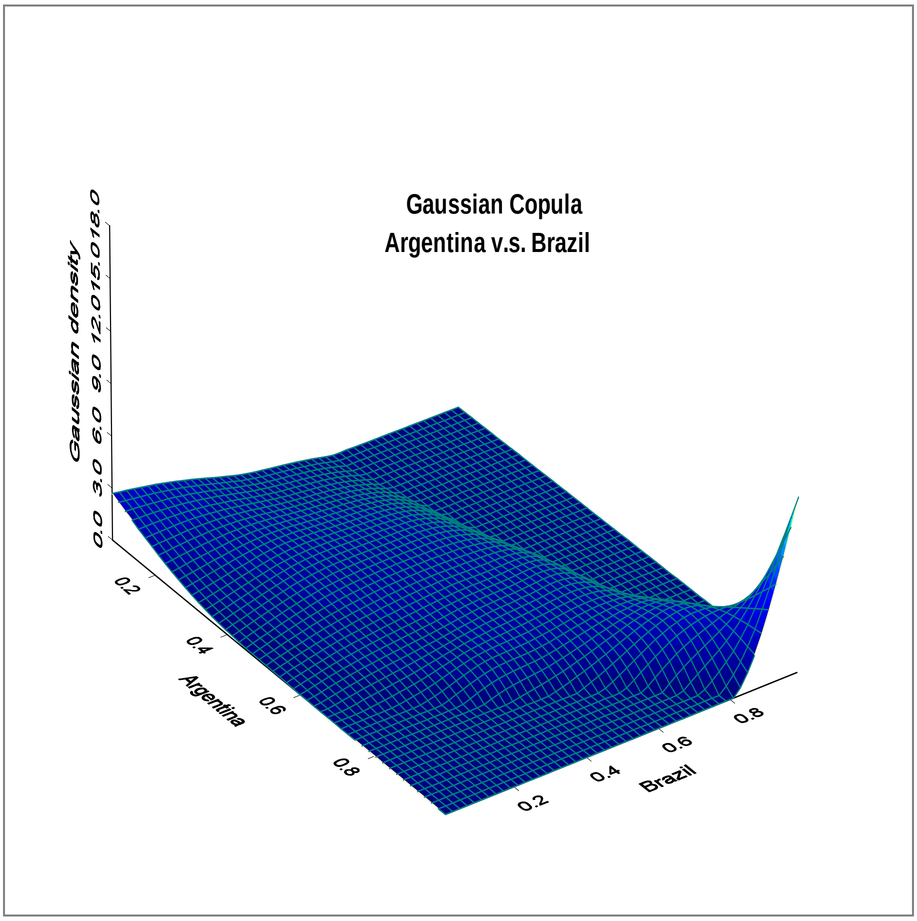
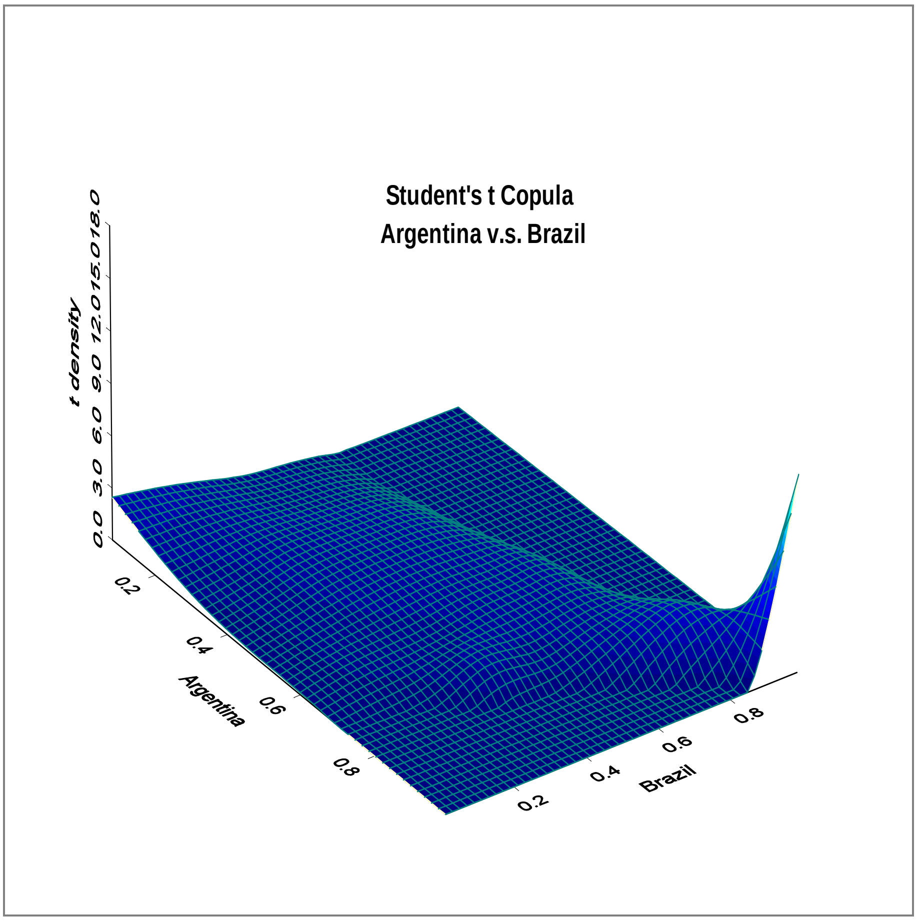
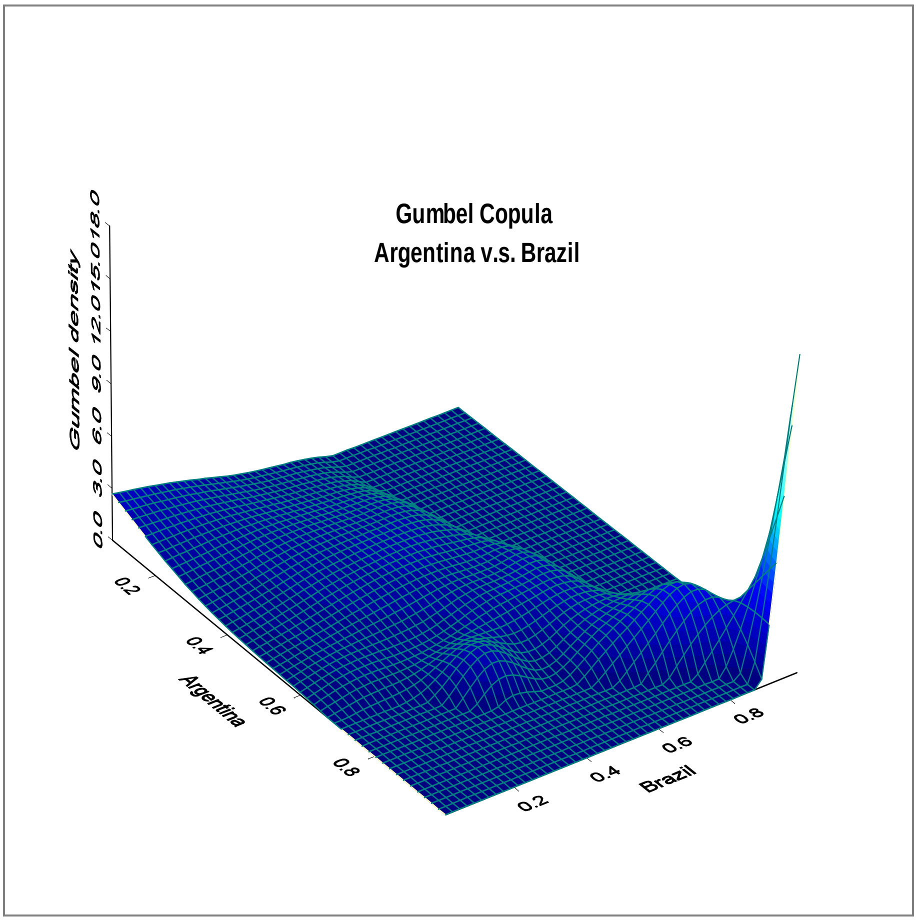

Gumbel Copula
Argentina v.s. Brazil
Gumbel density
0.0
3.0
6.0
9.0
12.0
15.0
18.0
Argentina
0.2
0.4
0.6
0.8
Brazil
0.2
0.4
0.6
0.8

Fig. 3. Copula Density Plots for the Crisis Period



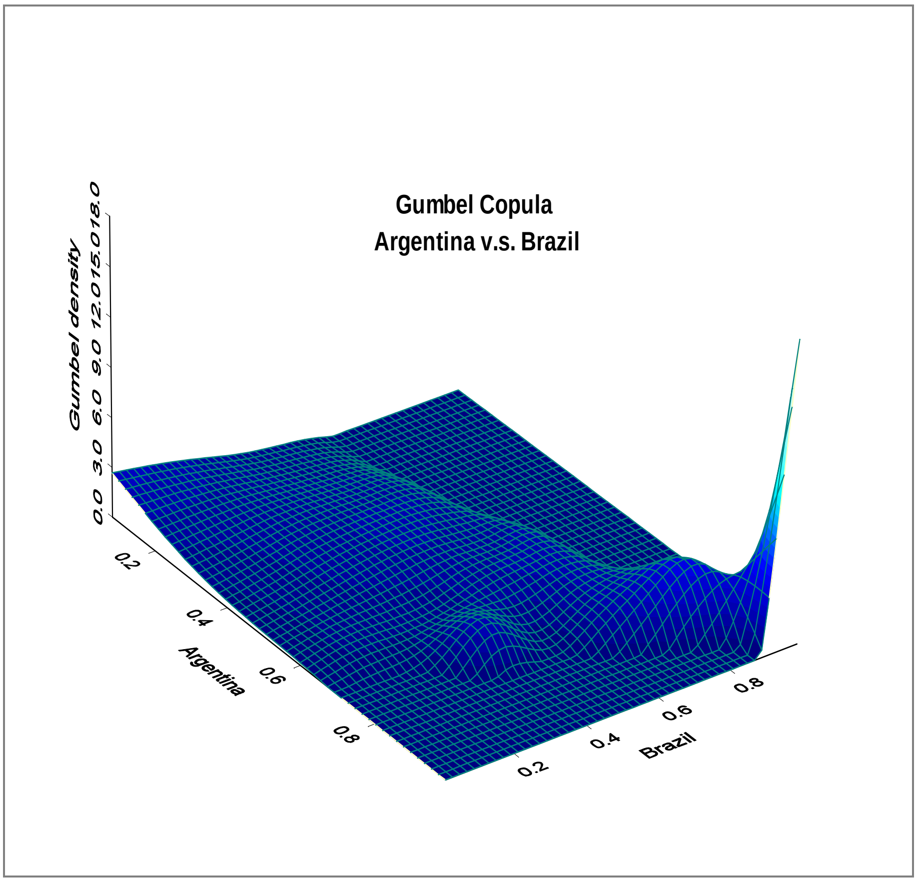


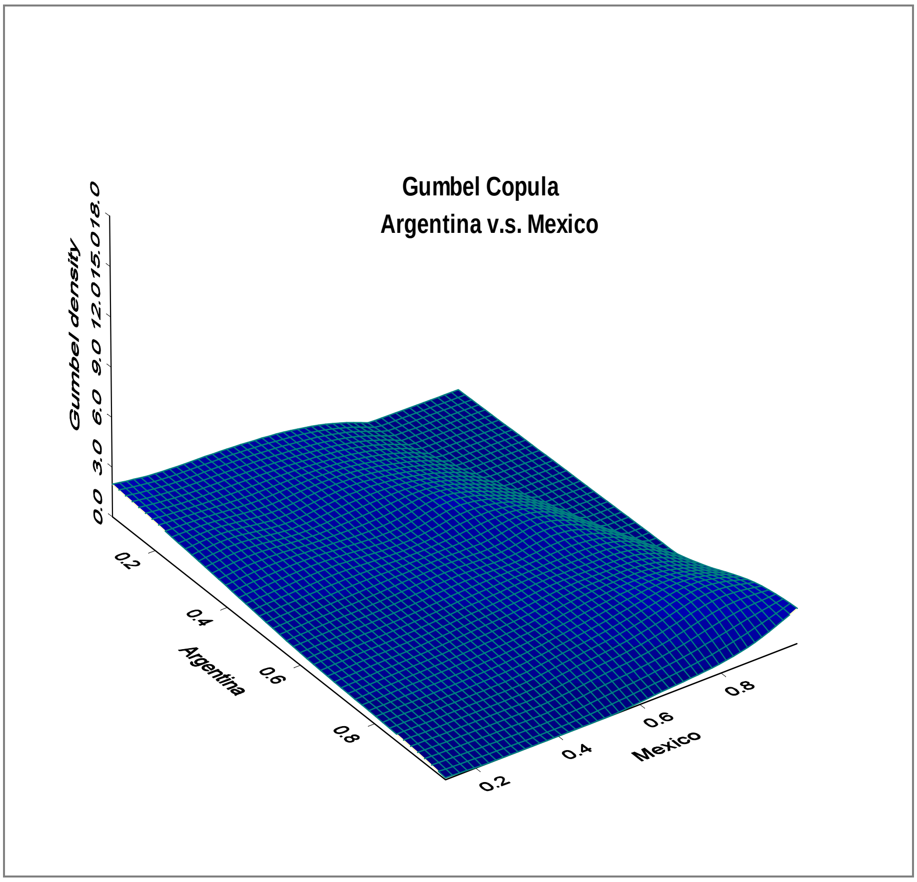
Student's t Copula
Argentina v.s. Brazil
t density
0.0 3.0 6.0 9.0 12.0 15.0 18.0
Argentina
0.2 0.4 0.6 0.8
Brazil
0.2 0.4 0.6 0.8



Gumbel Copula
Argentina v.s. Brazil
Gumbel density
0.0 3.0 6.0 9.0 12.0 15.0 18.0
Argentina
0.2 0.4 0.6 0.8
Brazil
0.2 0.4 0.6 0.8

Fig. 4. Tail Dependence Display from Gumbel Copula (Crisis Period)




Gumbel Copula
Argentina v.s. Mexico
Gumbel density
0.0 3.0 6.0 9.0 12.0 15.0 18.0
0.2 0.4 0.6 0.8
Argentina
0.2 0.4 0.6 0.8
Mexico

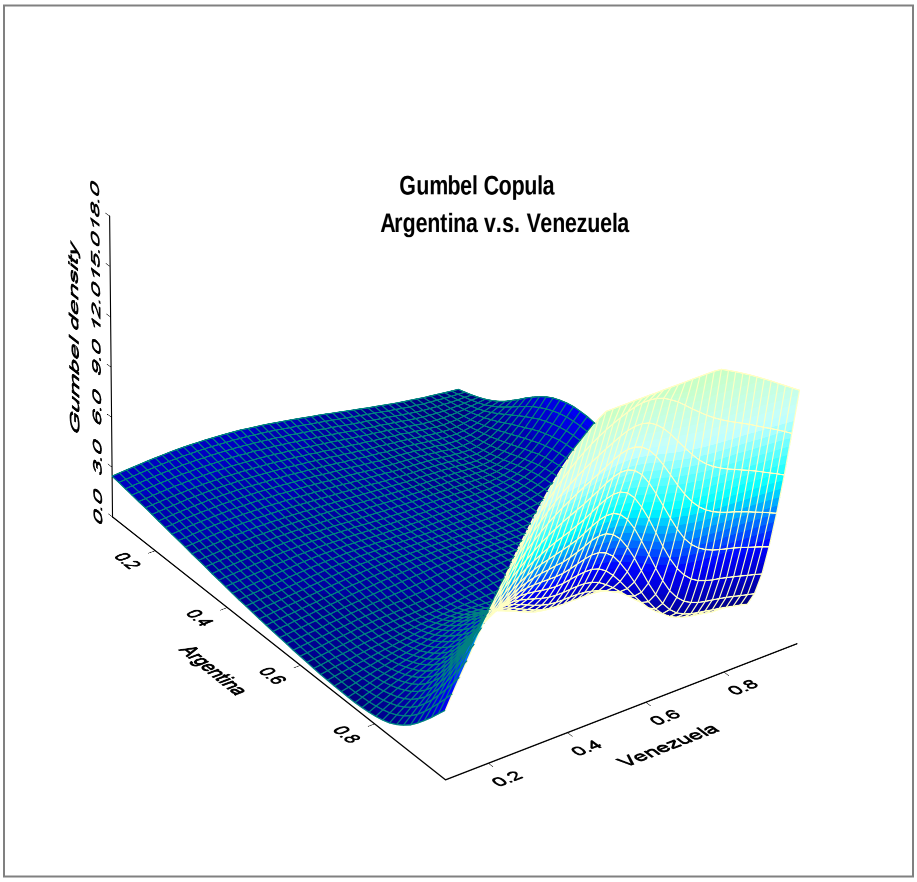

Gumbel Copula
Argentina v.s. Venezuela
Gumbel density
0.0 3.0 6.0 9.0 12.0 15.0 18.0
0.2 0.4 0.6 0.8
Argentina
0.2 0.4 0.6 0.8
Venezuela

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	

[a] Q1 represents the first and the third quantiles of CDS spread distribution

[b] Q3 represents the first and the third quantiles of CDS spread distribution

[c] p-value is for normality test in CDS spread distribution of each country.

Table 2

Measures of Association between Pair Countries before and during the Crisis

	Pre-crisis Period			Crisis Period		
Paired	*Argentina v.s.*			*Argentina v.s.*		
countries	*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

[a] Pearson's rho is a measure of linear dependence

[b] $\tau = 4\int\int_{I^2} C(u_1, u_2)\, dC(u_1, u_2) - 1$

[c] $\rho = 12\int\int_{I^2} u_1 u_2\, dC(u_1, u_2) - 3$

Table 3

Parameter Estimations and Goodness-of-Fit Test for Copula Functions

	Pre-Crisis Period			**Crisis Period**		
Paired		*Argentina v.s.*			*Argentina v.s.*	
countries	*Brazil*	*Mexico*	*Venezuela*	*Brazil*	*Mexico*	*Venezuela*
Panel A: Copula Estimation						
Gaussian						
ρ_{Gau} [a]	0.579	0.174	0.293	0.729	0.701	0.772
$\ln L$	22.108	5.939	4.613	28.292	23.767	36.544
Student's t						
ρ_t [b]	0.443	0.267	0.188	0.671	0.570	0.723
ν	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	1.054	1.070	2.198	1.615	1.834
$\ln L$	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's t	-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

[a] . ρ_{Gau} is the correlation parameter of Gaussian copula.

[b] . ρ_t is the correlation parameter of Student's t copula. ν 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 Akaike information criterion (AIC), $AIC = -2L(\hat{\theta}; x) + 2q$, where q is the number of parameters to be estimated in each specific model.

Table 4

Estimated Coefficients of Tail Dependence

	Pre-Crisis Period			Crisis Period		
Paired	*Argentina v.s.*			*Argentina v.s.*		
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_{Gum} [b]	0.375	0.070	0.089	0.629	0.464	0.541

[a] $\lambda_t = 2t_{v+1}\left(-\sqrt{v+1}\cdot\frac{\sqrt{1-\rho_t}}{\sqrt{1+\rho_t}}\right)$

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